ACE Engineering Publications

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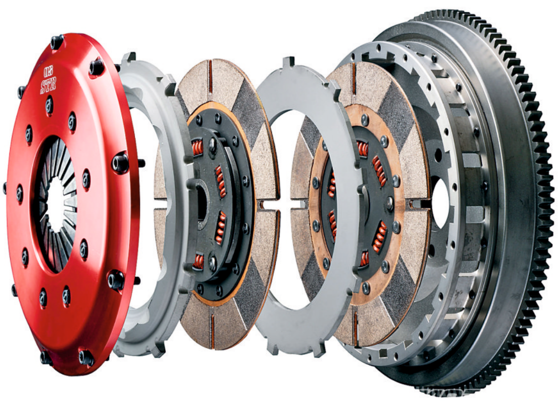


Mechanical Engineering

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 mm, d = 25 mm,

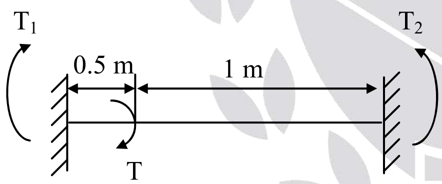
E = 100 GPa

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

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

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: $G = 0.8 \times 10^5$ MPa

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

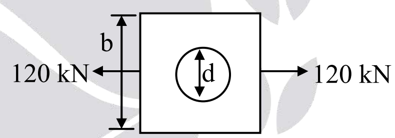
$$\theta_1 = \frac{4905.33 \times 10^3 \times 0.5 \times 10^3}{\frac{\pi}{32} \times 80^4 \times 0.8 \times 10^5}$$

$= 7.62 \times 10^{-3}$ radian

$= 7.62 \times 10^{-3} \times \frac{180}{\pi} = 0.436$ degrees

04. Ans: (b)

Sol:



P = 120 kN, t = 13 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 mm

05. Ans: (b)

Sol: Force applied on the bar $= 95 \times 100 \times t$ 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, $\sigma_x = \sigma_{axial} + \sigma_{bending}$

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

Hence point B is not critical here.

In case 4, Pure shear,

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

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

Chapter 2 Theories of Failure

01. Ans: (c)

Sol: $\sigma = 60$ MPa, $\tau = 40$MPa,

$S_{yt} = 330$ 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 $\sigma = \begin{bmatrix} 40 & 0 \\ 0 & -30 \end{bmatrix}$

$\sigma_1 = 40$, $\sigma_2 = -30$, $\sigma_{yt} = 350$ 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: (b)

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

$F_S = 18$ kN , $A = 600\ mm^2$, FS = ?

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

$$\sigma = \frac{48\times10^3}{600} = 80\ \text{MPa}$$

$$\tau = \frac{18\times10^3}{600} = 30\,\text{MPa}$$

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

$$= 50\ \text{MPa}$$

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

$d_i = 4.6$ m, $p = 0.210$ MPa

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

$F_s = ?$

$$\sigma_h = \frac{pd}{2t} = \frac{0.21\times4.6\times10^3}{2\times16}$$

$$\sigma_l = \frac{pd}{4t} = \frac{0.21\times4.6\times10^3}{4\times16} = 15.09\,MPa$$

$\sigma_h = \sigma_1 = 30.18$ MPa

$\sigma_t = \sigma_2 = 15.08$ MPa

$\sigma_3 = 0$

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

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

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

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

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

$$FS = \frac{260}{2\times15.09} = 8.615$$

05. Ans: (c)

Sol: $\sigma_t = 200$ MPa $= \sigma_1$

$\sigma_c = -100$ MPa $= \sigma_2$

$S_{yt} = 500$ 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

06. Ans: (b)

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

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

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

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

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

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

07. Ans: (a)

Sol: $F_T = 20$ kN, $F_s = 15$ kN

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

$$\sigma = \frac{F_T}{A} = \frac{20\times10^3}{A} N/mm^2$$

$$\tau = \frac{F_S}{A} = \frac{15\times10^3}{A} N/mm^2$$

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

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

According to distortion energy theory

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

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

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

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

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

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

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

$$= \sqrt{\left(\frac{20\times10^3}{A}\right)^2 + 3\times\left(\frac{15\times10^3}{A}\right)^2} = \frac{360}{3}$$

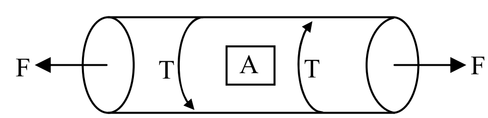
$$= \frac{10^3}{A}\sqrt{20^2 + 3\times15^2} = \frac{360}{3}$$

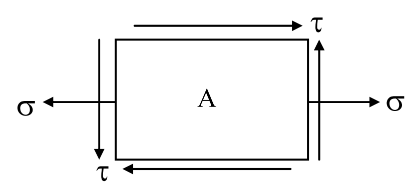
$\therefore$ A = 273.22 mm^2 = $(\pi/4)$ d^2

$\Rightarrow$ d = 18.65 mm

08. Ans: (b)

Sol:





FS = 2, $S_{yt} = 310$ MPa,

F = 40 kN ,

d = 20 mm, T = ?

According to Distortion Energy Theory

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

$$\sigma = \frac{F}{\frac{\pi}{4}\times d^2} = \frac{40\times10^3}{\frac{\pi}{4}\times20^2} = 127.32 \text{ MPa}$$

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

$\Rightarrow \tau = 51.03$ MPa

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

$$\Rightarrow 51.03 = \frac{16T}{\pi\times20^3}$$

$\Rightarrow T = 80157.73$ Nmm $= 80.157$ Nm

09. Ans: (b)

Sol: $P = 5$ kN , $d = 10$ cm $= 0.1$ m

Torque, $T = 5\times10^3\times0.5 = 2500$ Nm

$S_{yt} = 425$ MPa

Bending moment

$M = 5\times10^3\times2.5 = 12500$ Nm

Maximum shear stress

$$\tau = \frac{16T}{\pi d^3} = \frac{16\times2.5\times10^3}{\pi\times(0.1)^3}$$

$= 12732395$ N/m^2 $= 12.73$ MPa

Maximum bending stress

$$\sigma_b = \frac{32M}{\pi d^3} = \frac{32\times12500}{\pi\times(0.1)^3}$$

$= 127323954$ N/m^2

$= 127.32$ MPa

Major principal stress

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

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

$= 128.58$ MPa

Minor principal stress

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

$= -1.26$ 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: $S_{yt} = 200$ 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,

