



ACE
GATE | PSUs

MECHANICAL

ENGINEERING



MECHANICAL ENGINEERING

MACHINE DESIGN

Volume-1 : Study Material with Classroom Practice Questions

Machine Design

Solutions for Volume – I_ Classroom Practice Questions

Chapter- 1 Static Loads

01. Ans: (d)

Sol: $t = 0.2 \text{ mm}$, $d = 25 \text{ mm}$,

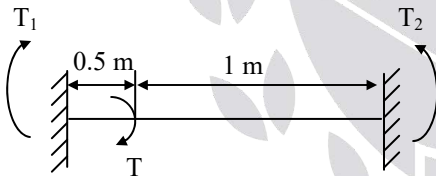
$E = 100 \text{ GPa}$

$$\frac{M}{I} = \frac{E}{R} = \frac{\sigma_b}{y}$$

$$\sigma_b = \frac{100 \times 10^3 \times \left(\frac{0.2}{2}\right)}{\left(\frac{25}{2}\right)} = 800 \text{ MPa}$$

02. Ans: (b)

Sol:



$$T = T_1 + T_2$$

$$\theta = \theta_1 = \theta_2$$

$$\frac{T_1 l_1}{GJ_1} = \frac{T_2 l_2}{GJ_2}$$

$$T_1 = \frac{7358 \times 1}{1.5} = 4905.33 \text{ Nm}$$

$$T_2 = \frac{7358 \times 0.5}{1.5} = 2452.66 \text{ Nm}$$

Maximum shear stress

$$\tau = \frac{16 T_1}{\pi d^3} = \frac{16 \times 4905.33 \times 10^3}{\pi \times 80^3} = 48.8 \text{ MPa}$$

03. Ans: (a)

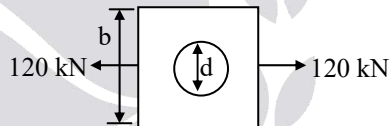
Sol: $G = 0.8 \times 10^3 \text{ MPa}$

$$\frac{T_1}{J_1} = \frac{G\theta_1}{l_1}$$

$$\begin{aligned} \theta_1 &= \frac{4905.33 \times 10^3 \times 0.5 \times 10^3}{\frac{\pi}{32} \times 80^4 \times 0.8 \times 10^5} \\ &= 7.62 \times 10^{-3} \text{ radian} \\ &= 7.62 \times 10^{-3} \times \frac{180}{\pi} = 0.436 \text{ degrees} \end{aligned}$$

04. Ans: (b)

Sol:



$P = 120 \text{ kN}$, $t = 13 \text{ mm}$

$$\frac{120 \times 10^3}{(b-d)t} = 75 \text{ MPa}$$

$$\frac{120 \times 10^3}{(b-22) \times 13} = 75$$

$$\Rightarrow b = 145 \text{ mm}$$

05. Ans: (b)

Sol: Force applied on the bar $= 95 \times 100 \times t \text{ N}$

Maximum stress induced

$$= \frac{\text{Force}}{\text{Minimum area}}$$

$$= \frac{95 \times 100 \times t}{(100-5) \times t} = 100 \text{ MPa}$$



06. Ans: (c)

Sol: By taking moment of force about the axis of fulcrum

$$2.25 \times 1.25 = P \times 15$$

$$P = 1.875 \text{ kN}$$

07. Ans: (c)

Sol: The reaction force acting on the pin

$$R = \sqrt{2.25^2 + 1.875^2} = 2.928 \text{ kN}$$

$$\begin{aligned} R &= \text{Pressure} \times (\text{Projected area of the pin}) \\ &= 6.5 \times (d_1 \times l_1) = 6.5 \times (d_1 \times 2 \times d_1) \\ &\quad (\because l_1 = 2d_1) \end{aligned}$$

$$2.928 \times 10^3 = 6.5 \times 2 \times d_1^2$$

$$d_1 = 15 \text{ mm}$$

08. Ans: (a)

Sol: $d = 30 \text{ mm}$, $t = 3 \text{ mm}$

$$\begin{aligned} \text{Outer diameter} &= 30 + 2 \times t \\ &= 30 + 2 \times 3 = 36 \text{ mm} \end{aligned}$$

Speed ratio = 4:1

$$T = \frac{60 \times 10 \times 10^3}{2\pi \times \frac{2000}{4}} = 190.985 \text{ Nm}$$

$$\frac{T}{J} = \frac{\tau}{r}$$

Maximum shear stress

$$\tau = \frac{16 \times 190.985 \times 10^3}{\pi \left(\frac{36^4 - 30^4}{36} \right)} = 40.27 \text{ MPa}$$

Chapter- 2 Theories of Failure

01. Ans: (c)

Sol: $\sigma = 60 \text{ MPa}$, $\tau = 40 \text{ MPa}$,
 $S_{yt} = 330 \text{ MPa}$

According to maximum principal theory

$$\sigma_1 = \frac{S_{yt}}{F.S}$$

$$\begin{aligned} \sigma_1 &= \frac{60+0}{2} + \sqrt{\left(\frac{60-0}{2}\right)^2 + \tau^2} \\ &= 30 + 50 = 80 \text{ MPa} \end{aligned}$$

$$\therefore 80 = \frac{330}{F.S} \Rightarrow F.S = 4.125$$

02. Ans: (c)

Sol: Given $\sigma = \begin{bmatrix} 40 & 0 \\ 0 & -30 \end{bmatrix}$

$$\sigma_1 = 40, \sigma_2 = -30, \sigma_{yt} = 350 \text{ MPa}$$

Max shear stress theory

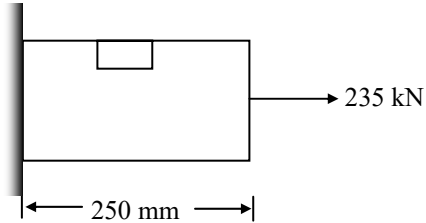
$$\tau_{\max} = \frac{\sigma_1 - \sigma_2}{2} = \frac{S_{sy}}{FOS} = \frac{S_{yt}}{2 \times FS}$$

$$\Rightarrow \frac{40+30}{2} = \frac{350}{2 \times FS}$$

$$\Rightarrow FS = \frac{350}{70} = 5$$

03. Ans: (d)

Sol: $d = 50 \text{ mm}$, $L = 250 \text{ mm}$,
 $P = 235 \text{ kN}$, $S_{ut} = 480 \text{ MPa}$



According maximum shear stress theory

$$\tau_{\max} = \frac{\sigma_1 - \sigma_2}{2} = \frac{S_{yt}}{2 \times F.S}$$

$$\therefore \sigma_x = \sigma \text{ \& } \sigma_y = 0 \text{ and } \tau_{xy} = 0$$

$$\sigma = \frac{235 \times 10^3}{\frac{\pi}{4} \times 50^2} = 119.68 \text{ MPa}$$

$$\tau_{\max} = \frac{\sigma}{2} = \frac{S_{ut}}{2 \times F.S}$$

$$\frac{480}{2 \times F.S} = \frac{119.68}{2}$$

$$\Rightarrow F.S = 4$$

04. Ans: (b)

Sol: $F_t = 48 \text{ kN}$

$S_{yt} = 200 \text{ MPa}$

$F_s = 18 \text{ kN}$

$F.S = ?$

Since bolts are made of ductile material, so we can use maximum shear stress theory

$$\sigma = \frac{48 \times 10^3}{600} = 80 \text{ MPa}$$

$$\tau = \frac{18 \times 10^3}{600} = 30 \text{ MPa}$$

$$\tau_{\max} = \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau^2} = \sqrt{\left(\frac{80}{2}\right)^2 + 30^2} = 50 \text{ MPa}$$

According to maximum shear stress theory

$$\tau_{\max} = \frac{S_{sy}}{F.S}$$

$$\tau_{\max} = \frac{S_{yt}}{2 \times F.S}$$

$$50 = \frac{200}{2 \times F.S} \Rightarrow F.S = 2$$

05. Ans: (d)

Sol: Given thin cylindrical shell

$d_i = 4.6 \text{ m}, \quad p = 0.210 \text{ MPa}$

$t = 16 \text{ mm}, \quad S_{yt} = 260 \text{ MPa}$

$F_s = ?$

$$\sigma_h = \frac{pd}{2t} = \frac{0.21 \times 4.6 \times 10^3}{2 \times 16}$$

$$\sigma_l = \frac{pd}{4t} = \frac{0.21 \times 4.6 \times 10^3}{4 \times 16} = 15.09 \text{ MPa}$$

$$\sigma_h = \sigma_l = 30.18 \text{ MPa}$$

$$\sigma_t = \sigma_2 = 15.08 \text{ MPa}$$

$$\sigma_3 = 0$$

$$\tau_{\max} = \text{Max. of } \left\{ \begin{array}{l} \left| \frac{\sigma_1 - \sigma_2}{2} \right| \\ \left| \frac{\sigma_1}{2} \right| \\ \left| \frac{\sigma_2}{2} \right| \end{array} \right.$$

$$\left| \frac{30.18 - 15.08}{2} \right| = 7.55$$

$$\text{i.e., } \left| \frac{30.18 - 0}{2} \right| = 15.09$$

$$\left| \frac{15.08}{2} \right| = 7.54$$

$$\tau_{\max} = 15.09$$



According max shear stress theory

$$15.09 = \frac{S_{sy}}{FS}$$

$$15.09 = \frac{S_y}{2 \times FS}$$

$$FS = \frac{260}{2 \times 15.09} = 8.62$$

06. Ans: (c)

Sol: $\sigma_t = 200 \text{ MPa} = \sigma_1$

$$\sigma_c = -100 \text{ MPa} = \sigma_2$$

$$S_{yt} = 500 \text{ MPa}$$

Tresca theory

$$\tau_{\max} = \frac{\sigma_1 - \sigma_2}{2} = \frac{S_{yt}}{2 \times FS}$$

$$\frac{200 - (-100)}{2} = \frac{500}{2 \times FS}$$

$$FS = 1.666 = 1.67$$

07. Ans: (b)

Sol: $\tau_{\max} = \frac{S_{sy}}{FS}$

$$\tau_{\max} = \frac{S_{yt}}{2 \times FS}$$

$$\text{But } \tau_{\max} = \sqrt{\left(\frac{\sigma_b}{2}\right)^2 + \tau^2}$$

$$= \sqrt{\left(\frac{55}{2}\right)^2 + (31.5)^2} = 41.81$$

$$FS = \frac{S_{yt}}{2 \times \tau_{\max}} = \frac{284}{2 \times 41.81} = 3.39$$

08. Ans: (a)

Sol: $F_T = 20 \text{ kN}, \quad F_s = 15 \text{ kN}$

$$S_{yt} = 360 \text{ MPa}, \quad F_s = 3, \quad d = ?$$

$$\sigma = \frac{F_T}{A} = \frac{20 \times 10^3}{A} \text{ N/mm}^2$$

$$\tau = \frac{F_s}{A} = \frac{15 \times 10^3}{A} \text{ N/mm}^2$$

$$\sigma_1 \text{ \& } \sigma_2 = \frac{\sigma}{2} \pm \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau^2}$$

$$\frac{S_{yt}}{FS} = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \sigma_2}$$

