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MECHANICAL ENGINEERING

MACHINE DESIGN

Volume - 1 : Study Material with Classroom Practice Questions

Machine Design

Solutions for Volume – I _ Classroom Practice Questions

Chapter- 1
Static Loads

01. Ans: (d)

Sol: t = 0.2 mm, d = 25 mm,

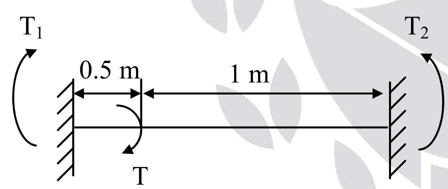
E = 100 GPa

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

$$\sigma_b=\frac{100\times10^3\times\left(\frac{0.2}{2}\right)}{\left(\frac{25}{2}\right)}=800\,\text{MPa}$$

02. Ans: (b)

Sol:



$T = T_1 + T_2$

$\theta = \theta_1 = \theta_2$

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

$$T_1=\frac{7358\times1}{1.5}=4905.33\ \text{Nm}$$

$$T_2=\frac{7358\times0.5}{1.5}=2452.66\,\text{Nm}$$

Maximum shear stress

$$\tau=\frac{16\,T_1}{\pi d^3}=\frac{16\times4905.33\times10^3}{\pi\times80^3}=48.8\ \text{MPa}$$

03. Ans: (a)

Sol: $G = 0.8\times10^3$ MPa

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

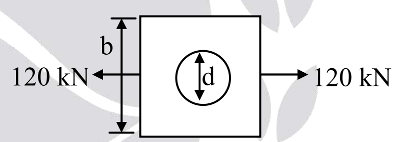
$$\theta_1=\frac{4905.33\times10^3\times0.5\times10^3}{\frac{\pi}{32}\times80^4\times0.8\times10^5}$$

$$=7.62\times10^{-3}\ \text{radian}$$

$$=7.62\times10^{-3}\times\frac{180}{\pi}=0.436\ \text{degrees}$$

04. Ans: (b)

Sol:



P = 120 kN, t = 13 mm

$$\frac{120\times10^3}{(b-d)t}=75\,\text{MPa}$$

$$\frac{120\times10^3}{(b-22)\times13}=75$$

$\Rightarrow$ b = 145 mm

05. Ans: (b)

Sol: Force applied on the bar = 95 × 100 × t N

Maximum stress induced

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

$$=\frac{95\times100\times t}{(100-5)\times t}=100\,\text{MPa}$$

06. Ans: (c)

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

$2.25 \times 1.25 = P \times 15$

$P = 1.875$ kN

07. Ans: (c)

Sol: The reaction force acting on the pin

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

R = Pressure × (Projected area of the pin)

$= 6.5 \times (d_1 \times l_1) = 6.5 \times (d_1 \times 2 \times d_1)$

$(\because l_1 = 2d_1)$

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

$d_1 = 15$ mm

08. Ans: (a)

Sol: d = 30 mm, t = 3 mm

Outer diameter = 30 + 2 × t

= 30 + 2 ×3 = 36mm

Speed ratio = 4:1

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

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

Maximum shear stress

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

Chapter- 2
Theories of Failure

01. Ans: (c)

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

$S_{yt} = 330$ MPa

According to maximum principal theory

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

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

$$= 30 + 50 = 80\,MPa$$

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

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

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

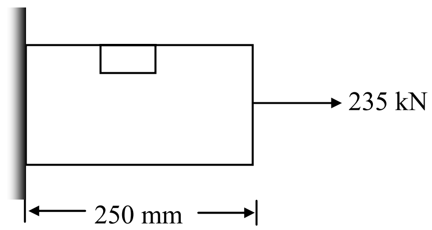
$$\Rightarrow \frac{40+30}{2} = \frac{350}{2 \times FS}$$

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

03. Ans: (d)

Sol: d = 50 mm, L = 250 mm,

P = 235 kN, $S_{ut} = 480$ MPa



According maximum shear stress theory

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

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

$$\sigma = \frac{235\times10^3}{\frac{\pi}{4}\times50^2} = 119.68\,\text{MPa}$$

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

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

$\Rightarrow$ F.S = 4

04. Ans: (b)

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

$F_S = 18$ kN $\qquad$ FS = ?

