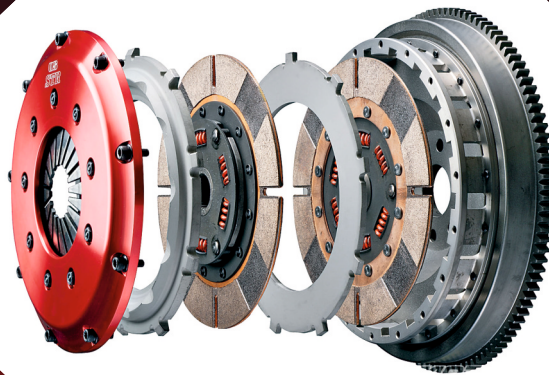




**GATE | PSUs**



# **MECHANICAL ENGINEERING**

**MACHINE DESIGN**

**Text Book:** Theory with worked out Examples and Practice Questions

# Machine Design

(Solutions for Text Book Practice Questions)

Chapter

1

## STATIC LOADS

01. Ans: (d)

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

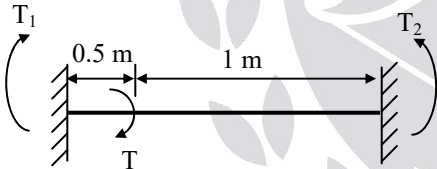
$E = 100 \text{ GPa}$

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

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

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)

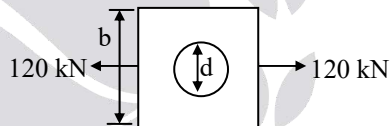
Sol:  $G = 0.8 \times 10^5 \text{ MPa}$

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

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

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: (a, b)**

**Sol:** In each case the loading on all sections is same, hence all sections are critical.

In each case, point A is critical.

In case 1,

At point A,  $\sigma_x = \sigma_{\text{axial}} + \sigma_{\text{bending}}$

At point B,  $\sigma_x = \sigma_{\text{axial}} - \sigma_{\text{bending}}$

Hence point B is not critical here.

In case 4, Pure shear,

$$\sigma_{\text{max}} = \frac{16T}{\pi d^3} \text{ \& } \tau_{\text{max}} = \frac{16T}{\pi d^3}$$

In each other case; the maximum normal stress is more than the maximum shear stress.

**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

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

$$\sigma_1 = \frac{60+0}{2} + \sqrt{\left(\frac{60-0}{2}\right)^2 + (40)^2}$$

$$= 30 + 50 = 80 \text{ MPa}$$

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

**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

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

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

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

**03. Ans: (b)**

**Sol:**  $F_t = 48 \text{ kN}$  ;  $S_{yt} = 200 \text{ MPa}$

$F_s = 18 \text{ kN}$ ,  $A = 600 \text{ mm}^2$ ,  $FS = ?$

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

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

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

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

**04. Ans: (d)**

**Sol:** Given thin cylindrical shell

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

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

$$F_s = ?$$

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

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

$$\sigma_h = \sigma_1 = 30.18 \text{ MPa}$$

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

$$\sigma_3 = 0$$

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

$$\begin{aligned} \left| \frac{30.18 - 15.08}{2} \right| &= 7.55 \\ \text{i.e., } \left| \frac{30.18 - 0}{2} \right| &= 15.09 \\ \left| \frac{15.08}{2} \right| &= 7.54 \end{aligned}$$

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

According max shear stress theory

$$15.09 = \frac{S_{sy}}{F.S}$$

$$15.09 = \frac{S_y}{2 \times F.S}$$

$$F.S = \frac{260}{2 \times 15.09} = 8.615$$

**05. Ans: (c)**

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

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

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

Tresca theory

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

$$\frac{200 - (-100)}{2} = \frac{500}{2 \times F.S}$$

$$F.S = 1.666 = 1.67$$

**06. Ans: (b)**

**Sol:**  $\sigma_b = 55 \text{ MPa}$ ,  $\tau = 31.5 \text{ MPa}$ ,  $S_{yt} = 284 \text{ MPa}$

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

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

$$\begin{aligned} \text{But } \tau_{\max} &= \sqrt{\left(\frac{\sigma_b}{2}\right)^2 + \tau^2} \\ &= \sqrt{\left(\frac{55}{2}\right)^2 + (31.5)^2} = 41.81 \end{aligned}$$

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

**07. Ans: (a)**

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

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

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

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

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

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

According to distortion energy theory

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

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

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

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

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

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

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

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

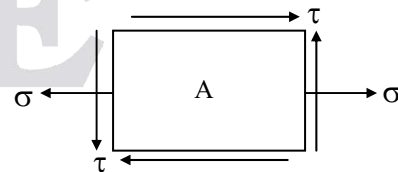
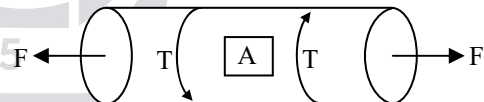
$$= \frac{10^3}{A} \sqrt{20^2 + 3 \times 15^2} = \frac{360}{3}$$

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

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

**08. 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

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

$$\sigma = \frac{F}{\frac{\pi}{4} \times d^2} = \frac{40 \times 10^3}{\frac{\pi}{4} \times 20^2} = 127.32 \text{ MPa}$$

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

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

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

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

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

**09. Ans: (b)**

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

$$\text{Torque, } T = 5 \times 10^3 \times 0.5 = 2500 \text{ Nm}$$

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

Bending moment

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

Maximum shear stress

$$\tau = \frac{16T}{\pi d^3} = \frac{16 \times 2.5 \times 10^3}{\pi \times (0.1)^3}$$

$$= 12732395 \text{ N/m}^2 = 12.73 \text{ MPa}$$

Maximum bending stress

$$\sigma_b = \frac{32M}{\pi d^3} = \frac{32 \times 12500}{\pi \times (0.1)^3}$$

$$= 127323954 \text{ N/m}^2$$

$$= 127.32 \text{ MPa}$$

Major principal stress

$$\sigma_1 = \frac{\sigma_b}{2} + \sqrt{\left(\frac{\sigma_b}{2}\right)^2 + \tau^2}$$