$M = 5\times1500 + 5\times500$

$= 10000\times10^3$ N-mm

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

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

$\Rightarrow b = 57.42$ mm

11. Ans: (b)

Sol: $\sigma_x = 100$ MPa , $\sigma_y = 40$ MPa, $\tau = 40$ 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 kN-m , M = 10 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 kN-m and T = 6 kN-m

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

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

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

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

$$\Rightarrow \quad FS = 2.7$$

13. Ans: (a, d)

Sol: Given data:

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

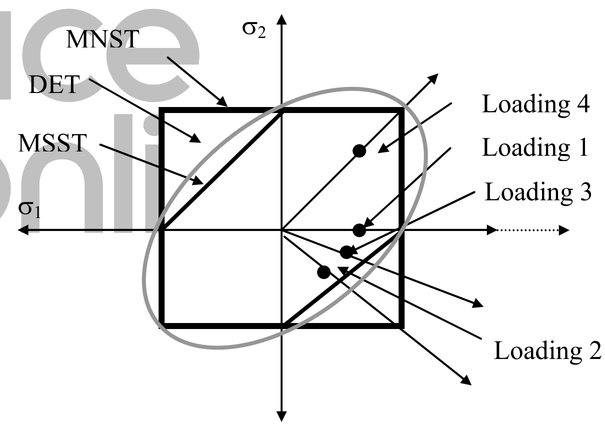
Loading 2: $\sigma_1 = \frac{16T}{\pi d^3}$ & $\sigma_2 = -\frac{16T}{\pi d^3}$

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

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

Loading 4: $\sigma_1 - \sigma_2 = 100$ 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:

$S_u = 440$ MPa, $q = 0.8$

$K_a = 0.67$ $K_b = 0.85$

$K_c = 0.9$ $K_d = 0.897$

$K_t = 2.37$ 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

$S_e = K_a K_b K_c K_d S_e'$

$S_e' = 0.5 S_{ut}$

$= 0.5\times440 = 220$MPa

$S_e = 0.67\times0.85\times0.9\times0.897\times K_e\times S_e'$

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

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

$\therefore S_e = 48.63$MPa

For completely reverse load

$\sigma_m = 0$

$$\sigma_a = \frac{16\times10^3}{(50-10)t}$$

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

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

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

$\therefore$ t = 12.3 mm

t = 12 mm

02. Ans: (b)

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

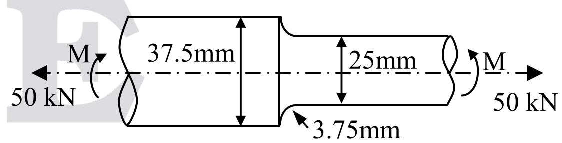
$S_e' = 200$ MN/m^2, $K_t = 1.55$, $q = 0.9$

M = ?

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

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

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



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

$$= \frac{F}{\frac{\pi}{4}d^2} = \frac{50\times10^3}{\frac{\pi}{4}(25)^2} \Rightarrow 101.85 \text{ MPa}$$

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

According to Goodman's equation

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

$$\frac{\frac{32M}{\pi(25)^3}}{133.779}+\frac{101.85}{300}=1$$

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

03. Ans: (b)

Sol: Given:

$\sigma_1 = -50$ MPa to $+150$ MPa

$\sigma_2 = 25$ MPa to 175 MPa

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

$K_t = 1.85$

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

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

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

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

Similarly

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

$\sigma_{2min} = 25$ 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,

$S_e = K_a K_b \ldots S_e'$

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

According DET

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

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

$$= 86.6\text{MPa}$$

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

$$= 90.14 \text{ MPa}$$

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: $S_e = 280$ MPa

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

$S_u = 600$ MPa

$N = 200\times10^3$ cycles ; $S_f = ?$

Basquin's equation,

$A = S_f L^B$

$A = 280(10^6)^B$ ……… (1)

$A = (0.9\times600)\times10^{3B}$

$A = 540 \times 10^{3B}$ ……… (2)

By solving (1) and (2),

$A = 1041.42$

$B = 0.095$

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

$1041.42 = S_f (200\times10^3)^{0.095}$

$S_f = 326$ MPa

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

$\Rightarrow L = 1.4 \times 10^4$ cycles

06. Ans: (d)

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

$L_1 = 1 \times 10^5$ cycles

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

$L_2 = 0.4 \times 10^5$ cycles

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

$L_3 = 0.15 \times 10^5$ cycles

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

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

$$\frac{10}{18(1\times10^5)} + \frac{5}{18(0.4\times10^5)} + \frac{3}{18(0.15\times10^5)} = \frac{1}{L}$$

$L = 42352.94$ Cycles

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

42352.94 cycles $\rightarrow$? L

$$\frac{42352.94}{10} = \frac{L}{30\,\text{sec}} = \frac{L\times3600}{30}$$

$\Rightarrow L = 19.6$ hrs

07. Ans: (a)

Sol: $d = 50$ mm

$T_{max} = 2$ kN-m

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

$S_{sy} = 225$ MPa,

FS = ? (Soderberg)

$S_{se} = 150$ MPa

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

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

$$\tau_m = \frac{16T_m}{\pi d^3} = \frac{16\times0.6\times10^6}{\pi(50)^3} = 24.446\,\text{MPa}$$

$$\tau_a = \frac{16T_a}{\pi d^3} = \frac{16(1.4)\times10^6}{\pi(50)^3} = 57.04\,\text{MPa}$$

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

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

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

$\Rightarrow FS = 2.04$

08. Ans: (c)

Sol: $L_1 = 10$ hours

$N_1 = 9.8$ hours

$N_2 = 8.2$ hours

$L_2 = ?$

According to Miner's Equation,

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

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

$L_2 = 410$ hours

Common Data for Questions 09 & 10

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

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

$\sigma_{min} = -130$ MPa

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

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

$$= 0.76 \times 0.85 \times 0.897 \times \frac{1}{1+0.95(1.85-1)}(0.5\times1400)$$

$$= 224.411 \text{ MPa}$$

$\therefore$ For a completely reversed,

$\sigma_m = 0$; $\sigma_a = 130$ MPa

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

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

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

$$\sigma_{meq} = \sqrt{\sigma_m^2 + 3\tau_m^2} = \sqrt{3\times36.5^2} = 63.21\,\text{MPa}$$

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

$$= 134.76 \text{ MPa}$$

According to Goodman's equation,

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

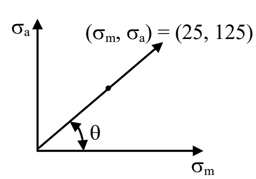
$$\frac{134.76}{224.4} + \frac{63.21}{1400} = \frac{1}{FS} \Rightarrow FS = 1.54$$

11. Ans: (a, c)

Sol: Given data;

$\sigma_{max} = +150$ MPa

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

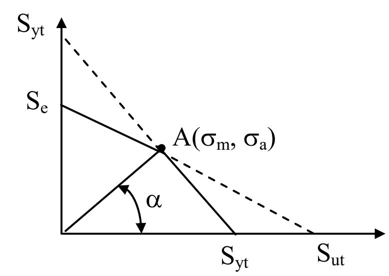


$$\sigma_a = \frac{150-(-100)}{2} = 125 \text{ MPa}$$

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

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

Modified Goodman Diagram:



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

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

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

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

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.