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

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

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

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

$= 50$ MPa

According to maximum shear stress theory

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

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

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

05. Ans: (d)

Sol: Given thin cylindrical shell

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

$t = 16$ mm, $\qquad S_{yt} = 260$ 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

$\sigma_3 = 0$

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

i.e., $\left|\frac{30.18-15.08}{2}\right| = 7.55$

$\left|\frac{30.18-0}{2}\right| = 15.09$

$\left|\frac{15.08}{2}\right| = 7..54$

$\tau_{max} = 15.09$

According max shear stress theory

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

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

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

06. 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

07. Ans: (b)

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

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

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

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

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

08. Ans: (a)

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

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

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

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

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

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

According to distortion energy theory

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

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

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

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

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

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

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

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

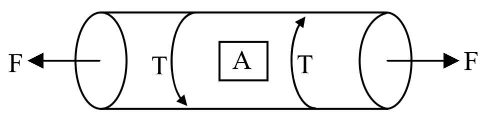
$$= \frac{10^3}{A}\sqrt{20^2 + 3 \times 15^2} = \frac{360}{3}$$

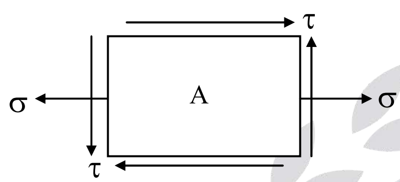
$\therefore$ A = 273.22 mm^2 = (π/4) d^2

$\Rightarrow$ d = 18.65mm

09. Ans: (b)

Sol:





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

F = 40 kN ,

d = 20 mm, $\quad$ T = ?

According to Distortion Energy Theory

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

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

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

$\Rightarrow \tau$ = 51.03 MPa

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

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

$\Rightarrow$ T = 80157.73 Nmm = 80.157 Nm

10. Ans: (b)

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

Torque, T = 5 × 10^3 × 0.5

S_{yt} = 425 MPa

Bending moment

M = 5 × 10^3 × 2.5 = 12500 Nm

Maximum shear stress

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

= 12732395 N/m^2 = 12.73 MPa

Maximum bending stress

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

= 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

11. Ans: (a)

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

FS = 2.5

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

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

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

Maximum Bending moment,

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

$= 10000 \times 10^3$ 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

12. Ans: (b)

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

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

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

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

According Distortion Energy Theory

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

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

13. Ans: (b)

Sol: T = 10 kN-m , M = 10 kN-m

Equivalent torque,

$T_e = \sqrt{10^2 + 10^2} = 14.14$ 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

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

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

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

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

$\Rightarrow$ FS = 2.7

Chapter- 3
Fluctuating Loads

01. Ans: (c)

Sol: Given:

$b = 50$ mm , $d = 10$ mm

$t = 10$ mm , $\sigma = 62.5$ MPa

Area, $A = (b - d)\,t$

$= (50 - 10)10 = 400\ \text{mm}^2$

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

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

$= 62.5 \times 400 = 25000$ N

$F = 25$ kN

02. 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

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

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

$= 0.5 \times 440 = 220$ 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

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

$\therefore S_e = 48.63$ MPa

For completely reverse load

$\sigma_m = 0$

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

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

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

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

$\therefore$ $t = 12.3$ mm

$t = 12$ mm

03. Ans: (b)

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

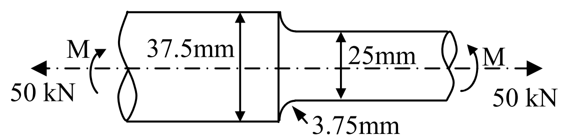
$S_e' = 200\ \text{MN/m}^2$, $K_t = 1.55$, $q = 0.9$

$M = ?$

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

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

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



Mean stress, $\sigma_m = \dfrac{F}{A}$

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

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

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 N-m

04. 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

$K_t = 1.85$

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

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

$\sigma_{2\min} = 25$ 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

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

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

$= 86.6$MPa

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

$= 90.14$ MPa

Substituting these values in Soderberg's equation

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

$\Rightarrow$ F.S = 1.2

Common Data for Questions 05 & 06

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

Sol: $S_e = 280$ MPa

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

$S_u = 600$ MPa

$N = 10^3$ 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

07. Ans: (d)

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

$L_1 = 1 \times 10^5$ cycles

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

$L_2 = 0.4 \times 10^5$ cycles

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

$L_3 = 0.15 \times 10^5$ cycles

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

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

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

$L = 42352.94$ Cycles

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

42352.94 cycles $\rightarrow$? L

$\Rightarrow L = 19.6$ hrs

08. 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

09. Ans: (c)

Sol: L_1= 10 hours

N_1 = 9.8 hours

N_2 = 8.2 hours

L_2 = ?