$$= \frac{127.32}{2} + \sqrt{\left(\frac{127.32}{2}\right)^2 + (12.73)^2}$$

$$= 128.58 \text{ MPa}$$

Minor principal stress

$$\sigma_2 = \frac{127.32}{2} - \sqrt{\left(\frac{127.32}{2}\right)^2 + (12.73)^2}$$

$$= -1.26 \text{ MPa}$$

According to Tresca's theory of failure

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

$$\therefore \frac{425}{FS} = \frac{128.58 + 1.26}{2}$$

$$FS = 3.27$$

**10. 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,

$$M = 5 \times 1500 + 5 \times 500$$

$$= 10000 \times 10^3 \text{ N-mm}$$

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

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

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

**11. 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

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

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

**12. Ans: (b)**

**Sol:**  $T = 10 \text{ kN-m}$ ,  $M = 10 \text{ kN-m}$ ,  $FS = 1.5$

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  $T = 6 \text{ kN-m}$

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

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

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

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

$$\Rightarrow FS = 2.7$$

**13. Ans: (a, d)**

**Sol: Given data:**

$$\text{Loading 1: } \sigma_1 = \frac{32M}{\pi d^3} \text{ \& } \sigma_2 = 0$$

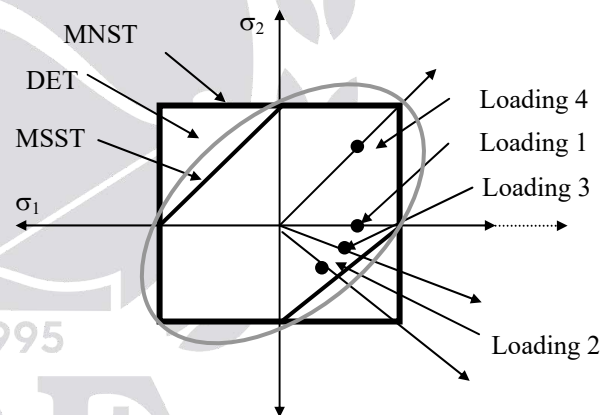
$$\text{Loading 2: } \sigma_1 = \frac{16T}{\pi d^3} \text{ \& } \sigma_2 = -\frac{16T}{\pi d^3}$$

$$\text{Loading 3: } \sigma_1 = \frac{16}{\pi d^3} (M + \sqrt{M^2 + T^2})$$

$$\sigma_2 = \frac{16}{\pi d^3} (M - \sqrt{M^2 + T^2})$$

$$\text{Loading 4: } \sigma_1 - \sigma_2 = 100 \text{ MPa}$$

**On plotting these loadings on safe diagram; as**



From diagram it is clear that, loading lines of loading 1 and 4 intersect at points which are common to all three mentioned theories. Hence for these loading all three theories will give same results.

Chapter

**3**

**FLUCTUATING LOADS**

**01. 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

$$\sigma_m = 0$$

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

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

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

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

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

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

**02. Ans: (b)**

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

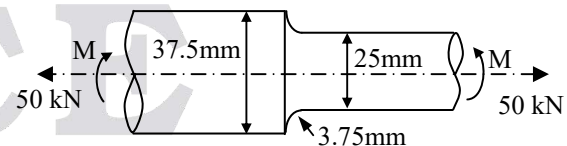
$$S_e' = 200 \text{ MN/m}^2, \quad K_t = 1.55, \quad q = 0.9$$

$$M = ?$$

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

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

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



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

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

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



According to Goodman's equation

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

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

$$133.779$$

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

**03. 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 to 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 04 & 05**

**04. Ans: (c) & 05. Ans: (a)**

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

$$S_f = 0.9 S_{ut} \text{ for } 10^3 \text{ cycles}$$

$$S_u = 600 \text{ MPa}$$

$$N = 200 \times 10^3 \text{ cycles}; \quad S_f = ?$$

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),

$$A = 1041.42$$

$$B = 0.095$$

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

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

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

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

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

**06. Ans: (d)**

**Sol:**  $S_{f1} = 500 \text{ MPa}$   $N_1 = 10 \text{ cycles}$

$$L_1 = 1 \times 10^5 \text{ cycles}$$

$S_{f2} = 600 \text{ MPa},$   $N_2 = 5 \text{ cycles}$

$$L_2 = 0.4 \times 10^5 \text{ cycles}$$

$S_{f3} = 700 \text{ MPa},$   $N_3 = 3 \text{ cycles}$

$$L_3 = 0.15 \times 10^5 \text{ cycles}$$

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

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

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

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

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

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

$$\frac{42352.94}{10} = \frac{L}{30 \text{ sec}} = \frac{L \times 3600}{30}$$

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

**07. 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 = ? (Soderberg)

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

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

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

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

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

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

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

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

$$\Rightarrow FS = 2.04$$

**08. Ans: (c)**

**Sol:**  $L_1 = 10 \text{ hours}$

$$N_1 = 9.8 \text{ hours}$$

$$N_2 = 8.2 \text{ hours}$$

$$L_2 = ?$$

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 09 & 10**

**09. Ans: (c) & 10. Ans: (d)**

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

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

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

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

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

$$= 224.411 \text{ MPa}$$

$\therefore$  For a completely reversed,

$$\sigma_m = 0 ; \quad \sigma_a = 130 \text{ MPa}$$

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

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

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

$$\sigma_{meq} = \sqrt{\sigma_m^2 + 3\tau_m^2} = \sqrt{3 \times 36.5^2} = 63.21 \text{ MPa}$$

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

$$= 134.76 \text{ MPa}$$

According to Goodman's equation,

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

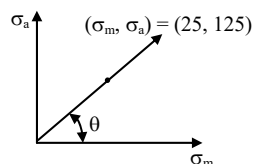
$$\frac{134.76}{224.4} + \frac{63.21}{1400} = \frac{1}{FS} \Rightarrow FS = 1.54$$