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

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

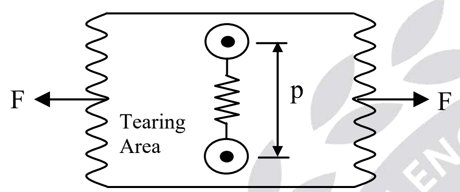
$\therefore$ FOS = 1.78

Chapter 4

Riveted Joints

01. Ans: (b)

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



Tearing efficiency $= \frac{p-d}{p}$

$= \frac{p\left(1-\frac{d}{p}\right)}{p}$

$= 1 - \frac{d}{p} = 1 - 0.5$

$= 0.5 \times 100 = 50\ \%$

Common Data Question (02, 03, 04)

Given, d = 30 mm

$\sigma_t = 40$ MPa = 40 N/mm^2

P = 90 mm

$\sigma_s = 30$ MPa = 30 N/mm^2

t = 12.5 mm

$\sigma_c = 55$ MPa = 55 N/mm^2

02. Ans: (b)

Sol: Tearing Efficiency $= \frac{p-d}{p}$

$= \frac{90-30}{90} = \frac{60}{90}$

$= \frac{2}{3} \times 100$

$\eta_{Tearing} = 66.67\%$

03. Ans: (b)

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

P = 90 × 12.5 × 40

= 45000 N

Shearing Resistance,

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

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

= 21206N

Shear efficiency $= \frac{P_S}{P} = \frac{21206}{45000}$

= 0.47 = 47%

04. Ans: (c)

Sol: Crushing Strength

$P_C = d \times t \times \sigma_c$

= 30 × 12.5 × 55

= 20625 N

Tearing Strength

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

= (90 – 30)×12.5 × 40 = 30,000 N

Shear Strength

$P_S = 21206$ N ,

$P = 45000$ 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 mm

$\tau_s = 60$ MPa $= 60$ N/mm^2

$\sigma_c = 120$ MPa $= 120$ N/mm^2

n = 3 (Triple riveted joint)

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

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

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

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

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 mm,

n = 3

$\sigma_t = 80$ MPa $= 80$ N/mm^2

$\tau_s = 60$ MPa $= 60$ N/mm^2

$\sigma_c = 120$ MPa $= 120$ N/mm^2

Let p = pitch of rivets,

d = 18 mm (*from Q. 5*)

Tearing resistance is

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

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

$= 560(p - 18)$ N ……. (1)

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

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

From equations (1) and (2)

$560(p-18) = 45804$

$p = 99.79$

$p \cong 100$ mm

07. Ans (a)

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

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

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

08. Ans: (b)

Sol: Given:

$\tau_s = 100$ MPa $= 100$ N/mm^2

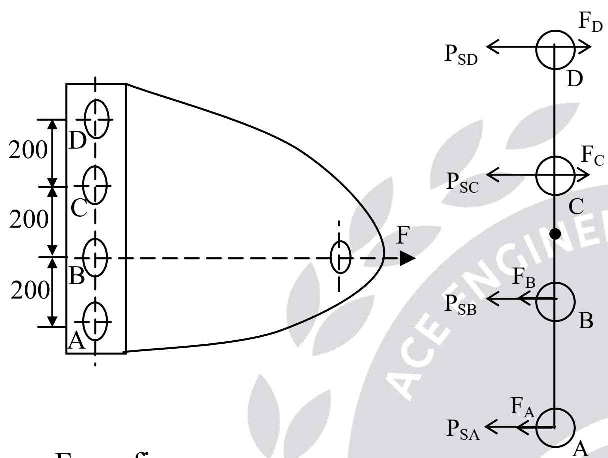
d = 20 mm, n = 4

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,

$l_A = l_D = 200 + 100 = 300$ mm

$l_B = l_C = 100$ mm

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

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

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

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

$$F_B = 0.05P = F_C$$

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

$$F_A = F_B = 0.15\ P$$

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 mm, d = 20 mm

p = 60 mm, τ = 90 MPa

σ_t = 120 MPa, σ_c = 160 MPa

Tensile load (F_t)

$$= (p - d)t \times \sigma_t$$
$$= (60-20) \times 15 \times 120 = 72000\text{N}$$
$$= 72\text{ kN}$$

$$\text{Shear Load } (F_s) = \frac{\pi}{4} \times d^2 \times \tau = \frac{\pi}{4} \times 20^2 \times 90$$
$$= 28274.33\text{ N} = 28.274\text{ kN}$$

$$\text{Crushing load } (F_c) = d \times t \times \sigma_c$$
$$= 20 \times 15 \times 160$$
$$= 48000\text{ N} = 48\text{ kN}$$

Load carrying capacity (F)

$= \text{Minimum of } (F_t, F_s \,\&\, F_c)$

$= 28.274$ kN

Linked Answer Questions 10 & 11:

10. Ans: (a)

Sol: d = 12 mm, P = 4 kN

No. of Rivets = 2

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

Secondary shear load,

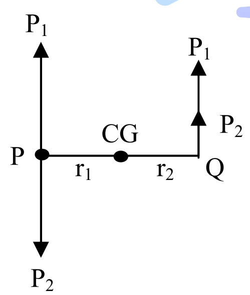
$$P_2 = \frac{P\,e\,r_1}{r_1^2 + r_2^2}$$

$$= \frac{4\times10^3\times(1.8+0.2)\times0.2}{0.2^2+0.2^2}$$

$= 20000$ N $= 20$ kN

11. Ans: (b)

Sol:



Resultant load on Rivet P = $P_2 - P_1$

$= 18$ kN

Resultant shear stress on Rivet P

$$= \frac{18\times10^3}{\frac{\pi}{4}\times12^2} = 159 \text{ MPa}$$

12. Ans: (b, c)

Sol:

- Shearing strength,

$$P_s = 4\times\frac{\pi}{4}\times10^2\times60 = 18.85 \text{ kN}$$

- Crushing strength,

$$P_c = 4\times10\times5\times120 = 24 \text{ kN}$$

- Tearing Strength at AA

$= (50 - 10)\times5\times80 = 16$

- Tearing Strength at BB

$= (150 - 2\times10)\times5\times80 + \dfrac{\pi}{4}\times10^2\times60$

$= 16.712$ kN

Chapter 5 Threaded Fasteners

01. Ans: (b)

Sol: Given d = 24 mm

$F_i = 2840\ d = 2840 \times 24$

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

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 N

P = 134 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

$F_i = 5.3$ kN ,

C = 0.25 ,

P = 9.6 kN

$F_b = CP + F_i$

= (0.25) (9.6) + (5.3)

$F_b = 7.7$ kN

05. Ans: (b)

Sol: Given

D = 250 mm

Pressure = 12 bar = 1.2 MPa

F.S = 5

$S_{yt} = 300$ MPa

n = 8

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

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

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

$$\Rightarrow \frac{7.36\times10^3}{A_b} = \frac{300}{5}$$

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

06. Ans: (d)

Sol: Given,

D = 500 mm

n = 8

P = 20 bar = 2 MPa

$K_m = 3K_b$

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

To avoid leakage

Load (P) = Pr ×A

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

For leak proof joint $F_m \le 0$

$F_i = (1 - C)\ P$

$F_i = (1 - 0.25)\ 49$

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

Linked Answer Q 07 & 08

07. Ans: (d)

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

A = 115 mm^2 , d = 14 mm

$K_m = 1.7\times10^6$ N/mm ,

$E_{cu} = 1.05\times10^5$ N/mm^2

$E_{steel} = 2\times10^5$ N/mm^2

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

$= 0.8\times650\times115 = 59800$ N

For bolt,

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

$$= \frac{115\times2\times10^5}{20+20} = 5.75\times10^5 \text{ N/mm}$$

Where, $l_b = t_1 + t_2 = 20 + 20 = 40$ 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

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

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

P = 79733 N = 79.733 kN

For strength

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

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

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

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

$$CP = \frac{650}{1}\times115 - 59800$$

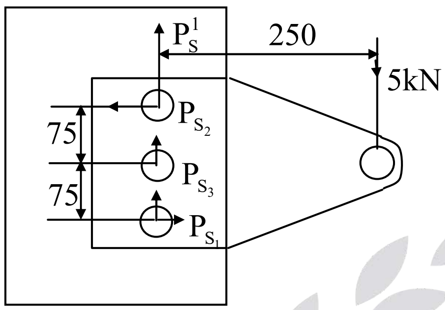
CP = 14950

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

09. Ans: (b)

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

Direct shear load



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

Secondary shear Load, P_{S1}

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

Resultant Load (R) = $\sqrt{P_S^2 + P_{S_1}^2}$

$$= \sqrt{(1.67)^2 + (8.3)^2}$$

= 8.498 kN

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

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

$\therefore$ d = 12.74mm ≈ 13mm

10. Ans: (a)

Sol: n = 4 , L = 550 mm

P = 10 kN, L_2 = 325 mm

$S_{yt} = 400\ N/mm^2$, L_1 = 75 mm

FS = 6

d_c = 0.8d

Using Rankine theory

$P_A' = CL_2$ (tensile load)

$$= \frac{PL}{2(L_1^2 + L_2^2)}\times L_2$$

$$= \frac{10\times 550}{2(75^2 + 325^2)}\times 325 = 8\ kN$$

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

Bolt 'A' is subjected to maximum load

Rankine Theory

$\therefore$ Total Tensile load on bolt = $P_A + P_A'$

= 8+ 2.5 = 10.5kN

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

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

d_c = 14.16

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

11. Ans: (c)

Sol: Given

n = 4 , P = 5 kN , L = 250 mm

L_1 = 75 mm, L_2 = 375 mm

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

F.S = 5 , d_c = 0.8 d

$P_{tA} = CL_2$ = (Tensile)

$$= \frac{PL}{2(L_1^2 + L_2^2)}\times L_2$$

$$= \frac{5\times 250}{2(75^2 + 375^2)}\times 375 = 1.6\ kN$$

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

Direct shear load,

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

Bolts at 'A' is under maximum bending

Rankine Theory

$$\tau = \frac{P_{SA}}{A} = \frac{1.25\times10^3}{A}$$

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

$$\sigma_t = \frac{P_{tA}}{A} = \frac{1.6\times10^3}{A}$$

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

$$\sigma_1 = \frac{1.6\times10^3}{2A} + \frac{1}{A}\sqrt{\left(\frac{1.6\times10^3}{2}\right)^2 + \left(1.25\times10^3\right)^2}$$

$$= \frac{2284.1}{A} \text{N/mm}^2$$

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 mm ,

$\tau = 80$ MPa

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

$= 0.707\times10\times10\times80 = 5.6$kN

02. Ans (b)

Sol: Given, P = 400 kN ,

$\tau = 80$ MPa

$$P = 2\times0.707\times s\times\ell\times\frac{S_{sy}}{FS}$$

$$400\times1000 = 2\times.707\times10\times80\times l$$

$$2l = \frac{400000}{0.707\times10\times80}$$

Total length = $2l \approx 703$ mm

03. Ans: (a)

Sol: Given:

P = 340 kN = 340000 N

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

s =15 mm

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

$$340\times10^3 = 0.707\times15\times\ell\times80$$

l = 400 mm length of weld adjusted on both sides i.e., 200 mm on each side.