According to Miner's Equation,

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

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

L_2 = 410 hours

Common Data for Questions 10 & 11

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

Sol: σ_{max} = + 130 MPa

σ_{min} = –130 MPa

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

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

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

= 224.411 MPa

$\therefore$ For a completely reversed,

σ_m = 0 ;

σ_a = 130 MPa

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

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

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

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

$$= 63.21\,\text{MPa}$$

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

$$= 134.76\text{ MPa}$$

According to Goodman's equation,

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

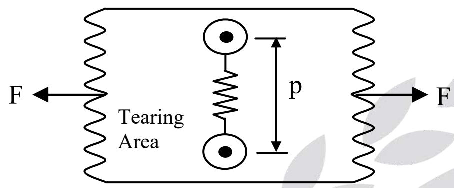
$$\frac{134.76}{224.4} + \frac{63.21}{1400} = \frac{1}{FS}$$

$$\Rightarrow FS = 1.54$$

Chapter- 4
Riveted Joints

01. Ans: (b)

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



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

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

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

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

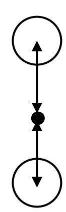
02. Ans: (d)

Sol: Resultant Force $= \sqrt{F_1^2 + F_2^2}$

$$= \sqrt{4^2+3^2}$$

$$= 5\text{ kN}$$

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



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

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

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

Common Data Question (03, 04, 05)

Given, d = 30 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

03. Ans: (b)

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

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

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

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

04. Ans: (b)

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

$P = 90 \times 12.5 \times 40$

$= 45000$ N

Shearing Resistance,

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

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

$$= 21206\text{N}$$

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

$= 0.47 = 47\%$

05. Ans: (c)

Sol: Crushing Strength

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

$= 30 \times 12.5 \times 55$

$= 20625$ N

Tearing Strength

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

$= (90 - 30) \times 12.5 \times 40 = 30{,}000$ N

Shear Strength

$P_S = 21206$ N , $P = 45000$ N

Strength of riveted joint

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

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

06. 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)

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

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

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

$= 2520d$ N …….. (2)

From equations (1) & (2)

$141.4\, d^2 = 2520d$

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

07. Ans: (d)

Sol: Given:

t = 7 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

Tearing resistance is

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

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

$= 560(p - 18)$ N ……. (1)

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

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

From equations (1) and (2)

$560(p-18) = 45804$

$p = 99.79$

$p \cong 100$ mm

08. 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

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

09. Ans: (b)

Sol: Given:

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

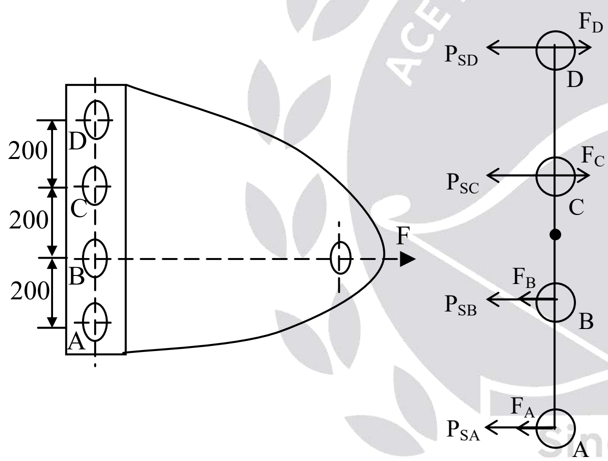
$d = 20$ mm, $n = 4$

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

[$\because$ 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

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

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

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

10. Ans: (b)

Sol: Tensile load (F_t)

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

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

$= 72$ kN

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

$= 28274.33$ N $= 28.274$ kN

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

$= 20\times 15\times 160$

$= 48000$ N $= 48$ Kn

Load carrying capacity (F)