According to distortion energy theory

$$\sigma_1 = \frac{\sigma}{2} + \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau^2} = \frac{\sigma}{2} + \tau_{\max} = \frac{\sigma}{2} + R$$

$$R = \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau^2}$$

$$\sigma_{eq} = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \sigma_2}$$

$$= \sqrt{\left(\frac{\sigma}{2} + R\right)^2 + \left(\frac{\sigma}{2} - R\right)^2 - \left(\frac{\sigma}{2} + R\right)\left(\frac{\sigma}{2} - R\right)}$$

$$\sigma_{eq} = \sqrt{\left(\frac{\sigma}{2}\right)^2 + 3R^2}$$

$$\sigma_{eq} = \sqrt{\left(\frac{\sigma}{2}\right)^2 + 3\left(\frac{\sigma}{2}\right)^2 + \tau^2}$$

$$\sigma_{eq} = \sqrt{\sigma^2 + 3\tau^2} = \frac{S_{yt}}{F_s}$$

$$= \sqrt{\left(\frac{20 \times 10^3}{A}\right)^2 + 3 \times \left(\frac{15 \times 10^3}{A}\right)^2} = \frac{360}{3}$$

$$= \frac{10^3}{A} \sqrt{20^2 + 3 \times 15^2} = \frac{360}{3}$$

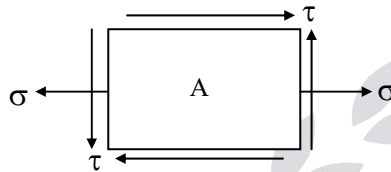
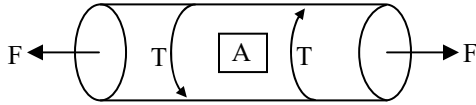


$$\therefore A = 273.22 \text{ mm}^2 = (\pi/4) d^2$$

$$\Rightarrow d = 18.65 \text{ mm}$$

09. Ans: (b)

Sol:



$$FS = 2, \quad S_{yt} = 310 \text{ MPa},$$

$$F = 40 \text{ kN},$$

$$d = 20 \text{ mm}, \quad T = ?$$

According to Distortion Energy Theory

$$\frac{S_{yt}}{FS} = \sqrt{\sigma^2 + 3\tau^2}$$

$$\sigma = \frac{F}{\frac{\pi}{4} \times d^2} = \frac{40}{\frac{\pi}{4} \times 20^2} = 127.32 \text{ MPa}$$

$$\frac{310}{2} = \sqrt{(127.32^2 + 3\tau^2)}$$

$$\Rightarrow \tau = 51.03 \text{ MPa}$$

$$\tau = \frac{16T}{\pi d^3}$$

$$\Rightarrow 51.03 = \frac{16T}{\pi \times 20^3}$$

$$\Rightarrow T = 80157.73 \text{ Nmm} = 80.157 \text{ Nm}$$

10. Ans: (b)

Sol: $P = 5 \text{ kN}$, $d = 10 \text{ cm} = 0.1 \text{ m}$

$$\text{Torque, } T = 5 \times 10^3 \times 0.5$$

$$S_{yt} = 425 \text{ MPa}$$

Bending moment

$$M = 5 \times 10^3 \times 2.5 = 12500 \text{ Nm}$$

Maximum shear stress

$$\begin{aligned} \tau &= \frac{16T}{\pi d^3} = \frac{16 \times 2.5 \times 10^3}{\pi \times (0.1)^3} \\ &= 12732395 \text{ N/m}^2 = 12.73 \text{ MPa} \end{aligned}$$

Maximum bending stress

$$\begin{aligned} \sigma_b &= \frac{32M}{\pi d^3} = \frac{32 \times 12500}{\pi \times (0.1)^3} \\ &= 127323954 \text{ N/m}^2 \\ &= 127.32 \text{ MPa} \end{aligned}$$

Major principal stress

$$\begin{aligned} \sigma_1 &= \frac{\sigma_b}{2} + \sqrt{\left(\frac{\sigma_b}{2}\right)^2 + \tau^2} \\ &= \frac{127.32}{2} + \sqrt{\left(\frac{127.32}{2}\right)^2 + (12.73)^2} \\ &= 128.58 \text{ MPa} \end{aligned}$$

Minor principal stress

$$\begin{aligned} \sigma_2 &= \frac{127.32}{2} - \sqrt{\left(\frac{127.32}{2}\right)^2 + (12.73)^2} \\ &= -1.26 \text{ MPa} \end{aligned}$$

According to Tresca's theory of failure

$$\begin{aligned} \frac{S_{sy}}{FS} &= \frac{S_{yt}}{2 \times FS} = \frac{\sigma_1 - \sigma_2}{2} \\ \therefore \frac{425}{FS} &= \frac{128.58 + 1.26}{2} \\ FS &= 3.27 \end{aligned}$$



11. Ans: (a)

Sol: $S_{yt} = 200 \text{ N/mm}^2$

$$FS = 2.5$$

$$\frac{d}{b} = 2$$

$$\frac{S_{yt}}{FS} = \sigma_b = \frac{200}{2.5} = 80 \text{ MPa}$$

$$I = \frac{bd^3}{12} = \frac{b(2b)^3}{12} = 0.66b^4$$

Maximum Bending moment,

$$M = 5 \times 1500 + 5 \times 500 \\ = 10000 \times 10^3 \text{ N-mm}$$

$$80 = \frac{M}{I} \times y = \frac{10^7}{0.66b^4} \times \frac{d}{2}$$

$$80 = \frac{10^7}{0.66b^4} \times \frac{2b}{2}$$

$$\Rightarrow b = 57.42 \text{ mm}$$

12. Ans: (b)

Sol: $\sigma_x = 100 \text{ MPa}$, $\sigma_y = 40 \text{ MPa}$, $\tau = 40 \text{ MPa}$

$$\sigma = \frac{100 + 40}{2} \pm \sqrt{\left(\frac{100 - 40}{2}\right)^2 + 40^2}$$

$$\sigma_1 = 70 + \sqrt{30^2 + 40^2} = 120 \text{ MPa}$$

$$\sigma_2 = 70 - \sqrt{30^2 + 40^2} = 20 \text{ MPa}$$

According Distortion Energy Theory

$$\sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2} = \frac{S_{yt}}{FS}$$

$$\sqrt{120^2 + 20^2 - 120 \times 20} = \frac{360}{FS} \Rightarrow FS = 3.23$$

13. Ans: (b)

Sol: $T = 10 \text{ kN-m}$, $M = 10 \text{ kN-m}$

Equivalent torque,

$$T_e = \sqrt{10^2 + 10^2} = 14.14 \text{ kN-m}$$

$$\tau_{\max} = \frac{16T_e}{\pi d^3} = \frac{16 \times 14.14}{\pi d^3}$$

According to Maximum shear stress theory

$$\tau_{\max} = \frac{S_{sy}}{FS}$$

$$\frac{16 \times 14.14}{\pi d^3} = \frac{S_{sy}}{1.5}$$

$$S_{sy} = \frac{16 \times 14.14 \times 1.5}{\pi d^3} = \frac{108.02}{d^3}$$

For $M = 5 \text{ kN-m}$ and $T = 6 \text{ kN-m}$

$$T_e = \sqrt{5^2 + 6^2} = 7.81 \text{ kN-m}$$

$$\tau_{\max} \times FS = \text{constant}$$

$$= \frac{16 \times 7.81 \times FS}{\pi d^3}$$

$$= \frac{16 \times 14.14 \times 1.5}{\pi d^3}$$

$$\Rightarrow FS = 2.7$$



Chapter- 3 Fluctuating Loads

01. Ans: (c)

Sol: Given:

$$b = 50 \text{ mm}, \quad d = 10 \text{ mm}$$

$$t = 10 \text{ mm}, \quad \sigma = 62.5 \text{ MPa}$$

$$\begin{aligned} \text{Area, } A &= (b - d) t \\ &= (50 - 10)10 = 400 \text{ mm}^2 \end{aligned}$$

$$\sigma_{\max} = \frac{F}{A}$$

$$\begin{aligned} F &= \sigma_{\max} \times A \\ &= 62.5 \times 400 = 25000 \text{ N} \end{aligned}$$

$$F = 25 \text{ kN}$$

02. Ans: (b)

Sol: Given:

$$S_u = 440 \text{ MPa} \quad q = 0.8$$

$$K_a = 0.67 \quad K_b = 0.85$$

$$K_c = 0.9 \quad K_d = 0.897$$

$$K_t = 2.37 \quad F.S = 1.5$$

Goodman's equation

$$\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}} = \frac{1}{F.S}$$

S_e' = Endurance strength of standard specimen under ideal conditions.

S_e = Modified endurance strength

$$S_e = K_a K_b K_c K_d S_e'$$

$$S_e' = 0.5 S_{ut}$$

$$= 0.5 \times 440 = 220 \text{ MPa}$$

$$S_e = 0.67 \times 0.85 \times 0.9 \times 0.897 \times K_e \times S_e'$$

K_f = Actual stress concentration modifying factor

$$K_f = 1 + q(K_t - 1)$$

$$= 1 + 0.8(1.37) = 2.096$$

K_e = Stress concentration modifying factor

$$= \frac{1}{K_f} = \frac{1}{2.096} = 0.48$$

$$\therefore S_e = 48.63 \text{ MPa}$$

For completely reverse load

$$\sigma_m = 0$$

$$\sigma_a = \frac{16 \times 10^3}{(50 - 10)t}$$

$$\therefore \sigma_a = \frac{400}{t} \text{ N/mm}^2$$

$$\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}} = \frac{1}{F.S} \quad \left(\text{Here } \frac{\sigma_m}{S_{ut}} = 0 \right)$$

$$\sigma_a = \frac{S_e}{F.S} = \frac{48.63}{1.5} = \frac{400}{t}$$

$$\therefore t = 12.3 \text{ mm}$$

$$t = 12 \text{ mm}$$

03. Ans: (b)

$$\text{Sol: } F = 50 \text{ kN}, \quad S_{ut} = 300 \text{ MN/m}^2$$

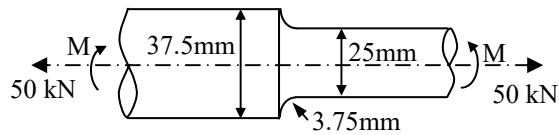
$$S_e' = 200 \text{ MN/m}^2, \quad K_t = 1.55, \quad q = 0.9$$

$$M = ?$$

$$K_f = 1 + q(K_t - 1)$$

$$= 1 + 0.9(1.55 - 1) = 1.495$$

$$S_e = \frac{1}{K_f} S_e' = \frac{200}{1.495} = 133.779$$



$$\text{Mean stress, } \sigma_m = \frac{F}{A}$$

$$= \frac{F}{\frac{\pi d^2}{4}} = \frac{50 \times 10^3}{\frac{\pi (25)^2}{4}} \Rightarrow 101.85 \text{ MPa}$$

$$\text{Stress amplitude, } \sigma_a = \frac{32 M}{\pi d^3} = \frac{32 M}{\pi (25)^3}$$

According to Goodman's equation

$$\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}} = \frac{1}{F.S}$$

$$\frac{32M}{\pi(25)^3} + \frac{101.85}{300} = 1$$

$$133.779$$

$$\Rightarrow M = 135.5 \text{ N-m}$$

04. Ans: (b)

Sol: Given:

$$\sigma_1 = -50 \text{ MPa to } +150 \text{ MPa}$$

$$\sigma_2 = 25 \text{ MPa to } 175 \text{ MPa}$$

$$S_{ut} = 500 \text{ MPa, } S_e = 250 \text{ MPa}$$

$$K_t = 1.85$$

$$\sigma_{1\max} = 150 \text{ MPa, } \sigma_{1\min} = -50 \text{ MPa}$$

$$\sigma_{1\text{mean}} = \frac{\sigma_{1\max} + \sigma_{1\min}}{2}$$

$$= \frac{150 - 50}{2} = 50 \text{ MPa}$$

$$\sigma_{1a} = \frac{150 + 50}{2} = 100 \text{ MPa}$$

Similarly

$$\sigma_{2\max} = 175 \text{ MPa,}$$

$$\sigma_{2\min} = 25 \text{ MPa}$$

$$\sigma_{2m} = \frac{175 + 25}{2} = 100 \text{ MPa}$$

$$\sigma_{2a} = \frac{150}{2} = 75 \text{ MPa}$$

According to Soderberg's equation

$$\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}} = \frac{1}{F.S}$$

Here,

$$S_e = K_a K_b \dots S'_e$$

$$= \frac{1}{1.85} \times 250 = 135 \text{ N/mm}^2$$

According DET

$$\sigma_{\text{meq}} \leftarrow \left(\frac{S_{yt}}{F.S} \right) = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \sigma_2}$$

$$\therefore \sigma_{\text{meq}} = \sqrt{\sigma_{1m}^2 + \sigma_{2m}^2 - \sigma_{1m} \sigma_{2m}}$$

$$= 86.6 \text{ MPa}$$

$$\sigma_{\text{aeq}} = \sqrt{\sigma_{1a}^2 + \sigma_{2a}^2 - \sigma_{1a} \sigma_{2a}}$$

$$= 90.14 \text{ MPa}$$

Substituting these values in Soderberg's equation

$$\frac{90.14}{135} + \frac{86.6}{500} = \frac{1}{F.S}$$

$$\Rightarrow F.S = 1.2$$



Common Data for Questions 05 & 06

05. Ans: (c) & 06. Ans: (a)

Sol: $S_e = 280 \text{ MPa}$

$S_f = 0.9 S_{ut}$ for 10^3 Cycles

$S_u = 600 \text{ MPa}$

$N = 10^3$ cycles $S_f = ?$

Basquin's equation,

$$A = S_f L^B$$

$$A = 280(10^6)^B \quad \dots\dots\dots (1)$$

$$A = (0.9 \times 600) \times 10^{3B}$$

$$A = 540 \times 10^{3B} \quad \dots\dots\dots (2)$$

By solving (1) and (2),

$$A = 1041.42$$

$$B = 0.095$$

$$\Rightarrow 1041.42 = S_f L^{0.095}$$

$$1041.42 = S_f (200 \times 10^3)^{0.095}$$

$$S_f = 326 \text{ MPa}$$

$$\Rightarrow 1041.42 = 420 \times L^{0.095}$$

$$\Rightarrow L = 1.4 \times 10^4 \text{ cycles}$$

07. Ans: (d)

Sol: $S_{f1} = 500 \text{ MPa}$

$N_1 = 10$ cycles

$L_1 = 1 \times 10^5$ cycles

$S_{f2} = 600 \text{ MPa},$

$N_2 = 5$ cycles

$L_2 = 0.4 \times 10^5$ cycles

$S_{f3} = 700 \text{ MPa},$

$N_3 = 3$ cycles

$L_3 = 0.15 \times 10^5$ cycles

$$\frac{\alpha_1}{L_1} + \frac{\alpha_2}{L_2} + \frac{\alpha_3}{L_3} = \frac{1}{L}$$