**11. Ans: (a, c)**

**Sol:** Given data;

$$\sigma_{\max} = +150 \text{ MPa}$$

$$\& \sigma_{\min} = -100 \text{ MPa}$$

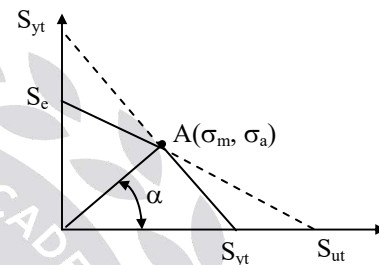


$$\sigma_a = \frac{150 - (-100)}{2} = 125 \text{ MPa}$$

$$\sigma_m = \frac{150 + 100}{2} = 25 \text{ MPa}$$

$$\tan \theta = \frac{\sigma_a}{\sigma_m} = \frac{125}{25} = 5$$

**Modified Goodman Diagram:**



$$\text{Yield Line} \Rightarrow \sigma_m + \sigma_a = S_{yt} = 0.5 S_{ut} \dots\dots(i)$$

$$\text{Goodman Line} \Rightarrow \frac{\sigma_m}{S_{ut}} + \frac{\sigma_a}{S_e} = 1$$

$$\therefore \sigma_m + 2.5\sigma_a = S_{ut} \dots\dots(ii)$$

$$\therefore S_e = 0.4S_{ut}$$

$$\text{From (i) \& (ii), } \sigma_a = 0.333 S_{ut}$$

$$\sigma_m = 0.16 S_{ut}$$

$$\therefore \tan \alpha = \frac{\sigma_a}{\sigma_m} = 2$$

- As  $\theta > \alpha$ , the loading line will cut Goodman Line.

$\therefore$  Goodman Line is the design line.

$$\bullet \quad \frac{\sigma_m}{S_{ut}} + \frac{\sigma_a}{S_e} = \frac{1}{FOS}$$

$$\therefore \frac{25}{600} + \frac{125}{240} = \frac{1}{FOS}$$

$$\therefore FOS = 1.78$$

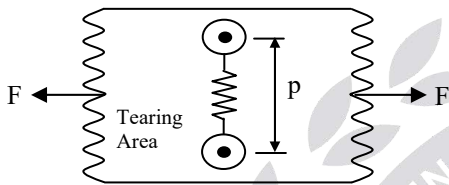
Chapter

**4**

**RIVETED JOINTS**

**01. Ans: (b)**

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



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

**Common Data Question (02, 03, 04)**

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

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

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

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

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

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

**02. Ans: (b)**

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

$$\eta_{\text{Tearing}} = 66.67\%$$

**03. 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,

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

$$\begin{aligned}P_s &= \frac{\pi}{4} (30)^2 \times 30 \\ &= 21206 \text{ N}\end{aligned}$$

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

**04. 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

$$P_s = 21206 \text{ N},$$

$$P = 45000 \text{ N}$$

Strength of riveted joint

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

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

**05. 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)

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

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

$$P_c = n \times d \times t \times \sigma_c = 3 \times d \times 7 \times 120$$

$$= 2520d \text{ N} \dots\dots(2)$$

From equations (1) & (2)

$$141.4 d^2 = 2520d$$

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

**06. 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,

$$d = 18 \text{ mm} \quad (\text{from Q. 5})$$

Tearing resistance is

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

$$= (p - 18)7 \times 80$$

$$= 560(p - 18) \text{ N} \dots\dots(1)$$

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

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

From equations (1) and (2)

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

$$p = 99.79$$

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

**07. Ans (a)**

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

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

$$\frac{S_{yc}}{FS} = 150 \text{ N/mm}^2, \quad t = 6 \text{ mm}$$

Shear strength = crushing strength

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

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

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

**08. Ans: (b)**

**Sol:** Given:

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

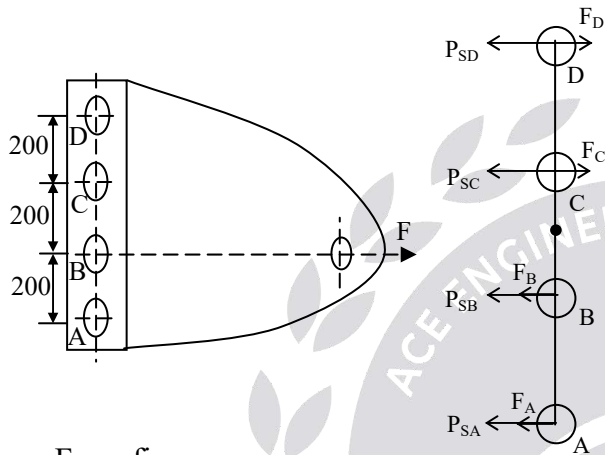
$$d = 20 \text{ mm}, \quad n = 4$$

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,

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

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

[ $\because$  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

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

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

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

**09. Ans: (b)**

**Sol:**  $t = 15 \text{ mm}, \quad d = 20 \text{ mm}$

$p = 60 \text{ mm}, \quad \tau = 90 \text{ MPa}$

$\sigma_t = 120 \text{ MPa}, \quad \sigma_c = 160 \text{ MPa}$

Tensile load ( $F_t$ )

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

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

$$= 72 \text{ kN}$$

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

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

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 10 & 11:**

**10. Ans: (a)**

**Sol:**  $d = 12 \text{ mm}$ ,  $P = 4 \text{ kN}$

No. of Rivets = 2

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

Secondary shear load,

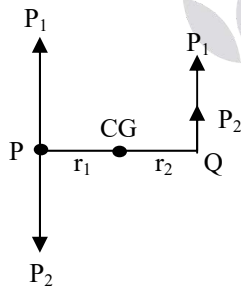
$$P_2 = \frac{P e r_1}{r_1^2 + r_2^2}$$

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

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

**11. Ans: (b)**

**Sol:**



Resultant load on Rivet P =  $P_2 - P_1$

= 18 kN

Resultant shear stress on Rivet P

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

**12. Ans: (b, c)**

**Sol:**

- Shearing strength,

$$P_s = 4 \times \frac{\pi}{4} \times 10^2 \times 60 = 18.85 \text{ kN}$$

- Crushing strength,

$$P_c = 4 \times 10 \times 5 \times 120 = 24 \text{ kN}$$

- Tearing Strength at AA

$$= (50 - 10) \times 5 \times 80 = 16$$

- Tearing Strength at BB

$$= (150 - 2 \times 10) \times 5 \times 80 + \frac{\pi}{4} \times 10^2 \times 60$$

$$= 16.712 \text{ kN}$$

## Chapter

**5**
**THREADED FASTENERS**
**01. Ans: (b)**
**Sol:** Given  $d = 24 \text{ mm}$ 

$$F_i = 2840 \text{ d} = 2840 \times 24$$

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

$$\text{Here, } d_c = 0.84d \Rightarrow d_c = 0.84 \times 24$$

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

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

**02. Ans: (c)**
**Sol:** Given

$$d = 36 \text{ mm}$$

$$d_c = 0.84 d = 0.84 \times 36$$

$$F.S = 1.5$$

$$S_{yt} = 280 \text{ MPa}$$

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

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

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

$$= 134066 \text{ N}$$

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

**03. Ans: (d)**
**Sol:** Given pitch = 4 mm

$$\text{Torque (T)} = 1.4 \text{ kN-mm}$$

$$\text{Work done} = \text{force} \times \text{distance}$$

$$\text{Force} \times \text{distance} = \text{Torque} \times \text{Angle of rotation}$$