= Minimum of (F_t, F_s & F_c)

= 28.274 kN

Linked Answer Questions 11 & 12:

11. Ans: (a)

Sol: No. of Rivets = 2

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

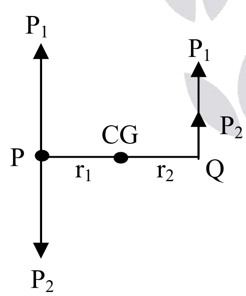
Secondary shear load $P_2 = \frac{Per_1}{r_1^2 + r_2^2}$

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

= 20000 N = 20 kN

12. Ans: (b)

Sol:



Resultant load on Rivet P = $P_2 - P_1$

= 18 kN

Resultant shear stress on Rivet P

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

Chapter- 5
Threaded Fasteners

01. Ans: (b)

Sol: Given d = 24 mm

$F_i = 2840\,d = 2840\times24$

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

Here, $d_c = 0.84d \Rightarrow d_c = 0.84\times24$

$$\sigma_t = \frac{2840\times24}{\frac{\pi}{4}(0.84\times24)^2}$$

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

02. Ans: (c)

Sol: Given

d = 36 mm

$d_c = 0.84\,d = 0.84\times36$

F.S = 1.5

S_{yt} = 280 MPa

$$\sigma_t = \frac{s_{yt}}{F.s} = \frac{280}{1.5}$$

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

$$= \frac{\pi}{4}(0.84\times36)^2\times\frac{280}{1.5}$$

= 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×4 = T×θ

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

04. Ans: (d)

Sol: Given

F = 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: (c)

Sol: $K_m = 4K_b$

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

To open the joint

$(1–C)P = F_i$

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

06. Ans: (b)

Sol: Given

D = 250 mm

Pressure = 12 bar = 1.2 MPa

F.S = 5

S_{yt} = 300 MPa

n = 8

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

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

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

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

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

07. 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

$= 36.75$ kN ≈ 37 kN

Linked Answer Q 08 & 09

08. Ans: (d)

Sol: $S_{yt} = 650$ MPa

$A = 115\ mm^2$

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

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

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

$F_i = 0.8S_{yt}\times A = 0.8\times650\times115 = 59800$ 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

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

09. Ans: (a)

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

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

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

$P = 79733$ N $= 79.733$ kN

For strength

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

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

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

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

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

$CP = 14950$

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

Linked Answer Q 10 & 11

10. Ans: (b)

11. Ans: (a)

Sol: Given

$d = 20$ mm, $S_{yt} = 630$ MPa

$S_e = 350$ MPa, F.S = 2.5

Core area of bolt = 2.45 cm^2 = 245 mm^2

$\sigma_m = 180$MPa

Soderberg's criterion

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

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

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

$\sigma_a = 40$MPa

For calculating maximum & minimum values of varying loads.

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

$P_{max} = \sigma_{max}\times$Area $= 220\times245 = 54$ kN

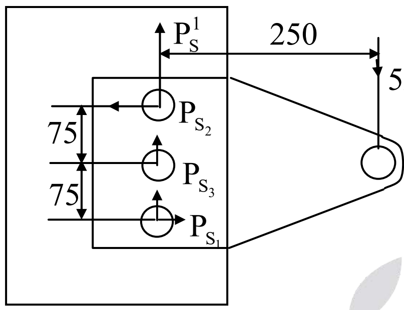
$\sigma_{min} = \sigma_{mean} - \sigma_a = 180 - 40 = 140$ MPa

$P_{min} = \sigma_{min}\times$Area $= 140\times245 = 34$ kN

12. 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}

$$= \frac{5\times250}{(75)^2+0^2+(75)^2}\times75 = 8.3\text{kN}$$

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 × S_{sy}]

$$8.498\times10^3 = \frac{\pi}{4}(d^2)\times\frac{S_{yt}}{2\times F.s}$$

$\therefore$ d = 12.74mm ≈ 13mm

13. Ans: (a)

Sol: n = 4

P = 10 kN

S_{yt} = 400 N/mm^2

FS = 6

d_c = 0.8d

Using Rankine theory

$P_A = CL_2$ (tensile load)