$$\alpha_1 = \frac{N_1}{N_1 + N_2 + N_3} = \frac{10}{18}$$

$$\frac{10}{18(1 \times 10^5)} + \frac{5}{18(0.4 \times 10^5)} + \frac{3}{18(0.15 \times 10^5)} = \frac{1}{L}$$

$$L = 42352.94 \text{ Cycles}$$

$$\text{For 18 cycles} \rightarrow \frac{1}{2} \times 60$$

$$42352.94 \text{ cycles} \rightarrow ? L$$

$$\Rightarrow L = 19.6 \text{ hrs}$$

08. Ans: (a)

Sol: $d = 50 \text{ mm}$

$$T_{\max} = 2 \text{ kN-m}$$

$$T_{\min} = -0.8 \text{ kN-m}$$

$$S_{sy} = 225 \text{ MPa},$$

$$FS = ? \text{ (Soderberg)}$$

$$S_{se} = 150 \text{ MPa}$$

$$T_a = \frac{2 - (-0.8)}{2} = 1.4 \text{ kN-m}$$

$$T_m = \frac{2 - 0.8}{2} = 0.6 \text{ kN-m}$$

$$\tau_m = \frac{16 T_m}{\pi d^3} = \frac{16 \times 0.6 \times 10^6}{\pi (50)^3} = 24.446 \text{ MPa}$$

$$\tau_a = \frac{16 T_a}{\pi d^3} = \frac{16(1.4) \times 10^6}{\pi (50)^3} = 57.04 \text{ MPa}$$

$$\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{yt}} = \frac{1}{FS}$$

$$\frac{\tau_a}{S_{se}} + \frac{\tau_m}{S_{sy}} = \frac{1}{FS}$$

$$\frac{24.446}{225} + \frac{57.04}{150} = \frac{1}{FS}$$

$$\Rightarrow FS = 2.04$$



09. Ans: (c)

Sol: $L_1 = 10$ hours

$N_1 = 9.8$ hours

$N_2 = 8.2$ hours

$L_2 = ?$

According to Miner's Equation,

$$\frac{N_1}{L_1} + \frac{N_2}{L_2} = 1$$

$$\Rightarrow \frac{9.8}{10} + \frac{8.2}{L_2} = 1$$

$$L_2 = 410 \text{ hours}$$

Common Data for Questions 10 & 11

10. Ans: (c) & 11. Ans: (d)

Sol: $\sigma_{\max} = +130$ MPa

$\sigma_{\min} = -130$ MPa

$$K_d = \frac{1}{K_f} = \frac{1}{1 + 0.95(1.85 - 1)}$$

$$S_e = K_a K_b K_c K_d S'_e$$

$$= 0.76 \times 0.85 \times 0.897 \times \frac{1}{1 + 0.95(1.85 - 1)} (0.5 \times 1400)$$

$$= 224.411 \text{ MPa}$$

$\therefore$ For a completely reversed,

$$\sigma_m = 0 ;$$

$$\sigma_a = 130 \text{ MPa}$$

$$\tau_m = \frac{57 + 16}{2} = 36.5 \text{ MPa}$$

$$\tau_a = \frac{57 - 16}{2} = 20.5 \text{ MPa}$$

$$\sigma_{eq} = \sqrt{\sigma^2 + 3\tau^2}$$

$$\sigma_{meq} = \sqrt{\sigma_m^2 + 3\tau_m^2} = \sqrt{3 \times 36.5^2}$$

$$= 63.21 \text{ MPa}$$

$$\sigma_{aeq} = \sqrt{\sigma_a^2 + 3\tau_a^2} = \sqrt{130^2 + 3(20.5)^2}$$

$$= 134.76 \text{ MPa}$$

According to Goodman's equation,

$$\frac{\sigma_{aeq}}{S_e} + \frac{\sigma_{meq}}{S_{ut}} = \frac{1}{FS}$$

$$\frac{134.76}{224.4} + \frac{63.21}{1400} = \frac{1}{FS}$$

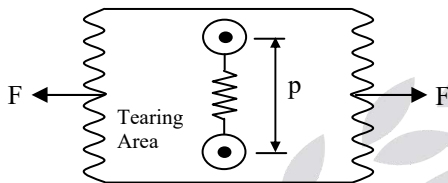
$$\Rightarrow FS = 1.54$$



Chapter- 4 Riveted Joints

01. Ans: (b)

Sol: Given $\frac{d}{p} = 0.5$



$$\begin{aligned}\text{Tearing efficiency} &= \frac{p-d}{p} \\ &= \frac{p\left(1-\frac{d}{p}\right)}{p} \\ &= 1 - \frac{d}{p} = 1 - 0.5 \\ &= 0.5 \times 100 = 50\%\end{aligned}$$

02. Ans: (d)

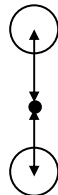
Sol: Resultant Force $= \sqrt{F_1^2 + F_2^2}$
 $= \sqrt{4^2 + 3^2}$
 $= 5 \text{ kN}$

$$F_1 = F_2 = \frac{F}{2} \Rightarrow F = 2F_2 = 2 \times 3 = 6 \text{ kN}$$

$$\text{Stress} = \frac{F}{2} = \frac{5000}{500} = 10 \text{ MPa}$$

$$C = \frac{F \times L}{r_1^2 + r_2^2}$$

As r_1 and r_2 not given, so it is not possible to calculate eccentricity (L).



Common Data Question (03, 04, 05)

Given, $d = 30 \text{ mm}$

$$\sigma_t = 40 \text{ MPa} = 40 \text{ N/mm}^2$$

$$P = 90 \text{ mm}$$

$$\sigma_s = 30 \text{ MPa} = 30 \text{ N/mm}^2$$

$$t = 12.5 \text{ mm}$$

$$\sigma_c = 55 \text{ MPa} = 55 \text{ N/mm}^2$$

03. Ans: (b)

$$\begin{aligned}\text{Sol: Tearing Efficiency} &= \frac{p-d}{p} \\ &= \frac{90-30}{90} = \frac{60}{90} \\ &= \frac{2}{3} \times 100 \\ \eta_{\text{Tearing}} &= 66.67\%\end{aligned}$$

04. Ans: (b)

Sol: Strength of Riveted plate $= P = p \times t \times \sigma_t$

$$\begin{aligned}P &= 90 \times 12.5 \times 40 \\ &= 45000 \text{ N}\end{aligned}$$

Shearing Resistance,

$$P_s = \frac{\pi}{4} d^2 \times \sigma_t$$

$$P_s = \frac{\pi}{4} (30)^2 \times 30$$

$$= 21206 \text{ N}$$

$$\begin{aligned}\text{Shear efficiency} &= \frac{P_s}{P} = \frac{21206}{45000} \\ &= 0.47 = 47\%\end{aligned}$$



05. Ans: (c)

Sol: Crushing Strength

$$\begin{aligned} P_C &= d \times t \times \sigma_c \\ &= 30 \times 12.5 \times 55 \\ &= 20625 \text{ N} \end{aligned}$$

Tearing Strength

$$\begin{aligned} P_t &= (p - d)t \times \sigma_t \\ &= (90 - 30) \times 12.5 \times 40 = 30,000 \text{ N} \end{aligned}$$

Shear Strength

$$P_s = 21206 \text{ N}, \quad P = 45000 \text{ N}$$

Strength of riveted joint

$$\eta = \frac{\text{Least value among } P_C, P_t \text{ \& } P_s}{P}$$

$$\eta = \frac{20625}{45000} = 0.458 = 45.8\%$$

06. Ans: (c)

Sol: Given $t = 7 \text{ mm}$

$$\tau_s = 60 \text{ MPa} = 60 \text{ N/mm}^2$$

$$\sigma_c = 120 \text{ MPa} = 120 \text{ N/mm}^2$$

$n = 3$ (Triple riveted joint)

$$P_s = n \times \frac{\pi}{4} \times d^2 \times \tau_s$$

$$= 3 \times \frac{\pi}{4} d^2 \times 60 = 141.4 d^2 \text{ N} \dots\dots(1)$$

$$\begin{aligned} P_C &= n \times d \times t \times \sigma_c = 3 \times d \times 7 \times 120 \\ &= 2520d \text{ N} \dots\dots(2) \end{aligned}$$

From equations (1) & (2)

$$141.4 d^2 = 2520d$$

$$d = \frac{2520}{141.4} = 17.8 \approx 18 \text{ mm}$$

07. Ans: (d)

Sol: Given:

$$t = 7 \text{ mm},$$

$$n = 3$$

$$\sigma_t = 80 \text{ MPa} = 80 \text{ N/mm}^2$$

$$\tau_s = 60 \text{ MPa} = 60 \text{ N/mm}^2$$

$$\sigma_c = 120 \text{ MPa} = 120 \text{ N/mm}^2$$

Let p = pitch of rivets,

$$d = 18 \text{ mm}$$

Tearing resistance is

$$\begin{aligned} P_t &= (p - d)t \times \sigma_t \\ &= (p - 18)7 \times 80 \\ &= 560(p - 18) \text{ N} \dots\dots(1) \end{aligned}$$

$$P_s = \frac{\pi}{4} d^2 \times \tau_s \times n$$

$$\frac{\pi}{4} (18)^2 \times 60 \times 3 = 45804 \text{ N} \dots\dots(2)$$

From equations (1) and (2)

$$560(p - 18) = 45804$$

$$p = 99.79$$

$$p \approx 100 \text{ mm}$$

08. Ans (a)

Sol: $\frac{S_{yt}}{FS} = 90 \text{ N/mm}^2$

$$\frac{S_{sy}}{FS} = 75 \text{ N/mm}^2$$

$$\frac{S_{yc}}{FS} = 150 \text{ N/mm}^2$$

Shear strength = crushing strength

$$\frac{\pi}{4} d^2 \times \frac{S_{sy}}{FS} = d \times t \times \frac{S_{yc}}{FS}$$



$$d = 6 \times \frac{150}{75 \times \pi} \times 4$$

$$d = 15.27 \text{ mm}$$

09. Ans: (b)

Sol: Given:

$$\tau_s = 100 \text{ MPa} = 100 \text{ N/mm}^2$$

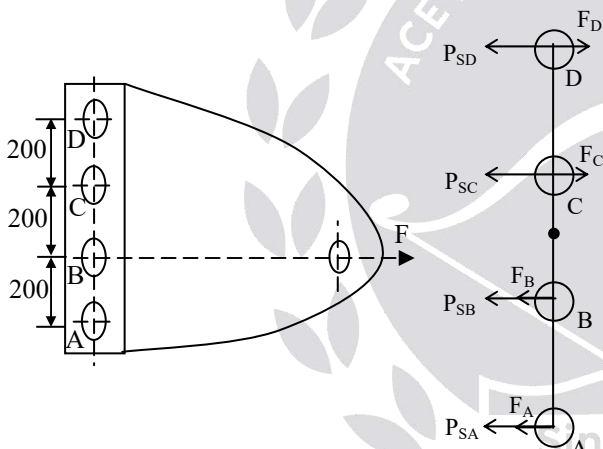
$$d = 20 \text{ mm}, \quad n = 4$$

Direct shear load on each rivet

$$P_s = \frac{P}{n} = \frac{P}{4} = 0.25P$$

$$P_A = P_B = P_C = P_D = P_s$$

All dimensions are in mm



From figure,

$$l_A = l_D = 200 + 100 = 300 \text{ mm}$$

$$l_B = l_C = 100 \text{ mm}$$

[$\therefore$ Secondary shear loads are proportional to their radial distances from the C.G.]