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

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

**04. Ans: (d)**
**Sol:** Given

$$F_i = 5.3 \text{ kN},$$

$$C = 0.25,$$

$$P = 9.6 \text{ kN}$$

$$F_b = CP + F_i$$

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

$$F_b = 7.7 \text{ kN}$$

**05. Ans: (b)**
**Sol:** Given

$$D = 250 \text{ mm}$$

$$\text{Pressure} = 12 \text{ bar} = 1.2 \text{ MPa}$$

$$F.S = 5$$

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

$$n = 8$$

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

$$= \frac{\frac{\pi}{4} (250)^2 \times 1.2}{8} = 7363.1 \text{ N}$$



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

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

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

**06. 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

$$\text{Load (P)} = Pr \times A$$

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

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 07 & 08**

**07. Ans: (d)**

**Sol:**  $S_{yt} = 650 \text{ MPa}$  ,  $t = 20 \text{ mm}$

$$A = 115 \text{ mm}^2$$
 ,  $d = 14 \text{ mm}$

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

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

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

$$F_i = 0.8 S_{yt} \times A$$

$$= 0.8 \times 650 \times 115 = 59800 \text{ N}$$

For bolt,

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

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

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

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

**08. 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

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

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

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

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

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

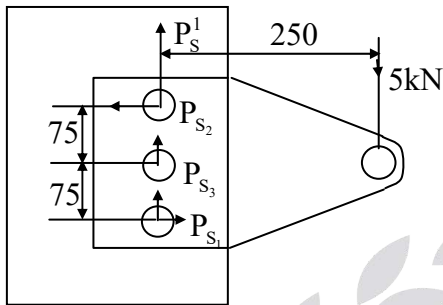
$$CP = 14950$$

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

**09. 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,  $P_{s1}$

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

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

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

$$8.498 \times 10^3 = \frac{\pi}{4} (d^2) \times \frac{400}{2 \times 3}$$

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

**10. Ans: (a)**

**Sol:**  $n = 4$ ,  $L = 550 \text{ mm}$   
 $P = 10 \text{ kN}$ ,  $L_2 = 325 \text{ mm}$   
 $S_{yt} = 400 \text{ N/mm}^2$ ,  $L_1 = 75 \text{ mm}$   
 $F.S = 6$   
 $d_c = 0.8d$

Using Rankine theory

$P_A' = CL_2$  (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**

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

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

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

$$d_c = 14.16$$

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

**11. Ans: (c)**

**Sol:** Given

$n = 4$ ,  $P = 5 \text{ kN}$ ,  $L = 250 \text{ mm}$

$L_1 = 75 \text{ mm}$ ,  $L_2 = 375 \text{ mm}$

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

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

$P_{tA} = CL_2$  (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

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

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

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

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

$$\begin{aligned} \sigma_1 &= \frac{1.6 \times 10^3}{2A} + \frac{1}{A} \sqrt{\left(\frac{1.6 \times 10^3}{2}\right)^2 + (1.25 \times 10^3)^2} \\ &= \frac{2284.1}{A} \text{ N/mm}^2 \end{aligned}$$

According to Rankine Theory

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

$$\Rightarrow \frac{2284.1}{A} = \frac{380}{5}$$

$$\Rightarrow A = 30.05 \text{ mm}^2 = \frac{\pi}{4} \times d_c^2$$

$$\Rightarrow d_c = 6.186 \text{ mm}$$

$$\Rightarrow d = \frac{6.196}{0.8} = 7.732 \text{ mm}$$

### 12. Ans: (a, c)

**Sol:** In threaded joints following statements are true:

- Pre loading decreases the stress fluctuations in bolt.
- Pre loading increases the stress in bolt.
- Soft gasket is more useful the stress in bolt than the hard gasket.
- It increases fatigue life.
- It decrease stress amplitude.

**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,  $P = 400 \text{ kN}$ ,

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

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

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

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

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

**03. Ans: (a)**

**Sol:** Given:

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

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

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

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

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

$l = 400 \text{ mm}$  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:  $d = 60 \text{ mm}$ ,  $s = 10 \text{ mm}$ ,

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

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

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

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

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

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

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

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

**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

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

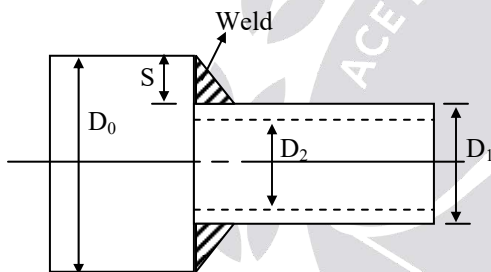
$$\frac{pd}{4t} = 85$$

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

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

**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

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

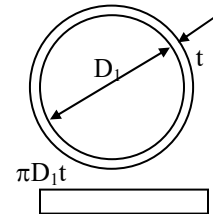
$$F = \pi D_1 t \times \frac{S_{sy}}{FS} \dots\dots\dots (2)$$

Equate (1) & (2)

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

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

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



**Linked questions (Q.08 & Q.09)**

**08. Ans: (a)**

**09. 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

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

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

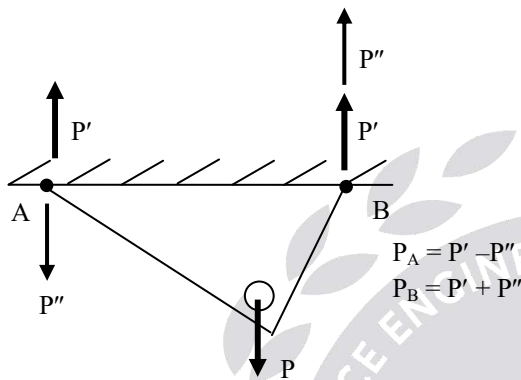
$$= 54986.9 \text{ N}$$

$$P = 54.9 \text{ kN} \approx 55 \text{ kN}$$

**10. Ans: (a, d)**

**Sol:** In first case; primary and secondary stresses, both are shear.

In second case; primary stress is shear but secondary stress is bending stress.