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

$$= \frac{10\times550}{2(75^2+325^2)}\times325 = 8\text{ kN}$$

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

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

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

14. Ans: (c)

Sol: Given

n = 4 , P = 5 kN

S_{yt} = 380 N/mm^2

F.S = 5 , d_c = 0.8 d

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

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

$$= \frac{5\times250}{2(75^2+375^2)}\times375$$

= 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

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

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

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

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

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

$$= \frac{2292.22}{A} \text{N/mm}^2$$

According to Rankine Theory

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

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

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

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

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

Chapter- 6
Welded Joints

01. Ans (b)

Sol: Given: s = 10 mm ,

τ = 80 MPa

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

$$= 0.707\times10 \times 10 \times 80 = 5.6\text{kN}$$

02. Ans (b)

Sol: Given, P = 400 kN ,

τ = 80 MPa

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

$$400\times 1000 = 2\times .707\times10\times80\times l$$

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

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

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

$$340\times10^3 = 0.707\times15\times1\times80$$

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, τ = 70MPa

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

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

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

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

s = Size of the weld

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

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

06. Ans (a)

Sol: t = 10 mm

$d = 15\times10^3$ mm

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

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

According to Rankine Theory

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

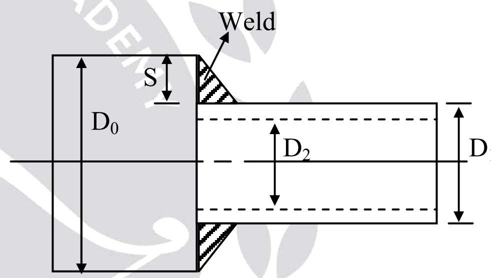
$$\frac{pd}{4t} = 85$$

$$\Rightarrow \frac{p\times15\times10^3}{4\times10} = 85$$

$\Rightarrow p = 0.226$ MPa

07. Ans: (b)

Sol:



$D_1 = 205$ mm, $D_2 = 200$ mm

$D_0 = 210$ mm,

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

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

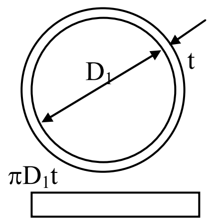
$t = 0.707\ s = 0.707\times 2.5 = 1.7675$ mm

Force = Pressure × Area

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

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

Equate (1) & (2)



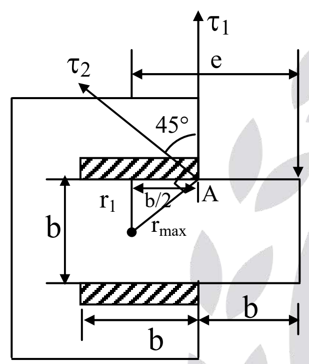
$$P \times \frac{\pi}{4} D_2^2 = \pi D_1 t \frac{S_{sy}}{FS}$$

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

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

08. Ans: (a)

Sol:



Primary shear stress

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

Secondary shear stress

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

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

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

$A = b \times t$

$l = b$

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

r_1 = distance between two centroids.

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

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

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

$$\tau_2 = \frac{T}{J} \times r_{max} = \left(\frac{1.5Pb}{\frac{2b^3 t}{3}}\right) \times \frac{b}{\sqrt{2}} = \frac{1.59P}{bt}$$

Resultant Shear stress

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

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

θ = Angle between τ_1 and τ_2

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

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

09. Ans: (a)

Sol: Given: τ =140 MPa , s = 6 mm

d = 50 mm , r = 25 mm

We know that

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

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

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

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

$$= 2332.161 \text{ Nm}$$

Linked questions (Q.10 &Q.11)

10. Ans: (a)

11. Ans: (a)

Sol: Given:

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

P = 200 kN , a = 145 mm

$P = 200\times10^3\ N$

b = 55mm

$P = \tau\times0.707s\times l$

$200\times10^3 = 75\times0.707\times10\times\ell$

$l = \dfrac{200\times10^3}{75\times0.707(10)}$

$l = 377.18$ mm

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

$= \dfrac{377.18\times55}{(145+55)} = 103.72\,\text{mm}$

For calculating force carried by top weld

$P = \tau\times0.707\times s\times\ell_a$

$= 75\times0.707\times10\times103.7$

= 54986.9 N

= 54.9 kN

P = 55 kN

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

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

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

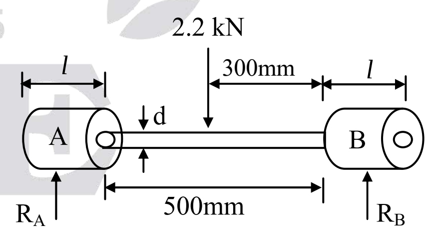
$= \dfrac{3000}{1.3\times40}$

$l = 57.69$ mm

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

02. Ans: (a)

Sol:



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

d = 25 mm $\quad$ l = 500 mm

W = 2.2 kN $\quad$ 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, $\varepsilon = 0.8$

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

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

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

05. Ans: (a)

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

$L = 225$ mm $= 0.225$ mm

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

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

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

$$0.0212 = 0.326\left(\frac{\mu\times1000}{0.267\times10^{6}}\right)1000 + 0.002$$

$\mu = 0.0157$ 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 , $T_r = 28^oC$

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 mm

$W = 4.5$ kN = 4500 N

$N = 600$ rpm

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

$C_d = 0.1$

$\varepsilon = 0.4$

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

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

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

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

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

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

$h_0 = 0.03$ 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

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

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

Chapter- 8
Rolling Contact Bearings

01. Ans: (d)

Sol: 6205 bearing

$C = 10.8$ kN

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

02. Ans: (b)

Sol: Given: 6210 bearing

$C = 22.5$ kN

$L = 27$ million rev

6 – series – Ball bearing

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

$K = 3$ for Ball bearing

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

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

$P = 7.5$ kN

03. 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

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

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

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

= 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 (04 & 05)

04. Ans: (a)

05. 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

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

= 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 kN

Linked Answer Question (06 & 07)

06. Ans: (c)

07. Ans: (a)

Sol: Given C = 16.6 kN

% of element time = α

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

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

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

$N = 270 + 576 + 216 = 1062$

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

K = 3 for Ball bearing

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

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

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

$P = 6.067$ 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 (08 to 11)

08. Ans: (b)

09. Ans: (a)

10. Ans: (b)

11. Ans: (a)

Sol: Given:

$T_1 = 3$ kN

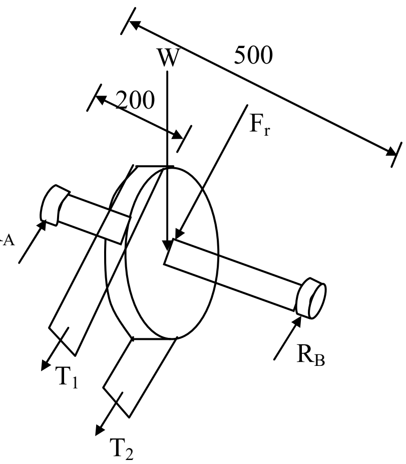
$T_2 = 1.5$ kN

$F_a = 2$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

$P = [XVF_r + F_a Y]$

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

$P = 4.546$ kN

Dynamic load rating

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

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

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

$C = 22.44$kN

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) $= \dfrac{r_1 + r_2}{2}$

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

$R = 125$ 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

$d_1 = 1.25d_2$

$r_1 = 1.25r_2$

$\mu = 0.3$

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

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

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

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

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

$r_1 = 130$ 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: (b)

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

$d_1 = 220$ mm, $d_2 = 150$ mm

$P_{max} = 0.25$ MPa

$\mu = 0.3$

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

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

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

i) $T_1 = 114$ N-m Slip takes place

ii) $T_2 = 148$ N-m suitable

iii) $T_3 = 173$ Nm

05. 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

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

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

$$T = n\mu W R$$

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

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

$\because$ Four springs exert axial load,

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

Linked Answer Question (06 & 07)

06. Ans: (b)

Sol: N = 1000 rpm,

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

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

$p = 70$ kN/m^2

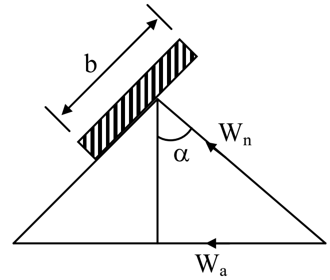
$$T = \frac{60P}{2\pi N} = \mu W_n r_m = \mu W_n\left(\frac{r_1 + r_2}{2}\right)$$