04. Ans: (b)

Sol: S = 10 mm, P = 4 kN/cm

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

4 kN → 1 cm

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

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

$\therefore\ l = 175$ mm

05. Ans (a)

Sol: Given: d = 60 mm , s = 10 mm,

$\tau = 70$MPa

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

$$= \frac{T}{2\pi r^2\times0.707s}$$

$$= \frac{T}{2\pi\times\frac{d^2}{4}\times0.707\times s}$$

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

s = Size of the weld

$$T = \frac{70\times\pi\times10\times(60)^2}{2.83}$$

= 2797460 N-mm ⇒ T = 2.797 kN-m

06. Ans (a)

Sol: t = 10 mm

d = 15×10^3 mm

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

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

According to Rankine Theory

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

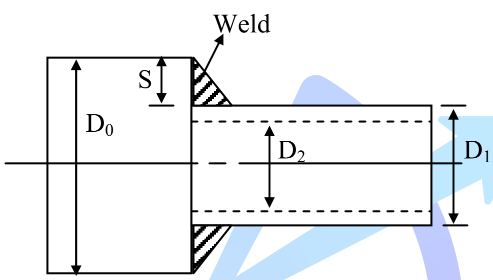
$\dfrac{pd}{4t} = 85$

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

$\Rightarrow p = 0.226$ MPa

07. Ans: (b)

Sol:



$D_1 = 205$ mm,

$D_2 = 200$ mm

$D_0 = 210$ mm,

$\dfrac{S_{sy}}{FS} = 110$ MPa

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

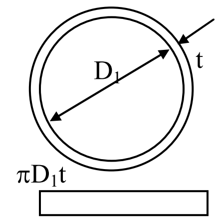
t = 0.707 s = 0.707× 2.5 = 1.7675 mm

Force = Pressure × Area

$= P \times \dfrac{\pi}{4} D_2^2$ .... (1)

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

Equate (1) & (2)



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

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

P = 3.9857 MPa

Linked questions (Q.08 &Q.09)

08. Ans: (a)

09. Ans: (a)

Sol: Given:

$\tau = 75 N/mm^2$, s = 10 mm

P = 200 kN , a = 145 mm

$P = 200 \times 10^3 N$

b = 55mm

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

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

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

$l = 377.18$ mm

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

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

For calculating force carried by top weld

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

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

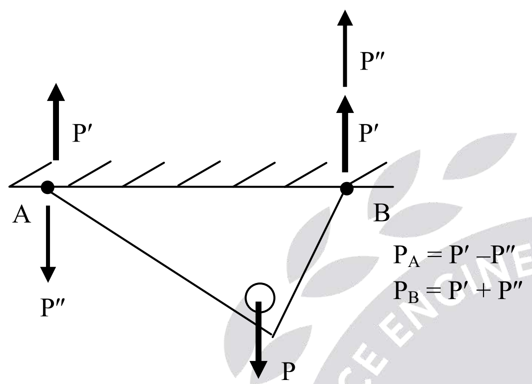
= 54986.9 N

P = 54.9 kN ≈ 55 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 kN

d = 40 mm

p = 1.3 MPa = 1.3 N/mm^2

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

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

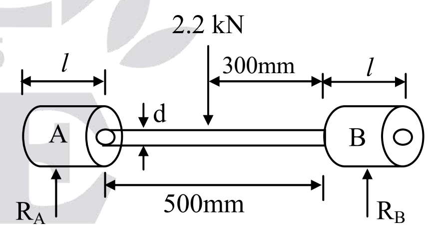
$$= \frac{3000}{1.3 \times 40}$$

l = 57.69 mm

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

02. Ans: (a)

Sol:



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

d = 25 mm　　　l = 500 mm

W = 2.2 kN　　　a = 300 mm

P = ?

$\Sigma M_B = 0$

$R_A \times 500 = 2.2 \times 300$

$R_A = 1.32$ kN

$R_B = 2.2$ kN $-1.32 = 0.88$ kN

Bearing pressure,

$$P = \frac{R_A}{\ell d} = \frac{1.32\times10^3}{25\times1.5\times25} = 1.408\,\text{MPa}$$

03. Ans: (a)

Sol: Given:

$d = 75$ mm , $N_1 = 300$ rpm

$p_1 = 1.4$ MPa $= 1.4$ N/mm^2

$\mu = 0.06$ Pa-sec , $N_2 = 400$ 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. $\mu_1 = \mu_2$

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

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

$$p_2 = \frac{400\times1.4}{300}$$

$p_2 = 1.87$ MPa

04. Ans: (b)

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

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

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

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

05. Ans: (a)

Sol: $d = 150$ mm $= 0.15$ m

$L = 225$ mm $= 0.225$ mm

Load (W) $= 9$ kN $= 9000$ N

$c = 0.075$ mm,

Diametral clearance

$(C_d) = 2 \times 0.075 = 0.15$ mm

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

$N = 1000$ 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

$$V = \frac{\pi d N}{60} = \frac{\pi\times0.15\times1000}{60}$$

$V = 7.85$ m/sec,

f = coefficient of friction

Load (W) $= 9000$N

Heat generated $= f.V.W$

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

$$f = \frac{1500}{7.85\times9000} = 0.021$$

$$\frac{d}{C_d} = \frac{150}{2\times0.075} = 1000$$

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

$$p = \frac{9000}{0.15\times0.225} = 0.267\text{MPa}$$

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 mm , l = 75 mm, f = 0.0015

p = 2 MPa , N = 500 rpm

C = 11.6 W/m^{2o}C , T_r = 28°C

Heat lost in friction = f× W×V

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

$$= 0.0015\times2\times50\times75\times\frac{\pi\times0.05\times500}{60}$$

= 14.72 Nm/sec

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

$14.72 = 11.6\times0.05\times0.075\times8(T_s - 28)$

$T_s = 70.2°C$

Linked Answer Question 07 & 08

07. Ans: (a)

08. Ans: (c)

Sol: Given:

d = 100 mm = 0.1 m

l = 150 mm = 0.15 m

W = 4.5 kN = 4500 N

N = 600 rpm

$\mu = 18.5\times10^{-3}$ kg/m–s = 0.0185 kg/m– s

$C_d = 0.1$

$\in = 0.4$

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

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

$$= \frac{4500}{0.15\times0.1} = 30\times10^4 \text{ N/m}^2$$

P = 0.3 MPa

Sommerfeld no "S"

$$= \frac{0.0185\times\left(\frac{600}{60}\right)}{0.3\times10^{6}}\left(\frac{100}{0.1}\right)^2$$

= 0.617

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

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

h_0 = 0.03 mm

09. Ans: (a)

Sol: Given

W = 150 kN , N = 1800 rpm

d = 300 mm = 0.3 m

p = 1.6 N/mm^2 = 1.6 ×10^6 Pa

C_d = 0.25, $\mu = 20\times10^{-3}$ Pa-sec

K = 0.002

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

$$= \left[0.326\left(\frac{20\times10^{-3}\times1800}{1.6\times10^{6}}\right)\left(\frac{300}{0.25}\right) + 0.002\right]$$

= 0.01

Heat generation = $0.01 \times 150 \times \pi \times d \times N$

$= 0.01 \times 150 \times \pi \times 0.3 \times 1800$

$= 2748.7$ kJ/min

10. Ans: (a)

Sol: Given: $d_1 = 75$ mm, $d_2 = 12$ mm

$p = 0.6$ MPa $= 0.6$ N/mm^2

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

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

$A = 4304.77$ mm^2

Axial load = $p \times A$

$= 0.6 \times 4304.77$ N

$= 2582.862$ N

$P = 2.58$ kN

11. Ans: (a)

Sol: $d = 60$ mm $= 0.06$ m

$N = 600$ rpm, $P = 120$ kPa

$\mu = 0.05$

For foot step bearing

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

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

$T_f = 0.339$ 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.