$$P \times e = \frac{F_B}{l_B} [l_A^2 + l_B^2 + l_C^2 + l_D^2]$$

$$= \frac{F_B}{l_B} [2l_A^2 + 2l_B^2] \quad (\because l_A = l_D \text{ \& } l_B = l_C)$$

$$P \times 100 = \frac{F_B}{100} [2(300)^2 + 2(100)^2]$$

$$F_B = 0.05P = F_C$$

$$P \times e = \frac{F_A}{l_A} [l_A^2 + l_B^2 + l_C^2 + l_D^2]$$

$$F_A = F_B = 0.15P$$

Resultant load on rivet A

$$R_A = P_s + F_A = 0.25P + 0.15P = 0.4P$$

Resultant load on rivet B,

$$R_B = P_s + F_B = 0.25P + 0.05P = 0.3P$$

Resultant load on rivet C,

$$R_C = P_s - F_C = 0.25P - 0.05P = 0.2P$$

Resultant load on rivet D,

$$R_D = P_s - F_D = 0.25P - 0.15P = 0.1P$$

R_A is the maximum shear load

$$0.40P = \frac{\pi}{4} d^2 \times \sigma_s$$

$$0.4P = \frac{\pi}{4} (20)^2 \times 100 = 31420$$

$$P = \frac{31420}{0.4} = 78.55 \text{ kN} \approx 78 \text{ kN}$$

10. Ans: (b)

Sol: Tensile load (F_t)

$$= (p - d) t \times \sigma_t$$

$$= (60 - 20) \times 15 \times 120 = 72000 \text{ N}$$

$$= 72 \text{ kN}$$

$$\text{Shear Load } (F_s) = \frac{\pi}{4} \times d^2 \times \tau = \frac{\pi}{4} \times 20^2 \times 90$$

$$= 28274.33 \text{ N} = 28.274 \text{ kN}$$

$$\text{Crushing load } (F_c) = d \times t \times \sigma_c$$

$$= 20 \times 15 \times 160$$

$$= 48000 \text{ N} = 48 \text{ kN}$$



Load carrying capacity (F)

= Minimum of (F_t , F_s & F_c)

= 28.274 kN

Linked Answer Questions 11 & 12:

11. Ans: (a)

Sol: No. of Rivets = 2

Primary shear load $P_1 = \frac{4}{2} = 2$ kN

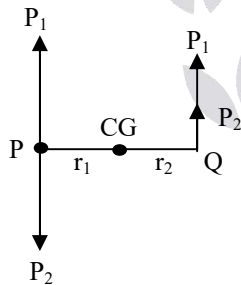
Secondary shear load $P_2 = \frac{Per_1}{r_1^2 + r_2^2}$

$$= \frac{4 \times 10^3 \times (1.8 + 0.2) \times 0.2}{0.2^2 + 0.2^2}$$

$$= 20000 \text{ N} = 20 \text{ kN}$$

12. Ans: (b)

Sol:



Resultant load on Rivet P = $P_2 - P_1$

$$= 18 \text{ kN}$$

Resultant shear stress on Rivet P

$$= \frac{18 \times 10^3}{\frac{\pi}{4} \times 12^2} = 159 \text{ MPa}$$

Chapter- 5 Threaded Fasteners

01. Ans: (b)

Sol: Given $d = 24$ mm

$F_i = 2840$ d = 2840 × 24

$$\sigma_t = \frac{F_i}{\frac{\pi}{4} d_c^2}$$

Here, $d_c = 0.84d \Rightarrow d_c = 0.84 \times 24$

$$\sigma_t = \frac{2840 \times 24}{\frac{\pi}{4} (0.84 \times 24)^2}$$

$$\sigma_t = 213.529 \text{ MPa}$$

02. Ans: (c)

Sol: Given

$d = 36$ mm

$d_c = 0.84 d = 0.84 \times 36$

F.S = 1.5

$S_{yt} = 280$ MPa

$$\sigma_t = \frac{S_{yt}}{F.S} = \frac{280}{1.5}$$

$$P = \frac{\pi}{4} d_c^2 \sigma_t$$

$$= \frac{\pi}{4} (0.84 \times 36)^2 \times \frac{280}{1.5}$$

$$= 134066 \text{ N}$$

$$P = 134 \text{ kN}$$



03. Ans: (d)

Sol: Given pitch = 4 mm

Torque (T) = 1.4 kN-mm

Work done = force × distance

Force × distance = Torque × Angle of rotation

$F \times 4 = T \times \theta$

$$F = \frac{1.4 \times 2\pi}{4} = 2.199 \text{ kN} = 2.2 \text{ kN}$$

04. Ans: (d)

Sol: Given

$F = 5.3 \text{ kN}$,

$C = 0.25$,

$P = 9.6 \text{ kN}$

$F_b = CP + F_i$

$$= (0.25)(9.6) + (5.3)$$

$F_b = 7.7 \text{ kN}$

05. Ans: (c)

Sol: $K_m = 4K_b$

$$C = \frac{K_b}{K_b + K_m} = 0.2$$

To open the joint

$(1-C)P = F_i$

$$\frac{P}{F_i} = \frac{1}{1-C} = \frac{1}{1-0.2} = 1.25$$

06. Ans: (b)

Sol: Given

$D = 250 \text{ mm}$

Pressure = 12 bar = 1.2 MPa

F.S = 5

$S_{yt} = 300 \text{ MPa}$

$n = 8$

$$F_b = \text{Load (P)} = \frac{\pi}{4}(D^2) \times P$$

$$= \frac{\pi}{4}(250)^2 \times 1.2$$

$$= \frac{736 \times 10^3}{n} = 7363.1 \text{ N}$$

$$\sigma_t = \frac{F_b}{A_b} = \frac{S_{yt}}{F.S}$$

$$\Rightarrow \frac{7.36 \times 10^3}{A_b} = \frac{300}{5}$$

$$\Rightarrow A_b = 122.66 \text{ mm}^2$$

07. Ans: (d)

Sol: Given,

$D = 500 \text{ mm}$

$n = 8$

$P = 20 \text{ bar} = 2 \text{ MPa}$

$K_m = 3K_b$

$$c = \frac{K_b}{K_b + K_m} = \frac{1}{4} = 0.25$$

To avoid leakage

Load (P) = $P_r \times A$

$$= \frac{2 \times \frac{\pi}{4}(500)^2}{8} = 49 \text{ kN}$$

For leak proof joint $F_m \leq 0$

$F_i = (1-C)P$

$F_i = (1-0.25)49$

$$= 36.75 \text{ kN} \approx 37 \text{ kN}$$



Linked Answer Q 08 & 09

08. Ans: (d)

Sol: $S_{yt} = 650 \text{ MPa}$

$$A = 115 \text{ mm}^2$$

$$K_m = 1.7 \times 10^6 \text{ N/mm},$$

$$E_{cu} = 1.05 \times 10^5 \text{ N/mm}^2$$

$$E_{steel} = 2 \times 10^5 \text{ N/mm}^2$$

$$F_i = 0.8 S_{yt} \times A = 0.8 \times 650 \times 115 = 59800 \text{ N}$$

For bolt,

$$K_b = \frac{P_b}{\delta_b} = \frac{P_b}{\frac{P_b \cdot l_b}{A_b E_b}} = \frac{A_b E_b}{l_b}$$

$$= \frac{115 \times 2 \times 10^5}{20 + 20} = 5.75 \times 10^5 \text{ N/mm}$$

$$\text{Where, } l_b = t_1 + t_2 = 20 + 20 = 40 \text{ mm}$$

$$\text{Stiffness factor } C = \frac{K_b}{K_b + K_m} = 0.25$$

09. Ans: (a)

Sol: Safe external load that can be applied safely on the joint

$$(1-C)P - F_i = 0$$

$$(1 - 0.25) \times P = 59800 \text{ N}$$

$$P = 79733 \text{ N} = 79.733 \text{ kN}$$

For strength

$$\sigma_t = \frac{F_b}{A} = \frac{S_{yt}}{FS}$$

$$\Rightarrow F_b = \frac{S_{yt} \times A_b}{FS}$$

$$CP + F_i = \frac{S_{yt} \times A_b}{FS}$$

$$CP = \frac{S_{yt}}{FS} \times A_b - F_i$$

$$CP = \frac{650}{1} \times 115 - 59800$$

$$CP = 14950$$

$$P = \frac{14950}{0.25} = 59800 \text{ N} = 59.8 \text{ kN} \cong 60 \text{ kN}$$

Linked Answer Q 10 & 11

10. Ans: (b)

11. Ans: (a)

Sol: Given

$$d = 20 \text{ mm},$$

$$S_{yt} = 630 \text{ MPa}$$

$$S_e = 350 \text{ MPa},$$

$$F.S = 2.5$$

$$\text{Core area of bolt} = 2.45 \text{ cm}^2 = 245 \text{ mm}^2$$

$$\sigma_m = 180 \text{ MPa}$$

Soderberg's criterion

$$\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{yt}} = \frac{1}{F.S}$$

$$\frac{\sigma_a}{350} + \frac{180}{630} = \frac{1}{2.5}$$

$$\frac{\sigma_a}{350} = \frac{1}{2.5} - \frac{180}{630}$$

$$\sigma_a = 40 \text{ MPa}$$

For calculating maximum & minimum values of varying loads.

$$\sigma_{\max} = \sigma_{\text{mean}} + \sigma_a = 180 + 40 = 220 \text{ MPa}$$

$$P_{\max} = \sigma_{\max} \times \text{Area} = 220 \times 245 = 54 \text{ kN}$$

$$\sigma_{\min} = \sigma_{\text{mean}} - \sigma_a = 180 - 40 = 140 \text{ MPa}$$

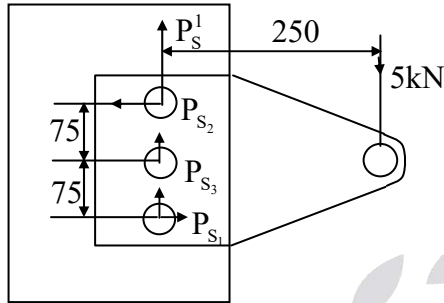
$$P_{\min} = \sigma_{\min} \times \text{Area} = 140 \times 245 = 34 \text{ kN}$$



12. Ans: (b)

Sol: F.S = 3, $S_{yt} = 400 \text{ N/mm}^2$, $P = 5 \text{ kN}$

Direct shear load



$$P_s = \frac{5}{3} = 1.67 \text{ kN}$$

Secondary shear Load, P_{s1}

$$= \frac{5 \times 250}{(75)^2 + 0^2 + (75)^2} \times 75 = 8.3 \text{ kN}$$

$$\begin{aligned} \text{Resultant Load (R)} &= \sqrt{P_s^2 + P_{s1}^2} \\ &= \sqrt{(1.67)^2 + (8.3)^2} \\ &= 8.498 \text{ kN} \end{aligned}$$

$$R = \frac{\pi}{4} d^2 \times \frac{S_{sy}}{F.S} \quad [S_{yt} = 2 \times S_{sy}]$$

$$8.498 \times 10^3 = \frac{\pi}{4} (d^2) \times \frac{S_{yt}}{2 \times F.S}$$

$$\therefore d = 12.74 \text{ mm} \approx 13 \text{ mm}$$

13. Ans: (a)

Sol: $n = 4$

$$P = 10 \text{ kN}$$

$$S_{yt} = 400 \text{ N/mm}^2$$

$$F.S = 6$$

$$d_c = 0.8d$$

Using Rankine theory

$$P_A = CL_2 \text{ (tensile load)}$$

$$\begin{aligned} &= \frac{PL}{2(L_1^2 + L_2^2)} \times L_2 \\ &= \frac{10 \times 550}{2(75^2 + 325^2)} \times 325 = 8 \text{ kN} \end{aligned}$$

$$P_{\text{direct}} = \frac{P}{4} = 2.5 \text{ kN} = P_A = P_B$$

Bolt 'A' is subjected to maximum load

Rankine Theory

$$\begin{aligned} \therefore \text{Total Tensile load on bolt} &= P_A + P'_A \\ &= 8 + 2.5 = 10.5 \text{ kN} \end{aligned}$$

$$\sigma_t = \frac{F}{\frac{\pi}{4} d_c^2} = \frac{S_{yt}}{F.S}$$

$$\frac{10.5}{\frac{\pi}{4} d_c^2} = \frac{400}{6}$$

$$d_c = 14.16$$

$$d = \frac{d_c}{0.8} = 17.7 = 18 \text{ mm}$$

14. Ans: (c)

Sol: Given

$$n = 4, \quad P = 5 \text{ kN}$$

$$S_{yt} = 380 \text{ N/mm}^2$$

$$F.S = 5, \quad d_c = 0.8d$$

$$P_{tA} = KL_2 = \text{(Tensile)}$$

$$\begin{aligned} &= \frac{PL}{2(L_1^2 + L_2^2)} \times L_2 \\ &= \frac{5 \times 250}{2(75^2 + 375^2)} \times 375 \\ &= 1.6 \text{ kN} \end{aligned}$$



$$P_{\text{shear}} = \frac{P}{4} = \frac{5}{4} = 1.25 \text{ kN}$$

Direct shear load,

$$P_{SA} = P_{SB} = \frac{P}{4} = 1.25 \text{ kN}$$

Bolts at 'A' is under maximum bending

Rankine Theory

$$\tau = \frac{P_{SA}}{A} = \frac{1.25 \times 10^3}{A}$$

$$\Rightarrow A = \frac{\pi}{4} d_c^2$$

$$\sigma_t = \frac{P_{tA}}{A} = \frac{1.6 \times 10^3}{A}$$

$$\sigma_1 = \frac{\sigma_t}{2} + \sqrt{\left(\frac{\sigma_t}{2}\right)^2 + \tau_{xy}^2}$$

$$\begin{aligned} \sigma_1 &= \frac{1.6 \times 10^3}{2A} + \frac{1}{A} \sqrt{\left(\frac{1.6 \times 10^3}{2}\right)^2 + (1.25 \times 10^3)^2} \\ &= \frac{2292.22}{A} \text{ N/mm}^2 \end{aligned}$$