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

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

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

$W_a = 1323.60$ N



Force required for engagement

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

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

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

07. Ans: (b)

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

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

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

Common Data for Q. 8 & 9

08. Ans: (c)

09. Ans: (a)

Sol: $N_1 = 200$ 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,

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

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

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

10. Ans: (a)

Sol: Given

D = 300 mm

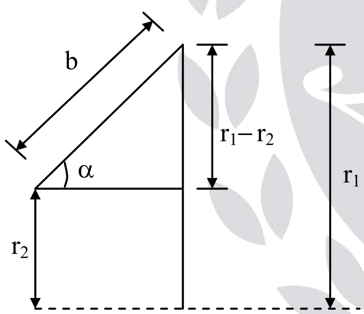
b = 100 mm

$\mu = 0.2$

$\alpha = 10^0$

p = 0.07 MPa = 0.07 N/mm^2

N = 500 rpm



We know that

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

$= 2\pi pr\,(r_1 - r_2)$ $\quad(\because C = p \times r)$

$= 2\pi prb\sin\alpha \quad (r_1 - r_2 = b\sin\alpha)$

$= 2\pi\times0.07\times150\ (100\sin10°)$

W = 1146 N

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

W_n = 6599 N

Force required for engagement

$W_{en} = W_n(\sin\alpha + \mu\cos\alpha)$

$= 6599(\sin10 + 0.2\cos10)$

W_{en} = 2445 N

11. Ans: (d)

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

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

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

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

$$318.3 = 4\times0.25\times m\times 0.125\left(1 - \frac{9}{16}\right)\times 78.5^2\times0.15$$

m = 6.3kg

12. Ans: 157mm & 135.22mm

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

Chapter- 10
Brakes

Linked Answer Questions (01 & 02)

01. Ans: (b)

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

$300 \times 500 = R_N \times 200$

$R_N = 750$ 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

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

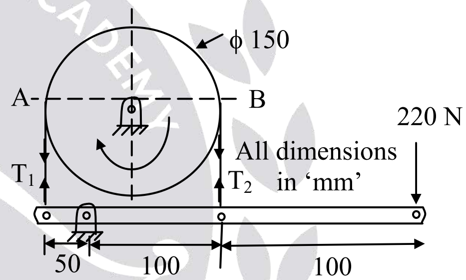
$$= \frac{4 \times 0.3 \times \sin 45^0}{\pi/2 + \sin 90^0}$$

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

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

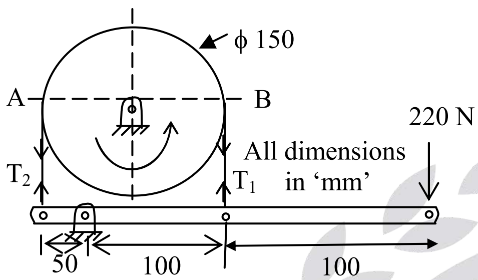
$$\frac{T_1}{T_2} = e^{\mu \times \theta}$$

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

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

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

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

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

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

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

$N_2 = 0 \rightarrow$ 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 × θ

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

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

$\Rightarrow$ 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

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

θ = 235°

09. Ans: (c)

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

$P_{max} = 126.67$ kPa

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 $C_V = 1$

$F_t = SwmyC_v$

$7.56\times10^3 = 35 \times10^6\times90\times8\times y$

$\Rightarrow$ y = 0.3

04. Ans: (a)

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

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

$P = F_t \times V$

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

05. Ans (b)

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

$V = 600\ m/min$

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

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

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

$F_t = 1\ kN$

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

$T = 50\ N\text{–}m$

06. Ans: (b)

Sol: Given $P = 20\ kW$

$N_P = 300\ rpm$

$\sigma_b = 80\ MPa$

$y = 0.094$, $C_v = 1$

$w = 14\ m$

$T_p = 18$, $m = ?$

$$F_t = \frac{P}{V} = SwmyC_v \times \pi$$

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

$(\because d_p = mT_p)$

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

$\Rightarrow m = 5.98 \approx 6$

Linked Answer Questions 07 & 08

07. Ans: (b)

08. Ans: (a)

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

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

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

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

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

$S = 210\ MPa$

$F_t = ?$, $w = ?$

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

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

$F_t = 1.46\ kN$

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

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

$\Rightarrow \quad w = 18\ mm$

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

$$\frac{T_G}{T_P} = 10:1$$

$$F_n = 200\ \frac{N}{mm}$$

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

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

$T_P = 15$

$T_G = 150$

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

$F_t = ?$

F_r on bearing = ?