From the figure it is clear that, point B is critical.

**Chapter**

**7**

**SLIDING CONTACT BEARINGS**

**01. Ans: (b)**

**Sol:** Given:

Load,  $W = 3 \text{ kN}$

$d = 40 \text{ mm}$

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

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

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

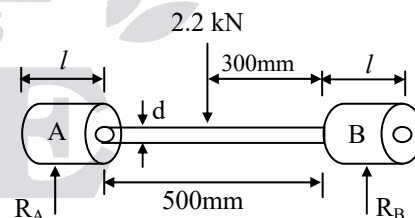
$$= \frac{3000}{1.3 \times 40}$$

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

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

**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,

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

**03. Ans: (a)**

**Sol:** Given:

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

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

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

$$p_2 = ?$$

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

Since, same oil is used  $\mu$  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,  $\epsilon = 0.8$

$$\epsilon = 1 - \frac{h_0}{c}$$

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

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

**05. Ans: (a)**

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

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

$$\text{Load (W)} = 9 \text{ kN} = 9000 \text{ N}$$

$$c = 0.075 \text{ mm},$$

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

$$\text{Load (W)} = 9000 \text{ N}$$

$$\text{Heat generated} = f \cdot V \cdot W$$

$$1500 = f (7.85) (9000)$$

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

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

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

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

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:

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

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

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

$$\text{Heat lost in friction} = f \times W \times V$$

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

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

$$= 14.72 \text{ Nm/sec}$$

$$14.72 = CA (T_s - T_r)$$

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

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

**Linked Answer Question 07 & 08**

**07. Ans: (a)**

**08. Ans: (c)**

**Sol:** Given:

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

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

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

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

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

$$C_d = 0.1$$

$$\epsilon = 0.4$$

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

$$\text{Here pressure } (p) = \frac{W}{A} = \frac{W}{l \times d}$$

$$= \frac{4500}{0.15 \times 0.1} = 30 \times 10^4 \text{ N/m}^2$$

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

Sommerfeld No. "S"

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

$$= 0.617$$

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

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

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

**09. Ans: (a)**

**Sol:** Given

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

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

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

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

$$K = 0.002$$

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

$$= \left[ 0.326 \left( \frac{20 \times 10^{-3} \times 1800}{1.6 \times 10^6} \right) \left( \frac{300}{0.25} \right) + 0.002 \right]$$

$$= 0.01$$



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

**10. Ans: (a)**

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

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

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

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

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

$$\text{Axial load} = p \times A$$

$$= 0.6 \times 4304.77 \text{ N}$$

$$= 2582.862 \text{ N}$$

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

**11. Ans: (a)**

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

$$N = 600 \text{ rpm},$$

$$P = 120 \text{ kPa}$$

$$\mu = 0.05$$

For foot step bearing

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

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

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

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

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

**12. Ans: (b, c)**

**Sol:** For a hydrodynamic bearing following statements are true:

- In counter-clockwise rotation of shaft at low speeds, the centre of shaft will shift to left side of bearing.
- In counter-clockwise rotation of shaft at high speeds, the centre of shaft will shift to right side of bearing.

**Chapter**
**8**
**ROLLING CONTACT BEARINGS**

**01. 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

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

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

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

**02. Ans: (b)**

**Sol:** Given:  $C = 48.545 \text{ kN}$

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

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

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

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 (03 & 04)**

**03. Ans: (a)**

**04. 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

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

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

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

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

$$L = 624 \text{ million revolutions}$$

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

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

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

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

**Linked Answer Question (05 & 06)**

**05. Ans: (c)**

**06. Ans: (a)**

**Sol:** Given  $C = 16.6 \text{ kN}$

% of element time =  $\alpha$

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

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

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

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

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

$K = 3$  for Ball bearing

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

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

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

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

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

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

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

**Linked Answer Question (07 to 10)**

**07. Ans: (b)**

**08. Ans: (a)**

**09. Ans: (b)**

**10. Ans: (a)**

**Sol:** Given:

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

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

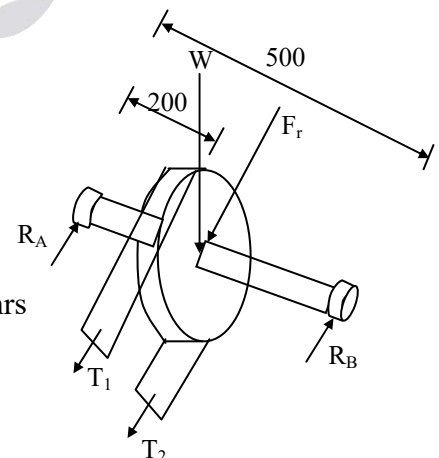
$$F_a = 2 \text{ kN}$$

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

$$X = 0.56$$

$$Y = 1.5$$

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



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

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

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

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

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

**11. Ans: (b, d)**

$$\text{Sol: } \frac{L_{95}}{L_{90}} = \left\{ \frac{\log_e(1/0.95)}{\log_e(1/0.9)} \right\}^{1/1.17}$$

$$L_{90} = L_{95} \times 0.54$$

$$L_{90} = 0.54 \times \frac{5000 \times 60 \times 720}{10^6} = \left( \frac{C}{2000} \right)^{10/3}$$

$$\therefore C = 8340.8 \text{ N}$$

Reliability of system,

$$R_s = R^N = (0.95)^3 = 85.73\%$$

### 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:**  $P = 10 \text{ kW}$

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

$$n = 2$$

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

$$d_1 = 1.25d_2$$

$$r_1 = 1.25r_2$$

$$\mu = 0.3$$

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

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

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

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

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

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

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

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

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

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

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

**04. Ans: (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 (05 & 06)**

**05. Ans: (b)**

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

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

$$\mu = 0.2,$$

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

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

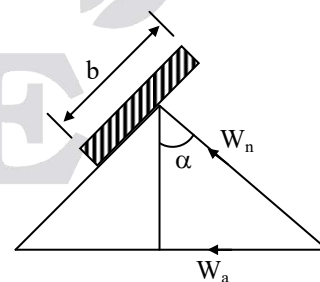
$$T = \frac{60P}{2\pi N} = \mu W_n r_m = \mu W_n \left( \frac{r_1 + r_2}{2} \right)$$