Note: Correct answer key is (b & c)

Chapter 8

Rolling Contact Bearings

01. Ans: (b)

Sol: Given: 6210 bearing

C = 22.5 kN

L = 27 million rev

6 – series – Ball bearing

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

K = 3 for Ball bearing

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

$$P^3 = \frac{11.39\times10^3}{27}$$

P = 7.5 kN

02. Ans: (b)

Sol: Given: C = 48.545 kN

L = 6000 hrs

N = 500 rpm

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

For Ball bearing, K = 3

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

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

$$L_{50} = \frac{60NL_H}{10^6} = \frac{60\times500\times6000}{10^6}$$

= 180 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 kN

Linked Answer Question (03 & 04)

03. Ans: (a)

04. Ans: (c)

Sol: F_r = 2.5 kN

F_a = 1.5 kN

C_s = 1.5

N = 1000 rpm

X = 0.56

Y = 1.4, V = race rotation factor = 1

Equivalent load (P) = $(XVF_r + YF_a)C_s$

V for most bearings = 1

P = [(0.56 × 1 × 2.5) + (1.4 × 1.5)]1.5

P = [11.4 + 2.1]1.5

P = (3.5)(1.5)

P = 5.25 kN

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

K = 3 for ball bearing

$$L_H = \frac{40\text{ hrs}}{\text{week}}\times\frac{52\text{ weeks}}{\text{yr}}\times5\text{ years}$$

= 10,400 hrs

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

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

L = 624 million revolutions

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

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

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

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

Linked Answer Question (05 & 06)

05. Ans: (c)

06. Ans: (a)

Sol: Given C = 16.6 kN

% of element time = α

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

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

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

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

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

K = 3 for Ball bearing

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

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

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

P = 6.067 kN

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

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

L = 20.5 million rev

Linked Answer Question (07 to 10)

07. Ans: (b)

08. Ans: (a)

09. Ans: (b)

10. Ans: (a)

Sol: Given:

$T_1 = 3$ kN

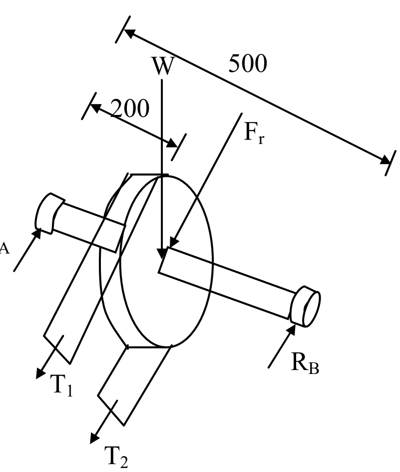
$T_2 = 1.5$ kN

$F_a = 2$kN

$L_H = 5000$ hrs

X = 0.56

Y = 1.5



W = weight of pulley = 1 kN

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

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

Take $\sum M_B = 0$

$R_A \times 500 = R \times 300$

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

$R_A = 2.766$ kN,

$R_B = 1.8436$ kN

Equivalent load

$P = [XVF_r + F_aY]$

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

$P = 4.546$ kN

Dynamic load rating

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

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

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

C = 22.44 kN

11. Ans: (b, d)

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 N

Reliability of system,

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

Chapter 9 Clutch Design

01. Ans: (b)

Sol: Given,

W = 1000 N, n = 2

r_1 = 150 mm = 0.15 mm

r_2 = 100 mm = 0.1 mm

$\mu = 0.5$

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

$= \frac{150+100}{2}$

R = 125 mm

Torque Transmitted,

$T = n\mu WR$

(For both sides effective n = 2)

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

= 125000 N–mm

T = 125 N–m

Linked Answer Questions (2 & 3)

02. Ans: (a)

03. Ans: (a)

Sol: P = 10 kW

T = 100 N-m

n = 2

p_{max} = 0.085 MPa

$d_1 = 1.25d_2$

$r_1 = 1.25r_2$

$\mu = 0.3$

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

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

[$\because W = 2\pi C(r_1 - r_2)$, $C = p_1r_1 = p_2r_2$]

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

$100\times10^3 = (0.3)2\pi(0.085)(r_2)[(1.25r_2)^2 - r_2^2]$

$r_1 = 130$ mm, $d_1 = 260$ mm

$r_2 = 104$ mm, $d_2 = 208$ mm

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

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

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

$W = 1.44$ kN

04. Ans: (c)

Sol: Given,

$\mu = 0.5$

$r_1 = 150$ mm $= 0.15$ m

$r_2 = 100$ mm $= 0.1$ m

$T = 0.4$ kN–m $= 400$ N–m

$n_1 + n_2 = 5$,

n = No. of pairs of contact surface

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

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

$T = n\mu W R$

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

$W = 1600$ N

$\because$ Four springs exert axial load,

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

Linked Answer Question (05 & 06)

05. Ans: (b)

Sol: N = 1000 rpm,

$2\alpha = 24^0 \Rightarrow \alpha = 12^0$

$\mu = 0.2$,

$r_m = 150$ mm, P = 20 kW

$p = 70$ kN/m^2

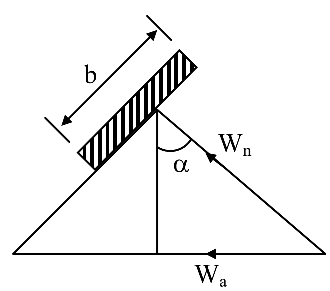
$T = \frac{60P}{2\pi N} = \mu W_n r_m = \mu W_n\left(\frac{r_1 + r_2}{2}\right)$