According to Rankine Theory

$$\sigma_1 = \frac{S_{yt}}{FS}$$

$$\Rightarrow \frac{2292.22}{A} = \frac{380}{5}$$

$$\Rightarrow A = 30.16 \text{ mm}^2 = \frac{\pi}{4} \times d_c^2$$

$$\Rightarrow d_c = 6.196 \text{ mm}$$

$$\Rightarrow d = \frac{6.196}{0.8} = 7.745 \text{ mm}$$

15. Ans: (a)

Sol: Given

$$K_m = 3K_b$$

$$P_{\min} = 0$$

$$P_{\max} = 5 \text{ kN}$$

$$F_i = 4.5 \text{ kN}$$

$$M8 \Rightarrow d = 8$$

$$A = 36.6 \text{ mm}^2$$

$$\sigma_a = \frac{CP}{2A}$$

$$\text{Here, } C = \frac{K_b}{K_b + K_m}$$

$$= \frac{K_b}{K_b + 3K_b} = \frac{K_b}{4K_b} = 0.25$$

$$\Rightarrow \sigma_a = \frac{0.25 \times 5 \times 10^3}{2 \times 36.6} = 17.07 \text{ MPa}$$

$$\sigma_a = 17 \text{ MPa}$$

$$\sigma_m = \sigma_a + \frac{F_i}{A}$$

$$= 17 + \frac{4.5 \times 10^3}{36.6}$$

$$\sigma_m = 140 \text{ MPa}$$



Chapter- 6 Welded Joints

01. Ans (b)

Sol: Given: $s = 10 \text{ mm}$,

$$\tau = 80 \text{ MPa}$$

$$P = 0.707 \times s \times l \times \tau$$

$$= 0.707 \times 10 \times 10 \times 80 = 5.6 \text{ kN}$$

02. Ans (b)

Sol: Given, $P = 400 \text{ kN}$,

$$\tau = 80 \text{ MPa}$$

$$P = 2 \times 0.707 \times s \times \ell \times \frac{S_{sy}}{FS}$$

$$400 \times 1000 = 2 \times 0.707 \times 10 \times 80 \times l$$

$$2l = \frac{400000}{0.707 \times 10 \times 80}$$

$$\text{Total length} = 2l \approx 703 \text{ mm}$$

03. Ans: (a)

Sol: Given:

$$P = 340 \text{ kN} = 340000 \text{ N}$$

$$\frac{S_{sy}}{FS} = 80 \text{ MPa},$$

$$s = 15 \text{ mm}$$

$$P = 0.707s l \times \frac{S_{sy}}{FS}$$

$$340 \times 10^3 = 0.707 \times 15 \times l \times 80$$

$l = 400 \text{ mm}$ length of weld adjusted on both sides i.e., 200 mm on each side.

04. Ans: (b)

Sol: $S = 10 \text{ mm}$, $P = 4 \text{ kN/cm}$

$$P_{\text{transverse}} = 0.707 \times S \times l \times \frac{S_{sy}}{FS}$$

$$4 \text{ kN} \rightarrow 1 \text{ cm}$$

$$180 \text{ kN} = \frac{180}{4} = 45 \text{ cm} = 450 \text{ mm}$$

$$\therefore l + 100 + l = 450$$

$$\therefore l = 175 \text{ mm}$$

05. Ans (a)

Sol: Given: $d = 60 \text{ mm}$, $s = 10 \text{ mm}$,

$$\tau = 70 \text{ MPa}$$

$$\tau = \frac{T}{J} \times r = \frac{T}{2\pi r^3 t} \times r = \frac{T}{2\pi r^2 t}$$

$$= \frac{T}{2\pi r^2 \times 0.707s}$$

$$= \frac{T}{2\pi \times \frac{d^2}{4} \times 0.707 \times s}$$

$$\tau = \frac{2.83T}{\pi s d^2}$$

$s = \text{Size of the weld}$

$$T = \frac{70 \times \pi \times 10 \times (60)^2}{2.83}$$

$$= 2797460 \text{ N-mm} \Rightarrow T = 2.797 \text{ kN-m}$$

06. Ans (a)

Sol: $t = 10 \text{ mm}$

$$d = 15 \times 10^3 \text{ mm}$$

$$\frac{S_{yt}}{FS} = 85 \text{ MPa}$$



$$\sigma_l = \sigma_h = \frac{pd}{4t} = \sigma_1$$

According to Rankine Theory

$$\sigma_1 = \frac{S_{yt}}{FS}$$

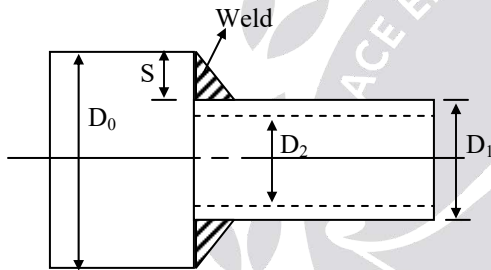
$$\frac{pd}{4t} = 85$$

$$\Rightarrow \frac{p \times 15 \times 10^3}{4 \times 10} = 85$$

$$\Rightarrow p = 0.226 \text{ MPa}$$

07. Ans: (b)

Sol:



$$D_1 = 205 \text{ mm}, D_2 = 200 \text{ mm}$$

$$D_0 = 210 \text{ mm},$$

$$\frac{S_{sy}}{FS} = 110 \text{ MPa}$$

$$s = \frac{210 - 205}{2} = 2.5 \text{ mm}$$

$$t = 0.707 s = 0.707 \times 2.5 = 1.7675 \text{ mm}$$

Force = Pressure $\times$ Area

$$= P \times \frac{\pi}{4} D_2^2 \dots\dots\dots (1)$$

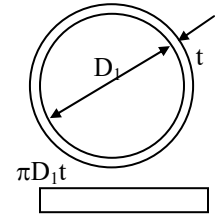
$$F = \pi D_1 t \times \frac{S_{sy}}{FS} \dots\dots\dots (2)$$

Equate (1) & (2)

$$P \times \frac{\pi}{4} D_2^2 = \pi D_1 t \frac{S_{sy}}{FS}$$

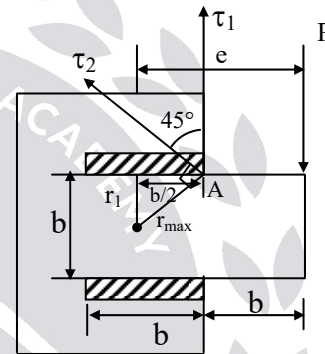
$$P = \frac{205 \times 4 \times 1.7675}{(200)^2} \times 110$$

$$P = 3.9857 \text{ MPa}$$



08. Ans: (a)

Sol:



Primary shear stress

$$\tau_1 = \frac{P}{b \times t \times 2}$$

Secondary shear stress

$$\tau_2 = \frac{T}{J} \times r_{\max}$$

$$T = P \times e = P \left(b + \frac{b}{2} \right) = 1.5 Pb$$

$$J = A \left(\frac{l^2}{12} + r_1^2 \right) \times 2$$

$$A = b \times t$$

$$l = b$$

$$r_1 = \left(\frac{b}{2} + \frac{t}{2} \right) = \frac{b}{2} (\because b \gg t)$$



r_1 = distance between two centroids.

$r_{\max}$ = distance from centroid to maximum distance on weld

$$\therefore J = b \times t \left[\frac{b^2}{12} + \frac{b^2}{4} \right] \times 2 = \frac{2b^3t}{3}$$

$$r_{\max} = \sqrt{\left(\frac{b}{2}\right)^2 + \left(\frac{b}{2}\right)^2} = \frac{b}{\sqrt{2}}$$

$$\tau_2 = \frac{T}{J} \times r_{\max} = \left(\frac{1.59Pb}{\frac{2b^3t}{3}} \right) \times \frac{b}{\sqrt{2}} = \frac{1.59P}{bt}$$

Resultant Shear stress

$$\tau = \sqrt{\tau_1^2 + \tau_2^2 + 2\tau_1\tau_2 \cos \theta}$$

$$= \sqrt{\left(\frac{P}{bt \times 2}\right)^2 + \left(\frac{1.59P}{bt}\right)^2 + 2\left(\frac{P}{2bt}\right)\left(\frac{1.59P}{bt}\right) \cos 45}$$

θ = Angle between τ_1 and τ_2

$$= \frac{P}{bt} \sqrt{\left(\frac{1}{2}\right)^2 + (1.59)^2 + 2 \times \frac{1}{2} \times 1.59 \times \cos 45}$$

$$= \frac{1.975P}{bt}$$

09. Ans: (a)

Sol: Given: $\tau = 140 \text{ MPa}$, $s = 6 \text{ mm}$
 $d = 50 \text{ mm}$, $r = 25 \text{ mm}$

We know that

$$\tau = \frac{T}{2\pi r^2 t}$$

$$\therefore T = 2\pi r^2 \times t \times \frac{S_{sy}}{FS}$$

$$= 2\pi \times 25^2 \times (0.707 \times 6) \times 140$$

$$\Rightarrow T = 2332161 \text{ N-mm}$$

$$= 2332.161 \text{ Nm}$$

Linked questions (Q.10 & Q.11)

10. Ans: (a)

11. Ans: (a)

Sol: Given:

$$\tau = 75 \text{ N/mm}^2, \quad s = 10 \text{ mm}$$

$$P = 200 \text{ kN}, \quad a = 145 \text{ mm}$$

$$P = 200 \times 10^3 \text{ N}$$

$$b = 55 \text{ mm}$$

$$P = \tau \times 0.707 s \times l$$

$$200 \times 10^3 = 75 \times 0.707 \times 10 \times l$$

$$l = \frac{200 \times 10^3}{75 \times 0.707 (10)}$$

$$l = 377.18 \text{ mm}$$

$$l_a = \frac{l \times b}{a + b}$$

$$= \frac{377.18 \times 55}{(145 + 55)} = 103.72 \text{ mm}$$

For calculating force carried by top weld

$$P = \tau \times 0.707 \times s \times l_a$$

$$= 75 \times 0.707 \times 10 \times 103.7$$

$$= 54986.9 \text{ N}$$

$$= 54.9 \text{ kN}$$

$$P = 55 \text{ kN}$$



Chapter- 7 Sliding Contact Bearings

01. Ans: (b)

Sol: Given:

Load $W = 3 \text{ kN}$

$d = 40 \text{ mm}$

$p = 1.3 \text{ MPa} = 1.3 \text{ N/mm}^2$

$$\text{Pressure } (p) = \frac{W}{l \times d}$$

$$l = \frac{W}{p \times d}$$

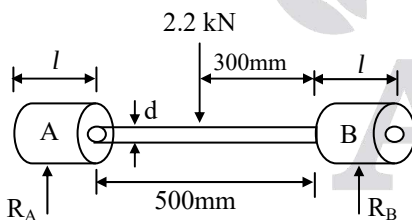
$$= \frac{3000}{1.3 \times 40}$$

$$l = 57.69 \text{ mm}$$

$$\frac{l}{d} = \frac{57.69}{40} = 1.44 \approx 1.45$$

02. Ans: (a)

Sol:



$$\frac{l}{d} = 1.5$$

$d = 25 \text{ mm}$

$l = 500 \text{ mm}$

$W = 2.2 \text{ kN}$

$a = 300 \text{ mm}$

$P = ?$

$$\Sigma M_B = 0$$

$$R_A \times 500 = 2.2 \times 300$$

$$R_A = 1.32 \text{ kN}$$

$$R_B = 2.2 \text{ kN} - 1.32 = 0.88 \text{ kN}$$

Bearing pressure,

$$P = \frac{R_A}{ld} = \frac{1.32 \times 10^3}{25 \times 1.5 \times 25} = 1.408 \text{ MPa}$$

03. Ans: (a)

Sol: Given:

$d = 75 \text{ mm}$, $N_1 = 300 \text{ rpm}$

$p_1 = 1.4 \text{ MPa} = 1.4 \text{ N/mm}^2$

$\mu = 0.06 \text{ Pa-sec}$, $N_2 = 400 \text{ rpm}$

$p_2 = ?$

$$\frac{\mu_1 N_1}{p_1} = \frac{\mu_2 N_2}{p_2}$$

Since, same oil is used μ is same i.e. $\mu_1 = \mu_2$

$$\Rightarrow \frac{N_1}{p_1} = \frac{N_2}{p_2}$$

$$\frac{300}{1.4} = \frac{400}{p_2}$$

$$p_2 = \frac{400 \times 1.4}{300}$$

$$p_2 = 1.87 \text{ MPa}$$

04. Ans: (b)

Sol: Given: Eccentricity ratio, $\varepsilon = 0.8$

$$\varepsilon = 1 - \frac{h_0}{C}$$

$$\frac{h_0}{C} = 1 - 0.8$$

$$\frac{h_0}{C} = 0.2$$



05. Ans: (a)

Sol: $d = 150 \text{ mm} = 0.15 \text{ m}$

$L = 225 \text{ mm} = 0.225 \text{ m}$

Load (W) = 9kN = 9000 N

$C = 0.075 \text{ mm}$,

Diametral clearance

$(C_d) = 2 \times 0.075 = 0.15 \text{ mm}$

$= 0.15 \times 10^{-3} \text{ m}$

$N = 1000 \text{ rpm}$

Heat dissipated by bearing = 90 kJ/min

$H = \frac{90}{60} \text{ kW} = 1.5 \text{ kW}$

Heat generated at the bearing = 1500 W

$V = \frac{\pi d N}{60} = \frac{\pi \times 0.15 \times 1000}{60}$

$V = 7.85 \text{ m/sec}$,

f = coefficient of friction

Load (W) = 9000N

Heat generated = $f \cdot V \cdot W$

$1500 = f (7.85) (9000)$

$f = \frac{1500}{7.85 \times 9000} = 0.021$

$\frac{d}{c_d} = \frac{150}{2 \times 0.075} = 1000$

Pressure (p) = $\frac{\text{Load}}{l \times d}$

$p = \frac{9000}{0.15 \times 0.225} = 0.267 \text{ MPa}$

According to Mckee equation

$f = 0.326 \left(\frac{\mu N}{p} \right) \left(\frac{d}{C_d} \right) + 0.002$

$0.0212 = 0.326 \left(\frac{\mu \times 1000}{0.267 \times 10^6} \right) 1000 + 0.002$

$\mu = 0.0157 \text{ Pa - sec}$

06. Ans: (a)

Sol: Given:

$d = 50 \text{ mm}$, $l = 75 \text{ mm}$, $f = 0.0015$

$p = 2 \text{ MPa}$, $N = 500 \text{ rpm}$

$C = 11.6 \text{ W/m}^2\text{C}$, $T_r = 28^\circ\text{C}$

Heat lost in friction = $f \times W \times V$

$= (f) (p \times l \times d) \left(\frac{\pi d N}{60} \right)$

$= 0.0015 \times 2 \times 50 \times 75 \times \frac{\pi \times 0.05 \times 500}{60}$

$= 14.72 \text{ Nm/sec}$

$14.72 = CA (T_s - T_r)$

$14.72 = 11.6 \times 0.05 \times 0.075 \times 8 (T_s - 28)$

$T_s = 70.2^\circ\text{C}$

Linked Answer Question 07 & 08

07. Ans: (a)

08. Ans: (c)

Sol: Given:

$d = 100 \text{ mm} = 0.1 \text{ m}$

$l = 150 \text{ mm} = 0.15 \text{ m}$

$W = 4.5 \text{ kN} = 4500 \text{ N}$

$N = 600 \text{ rpm}$

$\mu = 18.5 \times 10^{-3} \text{ kg/m-s} = 0.0185 \text{ kg/m-s}$

$C_d = 0.1$

$\varepsilon = 0.4$



$$\text{Sommerfeld Number} = \left(\frac{\mu N_s}{p} \right) \left(\frac{d}{C_d} \right)^2$$

$$\begin{aligned} \text{Here pressure } (p) &= \frac{W}{A} = \frac{W}{l \times d} \\ &= \frac{4500}{0.15 \times 0.1} = 30 \times 10^4 \text{ N/m}^2 \end{aligned}$$

$$P = 0.3 \text{ MPa}$$

Sommerfeld no "S"

$$\begin{aligned} &= \frac{0.0185 \times \left(\frac{600}{60} \right)}{0.3 \times 10^6} \left(\frac{100}{0.1} \right)^2 \\ &= 0.617 \end{aligned}$$

$$\text{Eccentricity ratio, } \varepsilon = 1 - \frac{h_0}{\left(\frac{C_d}{2} \right)}$$

$$0.4 = 1 - \frac{h_0}{\left(\frac{0.1}{2} \right)}$$

$$h_0 = 0.03 \text{ mm}$$

09. Ans: (a)

Sol: Given

$$W = 150 \text{ kN}, \quad N = 1800 \text{ rpm}$$

$$d = 300 \text{ mm} = 0.3 \text{ m}$$

$$p = 1.6 \text{ N/mm}^2 = 1.6 \times 10^6 \text{ Pa}$$

$$C_d = 0.25, \quad \mu = 20 \times 10^{-3} \text{ Pa-sec}$$

$$K = 0.002$$

$$\begin{aligned} f &= \left[0.326 \left(\frac{\mu N}{p} \right) \left(\frac{d}{C_d} \right) + K \right] \\ &= \left[0.326 \left(\frac{20 \times 10^{-3} \times 1800}{1.6 \times 10^6} \right) \left(\frac{300}{0.25} \right) + 0.002 \right] \\ &= 0.01 \end{aligned}$$

$$\begin{aligned} \text{Heat generation} &= 0.01 \times 150 \times \pi \times d \times N \\ &= 0.01 \times 150 \times \pi \times 0.3 \times 1800 \\ &= 2748.7 \text{ kJ/min} \end{aligned}$$

10. Ans: (a)

Sol: Given: $d_1 = 75 \text{ mm}$, $d_2 = 12 \text{ mm}$

$$p = 0.6 \text{ MPa} = 0.6 \text{ N/mm}^2$$

$$\text{Area} = \frac{\pi}{4} (d_1^2 - d_2^2)$$

$$A = \frac{\pi}{4} (75^2 - 12^2)$$

$$A = 4304.77 \text{ mm}^2$$

$$\begin{aligned} \text{Axial load} &= p \times A \\ &= 0.6 \times 4304.77 \text{ N} \\ &= 2582.862 \text{ N} \end{aligned}$$

$$P = 2.58 \text{ kN}$$

11. Ans: (a)

Sol: $d = 60 \text{ mm} = 0.06 \text{ m}$

$$N = 600 \text{ rpm}, \quad P = 120 \text{ kPa}$$

$$\mu = 0.05$$

For foot step bearing

$$T_f = \frac{2}{3} \mu \times F \times r$$

$$= \frac{2}{3} \times 0.05 \times 120 \times 10^3 \times \frac{\pi}{4} \times 0.06^2 \times 0.03$$

$$T_f = 0.339 \text{ N-m}$$

$$P = \frac{2\pi N T_f}{60}$$

$$= \frac{2\pi \times 600 \times 0.339}{60} = 21.29 \text{ W}$$



Chapter- 8 Rolling Contact Bearings

01. Ans: (d)

Sol: 6205 bearing

$$C = 10.8 \text{ kN}$$

6305 series bearing have higher load carrying capacity than 6205 bearing. Hence among the given option 16.2 kN is greater than 10.8kN.

02. Ans: (b)

Sol: Given: 6210 bearing

$$C = 22.5 \text{ kN}$$

$$L = 27 \text{ million rev}$$

6 – series – Ball bearing

$$L_{10} = \left(\frac{C}{P} \right)^3$$

K = 3 for Ball bearing

$$27 = \left(\frac{22.5}{P} \right)^3$$

$$P^3 = \frac{11.39 \times 10^3}{27}$$

$$P = 7.5 \text{ kN}$$

03. Ans: (b)

Sol: Given: C = 48.545 kN

$$L = 6000 \text{ hrs}$$

$$N = 500 \text{ rpm}$$

$$L_{10} = \left(\frac{C}{P} \right)^K$$

For Ball bearing, K = 3

$$L_{10} = \left(\frac{48.545}{P} \right)^3$$

$$L_{10} = \frac{L_{50}}{5} = \left(\frac{48.545}{P} \right)^3$$

$$L_{50} = \frac{60NL_H}{10^6} = \frac{60 \times 500 \times 6000}{10^6}$$

$$= 180 \text{ million rev}$$

$$L_{10} = \frac{L_{50}}{5} = \frac{180}{5} = \left(\frac{48.545}{P} \right)^3$$

$$36 = \left(\frac{48.545}{P} \right)^3$$

$$P = 14.7 \text{ kN}$$

Linked Answer Question (04 & 05)

04. Ans: (a)

05. Ans: (c)

Sol: $F_r = 2.5 \text{ kN}$

$$F_a = 1.5 \text{ kN}$$

$$C_s = 1.5$$

$$N = 1000 \text{ rpm}$$

$$X = 0.56$$

$$Y = 1.4, V = \text{race rotation factor} = 1$$

$$\text{Equivalent load (P)} = (XVF_r + YF_a)C_s$$

$$V \text{ for most bearings} = 1$$

$$P = [(0.56 \times 1 \times 2.5) + (1.4 \times 1.5)]1.5$$

$$P = [11.4 + 2.1]1.5$$

$$P = (3.5)(1.5)$$

$$P = 5.25 \text{ kN}$$



$$L_{10} = \left(\frac{C}{P} \right)^K$$

K = 3 for ball bearing

$$L_H = \frac{40 \text{ hrs}}{\text{week}} \times \frac{52 \text{ weeks}}{\text{yr}} \times 5 \text{ years}$$

$$= 10,400 \text{ hrs}$$

$$L = \frac{60 \times N \times L_H}{10^6}$$

$$= \frac{60 \times 1000 \times 10,400}{10^6}$$

L = 624 million revolutions

$$L_{10} = \left(\frac{C}{P} \right)^3$$

$$624 = \left(\frac{C}{5.25} \right)^3$$

$$\frac{C}{5.25} = 8.545$$

$$C = 44.86 \text{ kN}$$

$$N_3 = \alpha_3 n_3 = \frac{30}{100} \times 720 = 216$$

$$N = 270 + 576 + 216 = 1062$$

$$P = \left(\frac{N_1 P_1^3 + N_2 P_2^3 + N_3 P_3^3}{N_1 + N_2 + N_3} \right)^{1/K}$$

K = 3 for Ball bearing

$$= \left[\frac{(270 \times 5^3) + (576 \times 7^3) + (216 \times 3^3)}{270 + 576 + 216} \right]^{1/3}$$

$$= \left[\frac{33750 + 197568 + 5832}{1062} \right]^{1/3}$$

$$= \left[\frac{237150}{1062} \right]^{1/3}$$

$$P = 6.067 \text{ kN}$$

$$L = \left(\frac{C}{P} \right)^K$$

$$L = \left(\frac{16.6}{6.067} \right)^3$$

$$L = 20.5 \text{ million rev}$$

Linked Answer Question (06 & 07)

06. Ans: (c)

07. Ans: (a)

Sol: Given C = 16.6 kN

% of element time = α

$$N_1 = \alpha_1 n_1 = \frac{30}{100} \times 900 = 270$$

$$N_2 = \alpha_2 n_2 = \frac{40}{100} \times 1440 = 576$$

Linked Answer Question (08 to 11)