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

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

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

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



Force required for engagement

$$W_{ac} = W_a + \mu W_n \cos \alpha$$

$$= 1323.60 + [0.2 \times 6366.19 \times \cos 12^\circ]$$

$$W_{ac} = 2.56 \text{ kN}$$

**06. 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. 07 & 08**

**07. Ans: (c)**

**08. Ans: (a)**

**Sol:** Given :

$$d_1 = 120 \text{ mm}, \quad d_2 = 200 \text{ mm}$$

$$I = 20 \text{ kg-m}^2, \quad t = 5 \text{ sec}, \quad \mu = 0.3$$

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

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

$$\omega_2 = 0$$

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

$$\text{Torque } T = I \alpha = 20 \times 4.18 = 83.6 \text{ N-m}$$

$$\mu = 0.3$$

For uniform pressure,

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

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

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

**09. Ans: (d)**

**Sol:** Given,

$$n = 4, \quad P = 21 \text{ kW}$$

$$N = 750 \text{ rpm}, \quad \omega_1 = 0.75 \omega_2$$

$$R = 300 \text{ mm}, \quad r = 125 \text{ mm}, \quad \mu = 0.25$$

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

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

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

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

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

**10. Ans: 157 mm & 135.22 mm**

**Sol:** Centrifugal force between each shoe and drum

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

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

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

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

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

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

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

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

**11. Ans: (a, c)**

**Sol:**

- A new clutch designed based upon uniform wear theory will not slip in working.
- An old clutch designed based upon uniform pressure theory will slip in working.

Chapter

**10**

**BRAKES**

**Linked Answer Questions (01 & 02)**

**01. Ans: (b)**

**Sol:** Given,  $\mu = 0.24$ ,  $N = 100$  rpm,  $r = 150$  mm

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

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

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

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

$$T = F_t r$$

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

**02. Ans: (a)**

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

$$\omega_2 = 0$$

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:**  $\mu = 0.3$

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

$$\theta = 45^\circ$$

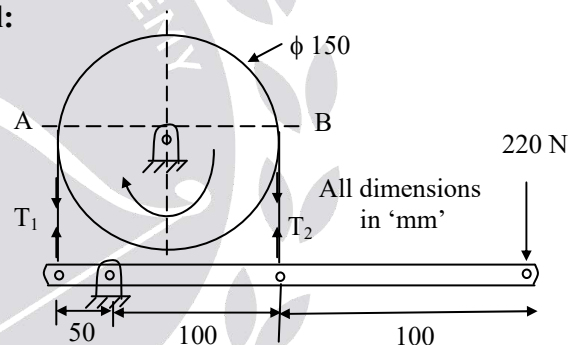
Equivalent coefficient of friction

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

**Common Data Question 04 & 05**

**04. Ans: (c)**

**Sol:**



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

$$\mu = ?$$

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

$$a = 50 \text{ mm}$$

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

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

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

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

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

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

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

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

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

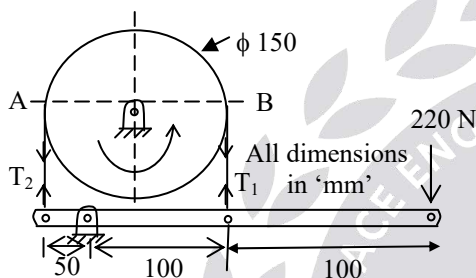
$$\frac{T_1}{T_2} = e^{\mu \times \theta}$$

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

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

**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

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

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

$$\begin{aligned} I &= 7200 \times \frac{\pi}{4} (0.25)^2 (0.02) \left( \frac{0.250}{2\sqrt{2}} \right)^2 \\ &= 0.055 \text{ kgm}^2 \end{aligned}$$

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

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



**07. Ans: (d)**

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

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

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

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

**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  $C_v = 1$

$$F_t = S w m y C_v$$

$$7.56 \times 10^3 = 35 \times 90 \times 8 \times y$$

$$\Rightarrow y = 0.3$$

**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: (b)**

**08. Ans: (a)**

**Sol:**  $P = 11 \text{ kW}$ ,  $N_P = 1440 \text{ rpm}$

$$\phi = 14 \frac{1}{2}^\circ, \quad m = 6 \text{ mm}$$

$$T_P = 25, \quad y = 0.1, \quad C_v = 0.21$$

$$\frac{T_G}{T_P} = \frac{N_P}{N_G} = 3 : 1$$

$$T_{\max} = 1.5 T_{\text{mean}}$$

$$S = 210 \text{ MPa}$$

$$F_t = ?, \quad w = ?$$

$$F_t = \frac{P}{V} C_s \quad \left( \because V = \frac{\pi d N}{60} \right) (d = m T)$$

$$F_t = \frac{11 \times 10^3}{\pi (6 \times 25) \times 1440} \times 1.5$$

$$F_t = 1.46 \text{ kN}$$

$$F_t = S w m y C_v$$

$$1.46 \times 10^3 = 210 \times w \times 6 \times 0.1 \pi \times 0.21$$

$$\Rightarrow w = 18 \text{ mm}$$

### Linked Answer Questions 09 to 11

**09. Ans: (b)**

**Sol:**  $P = 500 \text{ kW}$ ,  $N_P = 1800 \text{ rpm}$ ,

$$C = 660 \text{ mm}, \quad \phi = 22 \frac{1}{2}^\circ, \quad m = 8 \text{ mm}$$