$T = \frac{60(20)\times1000}{2\pi(1000)} = 191$ N-m

191×10^3 N-mm $= 0.2 \times W_n \times 150$

$W_n = 6366.19$ N [$\therefore W_a = W_n \sin\alpha$]

$W_a = 1323.60$ N



Force required for engagement

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

$= 1323.60 + [0.2\times6366.19\times\cos12]$

$W_{ae} = 2.56$ 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 :

$d_1 = 120$ mm, $d_2 = 200$ mm

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

$N_1 = 200$ 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 $T = I\,\alpha = 20 \times 4.18 = 83.6$ N-m

$\mu = 0.3$

For uniform pressure,

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

$$83.6\times10^3 = \frac{2}{3}\times 0.3\times W\left[\frac{100^3 - 60^3}{100^2 - 60^2}\right]\times 2$$

$W = 1706.12$ N

09. Ans: (d)

Sol: Given,

$n = 4$, $P = 21$ kW

$N = 750$ rpm, $\omega_1 = 0.75\,\omega_2$

$R = 300$ mm, $r = 125$ mm, $\mu = 0.25$

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

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

$$318.3 = n\times\mu\times mr\left(\omega_2^2 - \omega_1^2\right)\times R$$

$$318.3 = 4\times0.25\times m\times 0.125\left(1 - \frac{9}{16}\right)\times 78.5^2\times 0.15$$

$m = 6.3$ kg

10. Ans: 157 mm & 135.22 mm

Sol: Centrifugal force between each shoe and drum

$F = mr\left(\omega_2^2 - \omega_1^2\right)$

$F = 2123.08$ N

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

$$\text{width}\times\text{arc length} = w\times\frac{\pi}{3}\times150 = 21230.87$$

$w = 135.22$ mm

$$\text{Length} = \frac{\pi}{3}\times150 = 157\text{ mm}$$

Length = 157 mm

Width = 135.22 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

$\Sigma M_{Pivot} = 0$

$300 \times 500 = R_N \times 200$

$R_N = 750$ N

$F_t = \mu R_N = 180$ N

$T = F_t\, r$

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

02. Ans: (a)

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

$\omega_2 = 0$

Capacity to bring the system to rest from 100 rpm = work done = Heat generation = $T \times \theta$

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

$= 27 \times 5.235 \times 5 = 706.725$ J

03. Ans: (b)

Sol: $\mu = 0.3$

$2\theta = 90° = \pi/2$ rad

$\theta = 45°$

Equivalent coefficient of friction

$$\mu^1 = \frac{4\mu \sin\theta}{2\theta + \sin 2\theta}$$

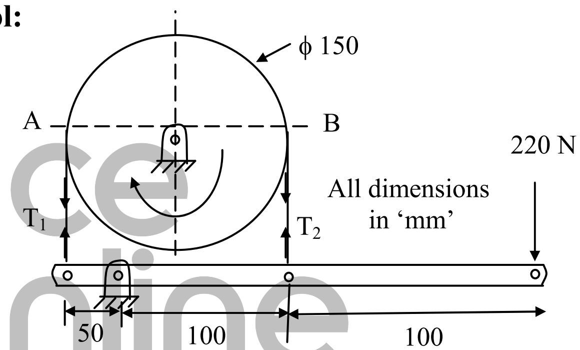
$$= \frac{4 \times 0.3 \times \sin 45^0}{\pi/2 + \sin 90^0}$$

$$= \frac{0.848}{2.57} = 0.329 = 0.33$$

Common Data Question 04 & 05

04. Ans: (c)

Sol:



$T = 450$ N-m $\qquad \mu = ?$

$P = 220$ N $\qquad a = 50$ mm

$b = 100$ mm

$\Sigma M_{pivot} = 0$

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

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

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

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

$T_1 - T_2 = 6000$ …… (2)

From (1) and (2) $T_1 = 12880$ N

$T_2 = 6880$ N

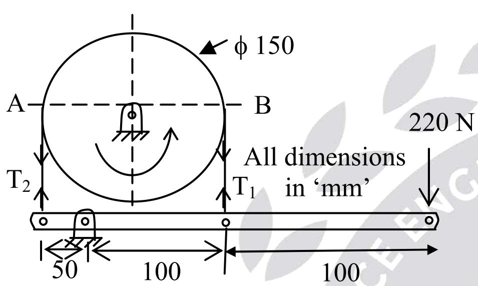
$$\frac{T_1}{T_2} = e^{\mu\times\theta}$$

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

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

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)

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

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

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

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"

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

By solving 1 & 2

$T_2 = 146.17$ N, $T_1 = 513$ N

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

$= (513 - 146.17)\times 75\times 10^{-3}$

$= 27.5$N-m

Linked Answer Questions 06 & 07

06. Ans: (b)

Sol: $d = 250$ mm

$\rho = 7200$ kg/m^3

$t = 20$ mm

$\tau = 0.40$ sec

$N = 500$ rpm

Energy absorbed by brake

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

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

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

$= 0.055$ kgm^2

$N_2 = 0 \rightarrow$ 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, $E = T \times \theta$

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

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

$\Rightarrow T = 7.16$ Nm

Linked Answer Question (08 & 09)

08. Ans: (c)

Sol: $T = 800$ N-m, $r = 0.5$ m

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

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

$T_1 - T_2 = 1600$ N

But, $T_2 = 300$ N

$T_1 = 1900$ N

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

$\theta = 235°$

09. Ans: (c)

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

$P_{max} = 126.67$ kPa

Common Data Question (10 & 11)

10. Ans: (a)

11. Ans: (b)

Sol: Given

$d = 320$ mm $= 0.32$ m

$r = 160$ mm $= 0.16$ m

$\mu = 0.3$

$F = 600$ N

Taking moments about 'O'

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

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

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

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

$R_N(350) + R_N(12) = 45000$

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

$R_N = 1243$ N

For calculating breaking torque (T_B)

$F_t = \mu R_N$

$F_t = 0.3 \times 1243$

$F_t = 372.9$ N

$T_B = F_t \times r = 372.9 \times 0.16 = 59.664$

$T_B = 60$ Nm

Chapter 11 Spur Gear Tooth

01. Ans: (b)

Sol: Given: $T_p = 25$, $m = 4$, $C = ?$

$N_p = 1200$ rpm, $N_G = 200$ 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, $T_1 = 19$, $T_2 = 37$, $C = 140$ 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: $m = 8$ mm

Face width (w) = 90 mm

$F_t = 7.56$ kN

Tensile stress = 35 MPa = S

Form factor (y) = ?