08. Ans: (b)

09. Ans: (a)

10. Ans: (b)



11. Ans: (a)

Sol: Given:

$$T_1 = 3 \text{ kN}$$

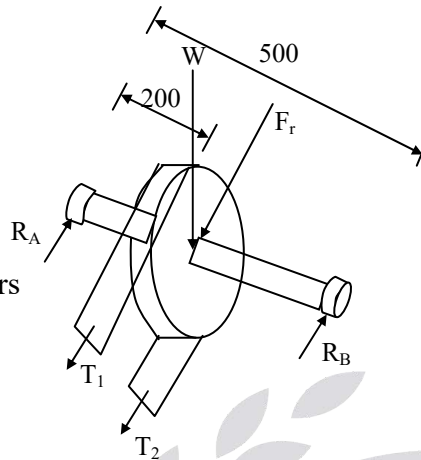
$$T_2 = 1.5 \text{ kN}$$

$$F_a = 2 \text{ kN}$$

$$L_H = 5000 \text{ hrs}$$

$$X = 0.56$$

$$Y = 1.5$$



$$W = \text{weight of pulley} = 1 \text{ kN}$$

$$\text{Resultant Radial load of shaft} = \sqrt{(3 + 1.5)^2 + 1^2}$$

$$R = 4.61 \text{ kN} = R_A + R_B$$

$$\text{Take } \sum M_B = 0$$

$$R_A \times 500 = R \times 300$$

$$R_A = \frac{4.61 \times 300}{500}$$

$$R_A = 2.766 \text{ kN},$$

$$R_B = 1.8436 \text{ kN}$$

Equivalent load

$$P = [XVF_r + F_a Y]$$

$$= (0.56 \times 1 \times 2.76) + (1.5 \times 2)$$

$$P = 4.546 \text{ kN}$$

Dynamic load rating

$$L_{10} = \left(\frac{C}{P} \right)^K, \quad [K = 3 \text{ For Ball bearing}]$$

$$L_{10} = \frac{60 \times 400 \times 5000}{10^6} = 120 \text{ million rev}$$

$$120 = \left(\frac{C}{4.55} \right)^3$$

$$C = 22.44 \text{ kN}$$

Chapter- 9 Clutch Design

01. Ans: (b)

Sol: Given,

$$W = 1000 \text{ N}, \quad n = 2$$

$$r_1 = 150 \text{ mm} = 0.15 \text{ m}$$

$$r_2 = 100 \text{ mm} = 0.1 \text{ m}$$

$$\mu = 0.5$$

$$\text{Mean Radius (R)} = \frac{r_1 + r_2}{2} = \frac{150 + 100}{2}$$

$$R = 125 \text{ mm}$$

Torque Transmitted,

$$T = n\mu WR$$

(For both sides effective $n = 2$)

$$= 2 \times 0.5 \times 1000 \times 125$$

$$= 125000 \text{ N-mm}$$

$$T = 125 \text{ N-m}$$

Linked Answer Questions (2 & 3)

02. Ans: (a)

03. Ans: (a)

Sol: $P = 10 \text{ kW}$

$$T = 100 \text{ N-m}$$

$$n = 2$$

$$p_{\max} = 0.085 \text{ MPa}$$

$$d_1 = 1.25d_2$$

$$r_1 = 1.25r_2$$

$$\mu = 0.3$$



$$T = \frac{\mu W(r_1 + r_2)}{2} \times n \text{ for uniform wear}$$

$$= \frac{\mu 2\pi C(r_1 - r_2)(r_1 + r_2)}{2} \times 2$$

$$[\because W = 2\pi C(r_1 - r_2), C = p_1 r_1 = p_2 r_2]$$

$$100 = (0.3)2\pi(0.085)(r_2)(r_1^2 - r_2^2)$$

$$100 \times 10^3 = (0.3)2\pi(0.085)(r_2)[(1.25r_2)^2 - r_2^2]$$

$$r_1 = 130 \text{ mm}, d_1 = 260 \text{ mm}$$

$$r_2 = 104 \text{ mm}, d_2 = 208 \text{ mm}$$

$$W = 2\pi C(r_1 - r_2)$$

$$= 2\pi(p_{\max})(r_2)(r_1 - r_2)$$

$$= 2\pi(0.085)(104)(130 - 104)$$

$$W = 1.44 \text{ kN}$$

04. Ans: (b)

Sol: $T_{\max} = 140 \text{ N-m}$

$$d_1 = 220 \text{ mm}, d_2 = 150 \text{ mm}$$

$$P_{\max} = 0.25 \text{ MPa}$$

$$\mu = 0.3$$

$$T = \mu W \left(\frac{r_1 + r_2}{2} \right)$$

$$= \mu(2\pi)C(r_1 - r_2) \left(\frac{r_1 + r_2}{2} \right)$$

$$= \mu 2\pi P_{\max} r_2 \left(\frac{r_1^2 - r_2^2}{2} \right)$$

i) $T_1 = 114 \text{ N-m}$ Slip takes place

ii) $T_2 = 148 \text{ N-m}$ suitable

iii) $T_3 = 173 \text{ Nm}$

05. Ans: (c)

Sol: Given, $\mu = 0.5$

$$r_1 = 150 \text{ mm} = 0.15 \text{ m}$$

$$r_2 = 100 \text{ mm} = 0.1 \text{ m}$$

$$T = 0.4 \text{ kN-m} = 400 \text{ N-m}$$

$$n_1 + n_2 = 5,$$

n = No. of pairs of contact surface

$$n = n_1 + n_2 - 1 = 5 - 1 = 4$$

$$R = \frac{r_1 + r_2}{2} = \frac{0.15 + 0.1}{2} = 0.125 \text{ m}$$

$$T = n\mu W R$$

$$400 = 4(0.5)(W) 0.125$$

$$W = 1600 \text{ N}$$

$\therefore$ Four springs exert axial load,

$$\text{Load per spring} = \frac{1600}{4} = 400 \text{ N}$$

Linked Answer Question (06 & 07)

06. Ans: (b)

Sol: $N = 1000 \text{ rpm},$

$$2\alpha = 24^\circ \Rightarrow \alpha = 12^\circ$$

$$\mu = 0.2, r_m = 150 \text{ mm}, P = 20 \text{ kW}$$

$$p = 70 \text{ kN/m}^2$$

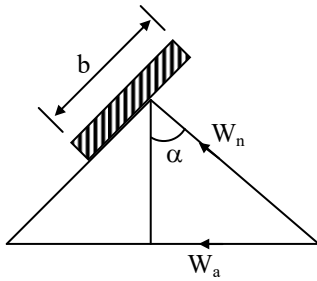
$$T = \frac{60P}{2\pi N} = \mu W_n r_m = \mu W_n \left(\frac{r_1 + r_2}{2} \right)$$

$$T = \frac{60(20) \times 1000}{2\pi(1000)} = 191 \text{ N-m}$$

$$191 \times 10^3 \text{ N-mm} = 0.2 \times W_n \times 150$$

$$W_n = 6366.19 \text{ N} \quad [\because W_a = W_n \sin \alpha]$$

$$W_a = 1323.60 \text{ N}$$



Force required for engagement

$$\begin{aligned} W_{ac} &= W_a + \mu W_n \cos \alpha \\ &= 1323.60 + [0.2 \times 6366.19 \times \cos 12] \\ W_{ac} &= 2.56 \text{ kN} \end{aligned}$$

07. Ans: (b)

Sol: $W_n = p \times 2\pi r_m \times b$

$$6366.19 = 70 \times 10^3 \times 2 \times \pi \times 0.15 \times b$$

$$\Rightarrow b = 0.0964 \text{ m} = 96.4 \text{ mm}$$

Common Data for Q. 8 & 9

08. Ans: (c)

09. Ans: (a)

Sol: $N_1 = 200 \text{ rpm}$,

$$\omega_1 = \frac{2\pi N}{60} = \frac{2 \times \pi \times 200}{60} = 20.95 \text{ rad/s}$$

$$\omega_2 = 0$$

$$\alpha = \frac{\omega_1 - \omega_2}{t} = \frac{20.95}{5} = 4.18 \text{ rad/s}^2$$

Torque $T = I\alpha$

$$= 20 \times 4.18 = 83.6 \text{ N-m}$$

$$\mu = 0.3$$

For uniform pressure,

$$T = \frac{2}{3} \mu W \left[\frac{r_1^3 - r_2^3}{r_1^2 - r_2^2} \right] \times n$$

$$83.6 \times 10^3 = \frac{2}{3} \times 0.3 \times W \left[\frac{100^3 - 60^3}{100^2 - 60^2} \right] \times 2$$

$$W = 1706.12 \text{ N}$$

10. Ans: (a)

Sol: Given

$$D = 300 \text{ mm}$$

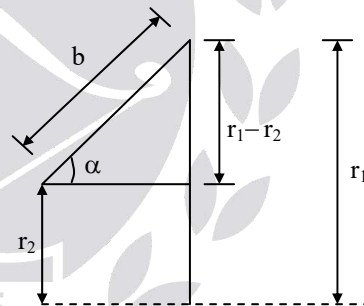
$$b = 100 \text{ mm}$$

$$\mu = 0.2$$

$$\alpha = 10^\circ$$

$$p = 0.07 \text{ MPa} = 0.07 \text{ N/mm}^2$$

$$N = 500 \text{ rpm}$$



We know that

$$\begin{aligned} W &= 2\pi C(r_1 - r_2) \\ &= 2\pi p r (r_1 - r_2) \quad (\because C = p \times r) \\ &= 2\pi p r b \sin \alpha \quad (r_1 - r_2 = b \sin \alpha) \\ &= 2\pi \times 0.07 \times 150 (100 \sin 10^\circ) \end{aligned}$$

$$W = 1146 \text{ N}$$

$$W_n = \frac{W}{\sin \alpha} = \frac{1146}{\sin 10}$$

$$W_n = 6599 \text{ N}$$



Force required for engagement

$$\begin{aligned} W_{en} &= W_n(\sin\alpha + \mu \cos\alpha) \\ &= 6599(\sin 10^\circ + 0.2 \cos 10^\circ) \\ W_{en} &= 2445 \text{ N} \end{aligned}$$

11. Ans: (d)

Sol: $T = \frac{60P}{2\pi N} = 318.3 \text{ N-m}$

$$\omega_2 = \frac{2\pi N}{60} = 78.5 \text{ rad/s}$$

$$318.3 = n \times \mu \times m r (\omega_2^2 - \omega_1^2) \times R$$

$$\omega_1 = 0.75\omega_2, \quad n = 4$$

$$318.3 = 4 \times 0.25 \times m \times 0.125 \left(1 - \frac{9}{16}\right) \times 78.5^2 \times 0.15$$

$$m = 6.3 \text{ kg}$$

12. Ans: 157mm & 135.22mm

Sol: Centrifugal force between each shoe and drum

$$F = m r (\omega_2^2 - \omega_1^2)$$

$$F = 2123.08 \text{ N}$$

$$\text{Area} = \frac{F}{0.1} = 21230.87 \text{ mm}^2$$

$$\text{width} \times \text{arc length} = w \times \frac{\pi}{3} \times 150 = 21230.87$$

$$w = 135.22 \text{ mm}$$

$$\text{Length} = \frac{\pi}{3} \times 150 = 157 \text{ mm}$$

$$\text{Length} = 157 \text{ mm}$$

$$\text{Width} = 135.22 \text{ mm}$$

Chapter- 10 Brakes

Linked Answer Questions (01 & 02)

01. Ans: (b)

Sol: $\Sigma M_{\text{Pivot}} = 0$

$$300 \times 500 = R_N \times 200$$

$$R_N = 750 \text{ N}$$

$$F_t = \mu R_N = 180 \text{ N}$$

$$T = F_t r$$

$$= 180 \times \left(\frac{300}{2}\right) \times 10^{-3} = 27 \text{ N-m}$$

02. Ans: (a)

Sol: $\omega_1 = \frac{2\pi \times 100}{60} = 10.47 \text{ rad/sec}$

$$\omega_2 = 0$$

Capacity to bring the system to rest from 100 rpm = work done = Heat generation =

$$T \times \theta$$

$$= T \times \left(\frac{\omega_1 + \omega_2}{2}\right) t$$

$$= 27 \times 5.235 \times 5 = 706.725 \text{ J}$$

03. Ans: (b)

Sol: $\mu = 0.3$

$$2\theta = 90^\circ = \pi/2 \text{ rad}$$

$$\theta = 45^\circ$$



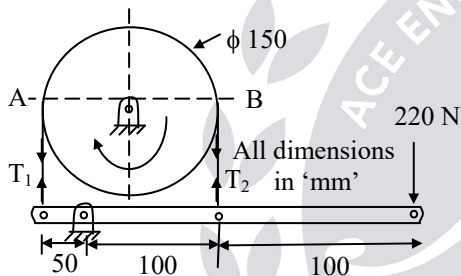
Equivalent coefficient of friction

$$\begin{aligned}\mu^1 &= \frac{4\mu \sin \theta}{2\theta + \sin 2\theta} \\ &= \frac{4 \times 0.3 \times \sin 45^\circ}{\frac{\pi}{2} + \sin 90^\circ} \\ &= \frac{0.848}{2.57} = 0.329 = 0.33\end{aligned}$$

Common Data Question 04 & 05

04. Ans: (c)

Sol:



$$T = 450 \text{ N-m}$$

$$P = 220 \text{ N}$$

$$b = 100 \text{ mm}$$

$$\sum M_{\text{pivot}} = 0$$

$$(220 \times 200) - (T_2 \times 100) + (T_1 \times 50) = 0$$

$$T_2 \times 100 - 50T_1 = 220 \times 200 \dots\dots (1)$$

$$T = (T_1 - T_2) \times r$$

$$T = (T_1 - T_2) \left(\frac{0.150}{2} \right)$$

$$T_1 - T_2 = 6000 \dots\dots (2)$$

$$\text{From (1) and (2) } T_1 = 12880 \text{ N}$$

$$T_2 = 6880 \text{ N}$$

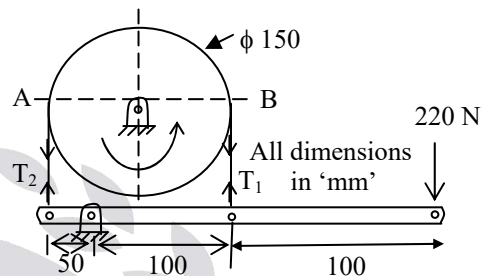
$$\frac{T_1}{T_2} = e^{\mu \times \theta}$$

$$\frac{12880}{6880} = e^{\mu \times \pi}$$

$$\Rightarrow \mu = 0.199 = 0.2$$

05. Ans: (a)

Sol:



We know that

$$\ln \left(\frac{T_1}{T_2} \right) = \mu \theta$$

Here, $\mu = 0.4$, as given

$$\ln \left(\frac{T_1}{T_2} \right) = 0.4 \times \pi$$

$$\ln \left(\frac{T_1}{T_2} \right) = 0.546$$

(or)

$$\left(\frac{T_1}{T_2} \right) = e^{\mu \theta}$$

$$\left(\frac{T_1}{T_2} \right) = e^{(0.4 \times \pi)}$$

$$\left(\frac{T_1}{T_2} \right) = 3.51 \dots\dots (1)$$

Here when the drum rotates in anti clockwise direction. T_1 will be attached to B and T_2 will be attached to A. i.e. tight side and slack side tensions will be changed.