$$\frac{T_G}{T_P} = 10:1; \quad F_n = 200 \text{ N/mm}$$

$$C = \frac{m(T_G + T_P)}{2}$$

$$660 = \frac{8(T_P + 10T_P)}{2}$$

$$T_P = 15 \text{ and } T_G = 150$$

$$d_p = m T_P = 8(15) = 120 \text{ mm}$$

$$F_r \text{ on bearing} = ?, \quad F_t = ?, \quad w = ?$$

$$F_t = \frac{P}{V} = \frac{500(\text{kW})}{\frac{\pi d_p N_P}{60}}$$

$$= \frac{500 \times 10^3}{\pi \left( \frac{120}{1000} \text{ m} \right) \times \left( \frac{1800}{60} \right) \frac{1}{\text{sec}}}$$

$$F_t = 44.2 \text{ kN}$$

**10. Ans: (c)**

**Sol:**  $F_r = F_t \tan \phi = 44.2 \tan (22.5) = 18.3 \text{ kN}$

$$F_n = \frac{F_t}{\cos \phi} = \frac{44.2}{\cos 22.5} = 47.85 \text{ kN}$$

**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:**  $S_{\text{steel}} = 120 \text{ MPa} \rightarrow$  for pinion

$S_{\text{CI}} = 100 \text{ MPa} \rightarrow$  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:  $G.R = \frac{T_G}{T_P} = 2$

$w = 10 \text{ cm} = 100 \text{ mm}$

$d_p = 40 \text{ cm} = 400 \text{ mm}$

Stress factor for fatigue  $= 1.5 \text{ N/mm}^2 = K$

$$Q = \frac{2T_G}{T_G + T_P} = \frac{2(2T_P)}{2T_P + T_P} = \frac{4}{3}$$

$F_w = K d_p w Q$

$$F_w = (1.5)(400)(100) \frac{4}{3} = 80 \times 10^3 = 80 \text{ kN}$$

**14. Ans: (b, c)**

**Sol:**

- In a single stage gear reduction system, the gear teeth are subjected to repeated loading.
- The teeth of idler gear are subjected to reversed loading.

**Chapter**
**12**
**SPRINGS**
**01. Ans: (d)**

**Sol:** Let,  $n =$  no. of active coils of spring

$$k = \frac{Gd^4}{8D^3n}$$

For a given spring  $G, d, D$  are constant

$$k \propto \frac{1}{n}$$

$$\frac{k_2}{k_1} = \frac{n_1}{n_2}$$

$$k_2 = \frac{n}{n/3} \times k_1$$

$$\Rightarrow k_2 = 3 k_1$$

**02. Ans: 668.4 MPa**

**Sol:** Given,  $C = 10$

$k_s =$  direct shear stress factor

$$= 1 + \frac{1}{2C}$$

$$= 1 + \frac{1}{20} = \frac{21}{20}$$

$$\tau_{\text{max}} = k_s \frac{8F \times D}{\pi d^3} = \frac{21}{20} \times \frac{8 \times 3600}{4 \times (36\pi)} \times 10$$

$$\tau_{\text{max}} = 668.45 \text{ MPa}$$

**03. Ans: (b)**

**Sol:** Wire of spring experiences direct shear load and twisting moment due to axial load which passes through the axis of spring.

**04. Ans: 10**

**Sol:** Given,

$$\frac{\tau_{\max}}{\delta} = \frac{10}{\pi}$$

$$\frac{8FD/\pi d^3}{8FD^3n/Gd^4} = \frac{10}{\pi}$$

$$\frac{G \times d}{\pi D^2 n} = \frac{10}{\pi}$$

$$\frac{80 \times 10^3 \times 8}{800\pi \times D} = \frac{10}{\pi}$$

$$D = 80 \text{ mm}$$

$$\Rightarrow \ell = \pi D n = 800\pi$$

$$\Rightarrow n = 10$$

**05. Ans: (b)**

**Sol:**  $\delta = \frac{F}{k_{eq}} = \frac{F}{3k + 5k} = \frac{F}{8k}$

**06. Ans: 300**

**Sol:**  $\delta = \frac{3}{8} \frac{WL^3}{nbt^3E}$

$$15 = \frac{3}{8} \times \frac{3600 \times 1800^3}{6 \times b \times 12^3 \times 200 \times 10^3}$$

$$\Rightarrow b = 253.125 \text{ mm}$$

$$\sigma = \frac{3WL}{2nbt^2}$$

$$37.5 = \frac{3 \times 3600 \times 1800}{2 \times 6 \times b \times 12^2}$$

$$\Rightarrow b = 300$$

$$\text{Safe width} = 300 \text{ mm}$$

Chapter

**13**

**SHAFTS**

**01. Ans: (c)**

**Sol:** Axle is designed against bending. Design of brittle material against bending is based on Rankine's theory.

**02. Ans: (a)**

**Sol:** We know that,  $\frac{T}{J} = \frac{\tau}{r}$

here,  $J = \frac{\pi d^4}{32}$  for solid circular shaft

and  $r = d/2$

$$\Rightarrow \tau_{\max} = \frac{16T}{\pi d^3}$$

**03. Ans: (a)**

**Sol:** *Equivalent Torque:* It is the twisting moment, which is acting along to produce the maximum shear stress due to combined bending and Torsion.

$$T_e = \sqrt{M^2 + T^2}$$

**04. Ans: (a)**

**Sol:** We know that,  $\frac{T}{J} = \frac{\tau}{r}$

here,  $J = \frac{\pi(D^4 - d^4)}{32}$  for hollow circular

shaft and  $r = D/2$

$$\Rightarrow \tau = \frac{16T}{\pi D^3(1 - k^4)} \quad (\text{where } k = d/D)$$

**05. Ans: (a)**

**Sol:** For a solid shaft,  $\tau_{\max} = \tau = \frac{16T}{\pi D^3}$

For a hollow shaft,

$$\tau_{\max} = \frac{16T}{\pi D^3 (1 - k^4)} = \frac{\tau}{(1 - k^4)}$$

here,  $k = d_i/d_o = 0.5$

$$\Rightarrow \tau_{\max} = 1.067 \tau$$

**06. Ans: (d)**

**Sol:** *Equivalent Bending Moment:* The bending moment is to produce the maximum bending stress equal to greater principle stress ' $\sigma_1$ '.

$$\begin{aligned} M_e &= \frac{1}{2} \left( M + \sqrt{T^2 + M^2} \right) \\ &= \frac{1}{2} \left( 40 + \sqrt{30^2 + 40^2} \right) \\ &= 45 \text{ kN-m} \end{aligned}$$

**07. Ans: (d)**

**Sol:** Equivalent twisting moment,

$$\begin{aligned} T_e &= \sqrt{(k_b M_b)^2 + (k_t M_t)^2} \\ &= \sqrt{(1.5 \times 0.5)^2 + (2 \times 1)^2} = 2.136 \text{ N-m} \end{aligned}$$

**08. Ans: (c)**

**Sol:** According to ASME code for shaft design under static load, the design stress must be least of  $0.3 S_{yt}$  and  $0.18 S_{ut}$ .