Let $C_V = 1$

$$F_t = S\, w\, m\, y\, C_v$$

$$7.56\times10^3 = 35 \times 90 \times 8 \times y$$

$\Rightarrow$ $y = 0.3$

04. Ans: (a)

Sol: $P = 9$ kW, $N = 1440$ rpm

$d = 100$ mm, $F_t = ?$

$P = F_t \times V$

$$F_t = \frac{P}{V} = \frac{9\times10^3}{\frac{\pi\times0.1\times1440}{60}} = 1.19 \text{ kN}$$

05. Ans (b)

Sol: $P = 10\text{ kW} = 10\times10^3\text{W}$

$V = 600$ m/min

$d = 100$ mm $\Rightarrow r = 50$ mm

$$F_t = \frac{P}{V}$$

$$= \frac{10\times10^3\times60}{600} = 10^3\text{ N}$$

$F_t = 1$ kN

$$\text{Torque} = F_t \times r = \frac{1\times10^3\times50}{1000}$$

$T = 50$ N–m

06. Ans: (b)

Sol: Given $P = 20$ kW

$N_P = 300$ rpm

$\sigma_b = 80$ MPa

$y = 0.094$,

$C_v = 1$

$w = 14$ m

$T_p = 18$,

$m = ?$

$$F_t = \frac{P}{V} = S w m y C_v \times \pi$$

$$\Rightarrow \frac{20\times10^3}{\left(\frac{\pi d_p\times300}{60\times1000}\right)} = 80\times10^6\times(14m)m\times0.094\times1\times\pi$$

$(\because d_p = mT_p)$

$$\Rightarrow \frac{20\times10^6\times60}{\pi\times18\times m\times300} = 80\times14\times0.094\times\pi\times m^2\times10^6$$

$\Rightarrow m = 5.98 \approx 6$

Linked Answer Questions 07 & 08

07. Ans: (b)

08. Ans: (a)

Sol: $P = 11$ kW , $N_P = 1440$ rpm

$\phi = 14\frac{1}{2}$, $m = 6$ mm

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

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

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

$S = 210$ MPa

$F_t = ?$, $w = ?$

$$F_t = \frac{P}{V}C_s \qquad \left(\because V = \frac{\pi dN}{60}\right)\ (d = mT)$$

$$F_t = \frac{11\times10^3}{\frac{\pi(6\times25)\times1440}{60\times1000}}\times1.5$$

$F_t = 1.46$ kN

$F_t = S\ w\ m\ y\ C_v$

$1.46\times10^3 = 210\times w\times6\times0.1\pi\times0.21$

$\Rightarrow w = 18$ mm

Linked Answer Questions 09 to 11

09. Ans: (b)

Sol: $P = 500$ kW, $N_P = 1800$ rpm,

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

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

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

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

$T_P = 15$ and $T_G = 150$

$d_p = mT_p = 8(15) = 120$ mm

F_r on bearing = ? , $F_t = ?$, $w = ?$

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

$$= \frac{500\times10^3}{\pi\left(\frac{120}{1000}m\right)\times\left(\frac{1800}{60}\right)\frac{1}{sec}}$$

$F_t = 44.2$ kN

10. Ans: (c)

Sol: $F_r = F_t\ \tan\phi = 44.2\tan(22.5) = 18.3$ kN

$$F_n = \frac{F_t}{\cos\phi} = \frac{44.2}{\cos22.5} = 47.85\text{ kN}$$

11. Ans: (d)

Sol: 200 N $\rightarrow$ 1 mm width

47.85 kN $\rightarrow$?

$$w = \frac{47.85\times10^3}{200} = 240\text{ mm}$$

12. Ans: (c)

Sol: $S_{teel} = 120$ MPa $\rightarrow$ for pinion

$S_{CI} = 100$ MPa $\rightarrow$ for gear

Form factors

For gear, for pinion $(y_{CI})_g = 0.13$

Form factors

$(y_{steel})_p = 0.093$

$S_{steel} \times y_{steel} = 120 \times 0.093 = 11.16$

$S_{CI} \times y_{CI} = 100 \times 0.13 = 13$

$\therefore \quad S_{steel} \times y_{steel} < S_{CI} \times y_{CI}$

$\therefore (\text{Strength})_{pinion} < (\text{Strength})_{gear}$

So Pinion is weaker than gear.

13. Ans: (b)

Sol: Given: $G.R = \frac{T_G}{T_P} = 2$

$w = 10$ cm $= 100$ mm

$d_p = 40$ cm $= 400$ mm

Stress factor for fatigue $= 1.5$ N/mm^2 $= K$

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

$F_w = Kd_pwQ$

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

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

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

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

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

$\Rightarrow \quad k_2 = 3$ k

02. Ans: 668.4 MPa

Sol: Given, C = 10

k_s = direct shear stress factor

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

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

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

$\tau_{max} = 668.45$ 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,

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

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

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

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

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

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

$$\Rightarrow n = 10$$

05. Ans: (b)

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

06. Ans: 300

Sol: $\delta = \frac{3}{8}\frac{WL^3}{n b t^3 E}$

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

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

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

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

$$\Rightarrow b = 300$$

Safe width = 300 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 $r = D/2$

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

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 'σ_1'.

$$M_e = \frac{1}{2}\left(M + \sqrt{T^2 + M^2}\right)$$

$$= \frac{1}{2}\left(40 + \sqrt{30^2 + 40^2}\right)$$

= 45 kN-m

07. Ans: (d)

Sol: Equivalent twisting moment,

$$T_e = \sqrt{(k_b M_b)^2 + (k_t M_t)^2}$$

$$= \sqrt{(1.5\times 0.5)^2 + (2\times 1)^2} = 2.136 \text{ N-m}$$

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 aas 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:

$d_A = 2d_B$

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

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

$\therefore\ P \propto d^3$

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

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

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

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 $\sigma_b = \frac{M}{I}.y$ and

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

  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

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

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

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

$$\sigma_{vm} = \sqrt{\sigma_x^2 + 3\times\sigma_{xy}^2}$$

$$= \sqrt{\left\{\frac{32M}{\pi d^3}\right\}^2 + 3\times\left\{\frac{16T}{\pi d^3}\right\}^2} \quad \text{........ (iii)}$$

Equivalent bending moment (M_e) :

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

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

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

As per shear stress theory, comparing ii & iv

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

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

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) :

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

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

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

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

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