Taking moments about "O"

$$220 \times 200 + T_2 \times 50 = T_1 \times 100 \dots(2)$$

By solving 1 & 2

$$T_2 = 146.17 \text{ N}, T_1 = 513 \text{ N}$$

$$\begin{aligned} \text{Torque} &= (T_1 - T_2) \times r \\ &= (513 - 146.17) \times 75 \times 10^{-3} \\ &= 27.5 \text{ N-m} \end{aligned}$$

Linked Answer Questions 06 & 07

06. Ans: (b)

Sol: $d = 250 \text{ mm}$

$$\rho = 7200 \text{ kg/m}^3$$

$$t = 20 \text{ mm}$$

$$\tau = 0.40 \text{ sec}$$

$$N = 500 \text{ rpm}$$

Energy absorbed by brake

$$E = \frac{1}{2} I (\omega_2^2 - \omega_1^2)$$

$$I = mK^2 = \rho A t \left(\frac{d}{2\sqrt{2}} \right)^2$$

$$I = 7200 \times \frac{\pi}{4} (0.25)^2 (0.02) \left(\frac{0.250}{2\sqrt{2}} \right)^2$$

$$= 0.055 \text{ kgm}^2$$

$$N_2 = 0 \rightarrow \text{Stop}$$

$$\Rightarrow E = \frac{1}{2} (0.05) \left(\frac{2\pi \times 500}{60} \right)^2 = 75 \text{ J}$$

07. Ans: (d)

Sol: Energy absorbed, $E = T \times \theta$

$$75 = T \times \left(\frac{\omega_1 + \omega_2}{2} \right) \times t$$

$$75 = T \times \left(\frac{2\pi \times 500}{60} + 0 \right) \times 0.4$$

$$\Rightarrow T = 7.16 \text{ Nm}$$

Linked Answer Question (08 & 09)

08. Ans: (c)

Sol: $T = 800 \text{ N-m}, r = 0.5 \text{ m}$

$$T = (T_1 - T_2) \times r$$

$$\Rightarrow T_1 - T_2 = \frac{800}{0.5}$$

$$T_1 - T_2 = 1600 \text{ N}$$

$$\text{But, } T_2 = 300 \text{ N}$$

$$T_1 = 1900 \text{ N}$$

$$\frac{T_1}{T_2} = e^{\mu\theta} \Rightarrow \frac{1900}{300} = e^{0.45 \times \theta}$$

$$\theta = 235^\circ$$

09. Ans: (c)

$$\text{Sol: } P_{\max} = \frac{T_1}{r \cdot W} = \frac{1900}{0.5 \times 0.03}$$

$$P_{\max} = 126.67 \text{ kPa}$$



Common Data Question (10 & 11)

10. Ans: (a)

11. Ans: (b)

Sol: Given

$$d = 320 \text{ mm} = 0.32 \text{ m}$$

$$r = 160 \text{ mm} = 0.16 \text{ m}$$

$$\mu = 0.3$$

$$F = 600 \text{ N}$$

Taking moments about 'O'

$$600(400 + 350) - F_t(200 - 160) = R_N(350)$$

$$600(750) - F_t(40) = R_N(350)$$

$$450000 - \mu R_N(40) = R_N(350) \quad (\because F_t = \mu R_N)$$

$$450000 - R_N(12) = R_N(350)$$

$$R_N(350) + R_N(12) = 450000$$

$$R_N = \frac{450000}{362}$$

$$R_N = 1243 \text{ N}$$

For calculating breaking torque (T_B)

$$F_t = \mu R_N$$

$$F_t = 0.3 \times 1243$$

$$F_t = 372.9 \text{ N}$$

$$T_B = F_t \times r = 372.9 \times 0.16 = 59.664$$

$$T_B = 60 \text{ Nm}$$

Chapter- 11
Spur Gear Tooth

01. Ans: (b)

Sol: Given: $T_p = 25$, $m = 4$, $C = ?$

$$N_p = 1200 \text{ rpm}, N_G = 200 \text{ rpm}$$

$$C = \frac{m(T_p + T_G)}{2}$$

$$\frac{T_p}{T_G} = \frac{N_G}{N_p} \Rightarrow T_G = \frac{1200}{200} \times 25 = 150$$

$$C = \frac{4(25 + 150)}{2} = 350 \text{ mm}$$

02. Ans: (b)

Sol: Given, $T_1 = 19$, $T_2 = 37$, $C = 140 \text{ mm}$

$$C = \frac{m(T_1 + T_2)}{2}$$

$$140 = \frac{m(19 + 37)}{2}$$

$$m = \frac{140 \times 2}{56} = 5 \text{ mm}$$

03. Ans: (c)

Sol: $m = 8 \text{ mm}$

Face width (w) = 90 mm

$$F_t = 7.56 \text{ kN}$$

Tensile stress = 35 MPa = S

Form factor (y) = ?

Let $C_V = 1$

$$F_t = S w m y C_V$$

$$7.56 \times 10^3 = 35 \times 10^6 \times 90 \times 8 \times y$$

$$\Rightarrow y = 0.3$$



04. Ans: (a)

Sol: $P = 9 \text{ kW}$, $N = 1440 \text{ rpm}$

$d = 100 \text{ mm}$, $F_t = ?$

$$P = F_t \times V$$

$$F_t = \frac{P}{V} = \frac{9 \times 10^3}{\frac{\pi \times 0.1 \times 1440}{60}} = 1.19 \text{ kN}$$

05. Ans (b)

Sol: $P = 10 \text{ kW} = 10 \times 10^3 \text{ W}$

$V = 600 \text{ m/min}$

$d = 100 \text{ mm} \Rightarrow r = 50 \text{ mm}$

$$F_t = \frac{P}{V}$$

$$= \frac{10 \times 10^3 \times 60}{600} = 10^3 \text{ N}$$

$F_t = 1 \text{ kN}$

$$\text{Torque} = F_t \times r = \frac{1 \times 10^3 \times 50}{1000}$$

$T = 50 \text{ N-m}$

06. Ans: (b)

Sol: Given $P = 20 \text{ kW}$

$N_p = 300 \text{ rpm}$

$\sigma_b = 80 \text{ MPa}$

$y = 0.094$, $C_v = 1$

$w = 14 \text{ m}$

$T_p = 18$, $m = ?$

$$F_t = \frac{P}{V} = S w m y C_v \times \pi$$

$$\Rightarrow \frac{20 \times 10^3}{\left(\frac{\pi d_p \times 300}{60 \times 1000} \right)} = 80 \times 10^6 \times (14 \text{ m}) \times 0.094 \times 1 \times \pi$$

$$(\because d_p = m T_p)$$

$$\Rightarrow \frac{20 \times 10^6 \times 60}{\pi \times 18 \times m \times 300} = 80 \times 14 \times 0.094 \times \pi \times m^2 \times 10^6$$

$$\Rightarrow m = 5.98 \approx 6$$

Linked Answer Questions 07 & 08

07. Ans: (a)

08. Ans: (b)

Sol: $P = 11 \text{ kW}$, $N_p = 1440 \text{ rpm}$

$\phi = 14 \frac{1}{2}$, $m = 6 \text{ mm}$

$T_p = 25$, $y = 0.1$, $C_v = 0.21$

$$\frac{T_G}{T_p} = \frac{N_p}{N_G} = 3 : 1$$

$$T_{\max} = 1.5 T_{\text{mean}}$$

$S = 210 \text{ MPa}$

$F_t = ?$, $w = ?$

$$F_t = \frac{P}{V} C_s \quad \left(\because V = \frac{\pi d N}{60} \right) (d = m T)$$

$$F_t = \frac{11 \times 10^3}{\pi (6 \times 25) \times 1440 / 60 \times 1000}$$

$F_t = 0.98 \text{ kN}$

$$F_t = S w m y C_v$$

$$0.98 \times 10^3 = 210 \times w \times 6 \times 0.1 \times 0.21 w$$

$$= 37 \text{ mm}$$



Linked Answer Questions 09 to 11

09. Ans: (b)

Sol: $P = 500 \text{ kW}$, $N_p = 1800 \text{ rpm}$,

$$C = 660 \text{ mm}, \quad \phi = 22\frac{1}{2}, \quad m = 8 \text{ mm}$$

$$\frac{T_G}{T_P} = 10:1$$

$$F_n = 200 \frac{\text{N}}{\text{mm}}$$

$$C = \frac{m(T_G + T_P)}{2}$$

$$660 = \frac{8(T_P + 10T_P)}{2}$$

$$T_P = 15$$

$$T_G = 150$$

$$d_p = mT_P = 8(15) = 120 \text{ mm}$$

$$F_t = ?$$

$$F_r \text{ on bearing} = ?$$

$$w = ?$$

$$F_t = \frac{P}{V} = \frac{500(\text{kW})}{\frac{\pi d_p N_p}{60}}$$

$$= \frac{500 \times 10^3}{\pi \left(\frac{120}{1000} \text{ m} \right) \times \left(\frac{1800}{60} \right) \frac{1}{\text{sec}}}$$

$$F_t = 44.2 \text{ kN}$$

10. Ans: (c)

Sol: $F_r = F_t \cdot \tan \phi$

$$= 44.2 \tan (22.5) = 18.3 \text{ kN}$$

$$F_n = \frac{F_t}{\cos \phi} = \frac{44.2}{\cos 22.5} = 47.85 \text{ kN}$$

11. Ans: (d)

Sol: $200 \text{ N} \rightarrow 1 \text{ mm width}$

$$47.85 \text{ kN} \rightarrow ?$$

$$w = \frac{47.85 \times 10^3}{200} = 240 \text{ mm}$$

12. Ans: (c)

Sol: $S_{\text{steel}} = 120 \text{ MPa} \rightarrow \text{for pinion}$

$S_{\text{CI}} = 100 \text{ MPa} \rightarrow \text{for gear}$

Form factors

For gear, for pinion $(y_{\text{CI}})_g = 0.13$

Form factors

$$(y_{\text{steel}})_p = 0.093$$

$$S_{\text{steel}} \times y_{\text{steel}} = 120 \times 0.093 = 11.16$$

$$S_{\text{CI}} \times y_{\text{CI}} = 100 \times 0.13 = 13$$

$$\therefore S_{\text{steel}} \times y_{\text{steel}} < S_{\text{CI}} \times y_{\text{CI}}$$

$$\therefore (\text{Strength})_{\text{pinion}} < (\text{Strength})_{\text{gear}}$$

So Pinion is weaker than gear

13. Ans: (b)

Sol: Given: $G.R = \frac{T_G}{T_P} = 2$

$$w = 10 \text{ cm} = 100 \text{ mm}$$

$$d_p = 40 \text{ cm} = 400 \text{ mm}$$

$$\text{Stress factor for fatigue} = 1.5 \text{ N/mm}^2 = K$$

$$Q = \frac{2T_G}{T_G + T_P} = \frac{2(2T_P)}{2T_P + T_P} = \frac{4}{3}$$

$$F_w = K d_p w Q$$

$$F_w = (1.5)(400)(100) \frac{4}{3} = 80 \times 10^3$$

$$= 80 \text{ kN}$$