**09. Ans: (d)**

**Sol:** In general, axles are not rotating member but it supports the transverse loads like bearing reactions which causes bending moment and does not transmit any useful torque. Thus, axles are designed for bending moment.

Shafts are subjected to torque as well as bending. Thus, they are designed for bending as well as torsion.

**10. Ans: (c)**

**Sol:** A transmission shaft subjected to bending should be designed to resist torsional as well as bending moment both. Thus, equivalent torsional moment and equivalent bending moment is used for designing the shaft which are based on Guest's and Rankine's theory, respectively.

**11. Ans: (c)**

**Sol:** Given data:

$$d_A = 2d_B$$

$$\text{Power, 'P'} = \frac{2\pi NT}{60}$$

$$\text{Torque, 'T'} = \frac{\pi}{16} d^3 \tau$$

$$\therefore P \propto d^3$$

$$\therefore \frac{P_A}{P_B} = \left( \frac{d_A}{d_B} \right)^3$$

$$\therefore \frac{P_A}{P_B} = \frac{d_A^3}{8d_B^3} \quad (\because d_B = 2d_A)$$

$$\therefore \frac{P_A}{P_B} = \frac{1}{8}$$

**12. Ans: (a)**

**Sol:** When a transmission shaft transmits load through spur gear, along with the torsion, shaft is also subjected to radial and tangential load which are transmitted through spur gear.

**13. Ans: (c)**

**Sol:** The resultant force acting on a tooth of helical gear is resolved into three components.

- Tangential component
- Radial component
- Axial (or) thrust component

**14. Ans: (a)**
**15. Ans: (d)**

**Sol:** Shaft is generally made of ductile materials. For ductile materials maximum shear stress (Tresca) and distortion energy (von-Mises) theories can be used.

Out of these two theories von-Mises theory is best suitable for ductile materials. Rankine's theory or principal stress theory is suitable for brittle materials only.

**16. Ans: (b)**

**Sol:** The term 'transmission shaft' usually refers to a rotating machine element. Thus, shaft in power transmission is inherently subjected to torsional moment.

**17. Ans: (b)**

**Sol:**

- Bending stress  $\sigma_b = \frac{M}{I} \cdot y$  and

$$\text{Torsional shear stress } \tau_{xy} = \frac{T}{J} \cdot r$$

where,  $y$  = distance from neutral axis and

$r$  = radial distance from centre of shaft.

- As the shaft rotates, the radial distance of any point from centre of the shaft does not change, so the torsional stress would remain constant.
- As the shaft rotates, the distance of any point from the neutral axis does change with the rotation of the shaft; so the bending stress will also change.
- Hence the shaft experiences varying bending stress and constant torsional stress.

**18. Ans: (a, b, d)**

**Sol:** Shaft Load: Bending moment & Twisting moment

$$\therefore \sigma_{\max} = \frac{32M}{\pi d^3}, \sigma_{xy} = \frac{16T}{\pi d^3}, \sigma_y = 0$$

$$\therefore \sigma_{\max} = \frac{16}{\pi d^3} \left( M + \sqrt{M^2 + T^2} \right) \dots\dots\dots (i)$$



$$\sigma_{\max} = \frac{16}{\pi d^3} \sqrt{(M^2 + T^2)} \quad \dots\dots\dots (ii)$$

$$\begin{aligned} \sigma_{vm} &= \sqrt{\sigma_x^2 + 3 \times \sigma_{xy}^2} \\ &= \sqrt{\left\{ \frac{32M}{\pi d^3} \right\}^2 + 3 \times \left\{ \frac{16T}{\pi d^3} \right\}^2} \quad \dots\dots\dots (iii) \end{aligned}$$

**Equivalent bending moment ( $M_e$ ) :**

$$\therefore \sigma_x = \frac{32M_e}{\pi d^3}, \sigma_y = 0 = \tau_{xy}$$

$$\therefore \sigma_{\max} = -\frac{\sigma_x}{x} = \frac{16M_e}{\pi d^3} \quad \dots\dots\dots (iv)$$

$$\& \sigma_{vm} = \sigma_x = \frac{32M_e}{\pi d^3} \quad \dots\dots\dots (v)$$

As per shear stress theory, comparing ii & iv

$$\tau_{\max} = \frac{16}{\pi d^3} \cdot \sqrt{M^2 + T^2} = \frac{16M_e}{\pi d^3}$$

$$\therefore M_e = \sqrt{M^2 + T^2}$$

As per direction energy theory: from iii & v

$$\sigma_{vm} = \left\{ \left( \frac{32M}{\pi d^3} \right)^2 + 3 \times \left( \frac{16T}{\pi d^3} \right)^2 \right\}^{1/2} = \frac{32M}{\pi d^3}$$

$$\therefore M_e = \sqrt{M^2 + \frac{3}{4} \times T^2}$$

**Equivalent torsional moment ( $T_e$ ) :**

$$\therefore \sigma_x = 0 = \sigma_y \quad \& \quad \sigma_{xy} = \frac{16T_e}{\pi d^3}$$

$$\therefore \sigma_{\max} = \sigma_{xy} = \frac{16T_e}{\pi d^3} \quad \dots\dots\dots (vi)$$

As per Normal stress theory, from (vi) & (i)

$$\sigma_{\max} = \frac{16}{\pi d^3} \times (M + \sqrt{M^2 + T^2}) = \frac{16T_e}{\pi d^3}$$

$$\therefore T_e = M + \sqrt{M^2 + T^2}$$