$w = ?$

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

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

$F_t = 44.2$ kN

10. Ans: (c)

Sol: $F_r = F_t . \tan\phi$

$= 44.2 \tan(22.5) = 18.3$ kN

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

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

$(y_{steel})_p = 0.093$

$S_{steel}\times y_{steel} = 120\times0.093 = 11.16$

$S_{CI}\times y_{CI} = 100\times0.13 = 13$

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

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

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

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

$F_w = Kd_pwQ$

$$F_w = (1.5)(400)(100)\frac{4}{3} = 80\times10^3$$

$= 80$ kN

Chapter- 12
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, $J = \frac{\pi\left(D^4 - d^4\right)}{32}$ 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 '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: Statement (I) is false, (II) is true.

Sol:

- Surface cold rolling is the most common mechanical method for introducing compressive residual surface stresses. Thus, Statement (I) is incorrect.
- After rolling, surface roughness of the shaft is decreased. Thus, the effective contact area increases which results into more resistant capability. On the other hand for machined shaft, roughness is more. Thus, components are sensitive to stress concentration and hence fatigue strength is affected. Thus, statement (II) is correct.

13. Ans: (a)

Sol: The total bending force on the shaft carrying the sprocket is equal to the tension in the tight side of tension.

14. 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.

15. 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

16. Ans: (a)

17. 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.

18. 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.

19. 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.

Chapter- 13
Flywheels

Common Data for Solution of Q. 01 & 02

01. Ans: (b)

02. Ans: (a)

Sol: Given data,

$D = 0.5$ m, $t = 80$ mm,

$\rho = 7\times10^3$ kg/m^3

$N = 600$ rpm

$$I = \frac{mR^2}{2}$$

here, $m = \pi R^2 t\, \rho$

$= \pi\times(0.25)^2 \times 0.08 \times 7000$

$= 109.96$ kg

$$I = \frac{109.96\times(0.25)^2}{2} = 3.43 \text{ kg.m}^2$$

$$K.E = \frac{1}{2} I\omega^2$$

$$= \frac{1}{2}\times I\times\left(\frac{2\pi N}{60}\right)^2$$

$$= \frac{1}{2}\times 3.43\times\left(\frac{2\times\pi\times600}{60}\right)^2$$

$= 6782.6$ J

$= 6.78$ kJ

03. Ans: (a)

Sol: Given data,

$I = 600$ kg.m^2 ,

$N = 300$ rpm, $C_s = 0.03$

we know that, $C_e = 2\, C_s = 0.06$

$$\frac{\Delta E}{E} = 0.06$$

$$\therefore \quad \Delta E = 0.06\times\frac{1}{2}\times I\omega^2$$

$$= 0.06\times\frac{1}{2}\times600\times\left(\frac{2\pi\times300}{60}\right)^2$$

$= 17765.29$ J $= 17.765$ kJ

Common Data for Solution of Q. 04 & 05

04. Ans: (b)

05. Ans: (a)

Sol: Given data,

$T = 2000 + 950 \sin 2\theta - 570 \cos 2\theta$ N.m

$C_s = 0.02$

$N = 180$ rpm

$$T_{mean} = \frac{1}{\pi}\int_0^{\pi} T d\theta = \frac{1}{\pi}\int_0^{\pi}\left(2000 + 950\sin 2\theta - 570\cos 2\theta\right)d\theta$$

$$= \frac{1}{\pi}\left[2000\theta - 950\frac{\cos 2\theta}{2} - 570\frac{\sin 2\theta}{2}\right]_0^{\pi}$$

$$= \frac{1}{\pi}\left[\left(2000\pi - \frac{950}{2} - 0\right) - \left(0 - \frac{950}{2} - 0\right)\right]$$

$= 2000$ N.m

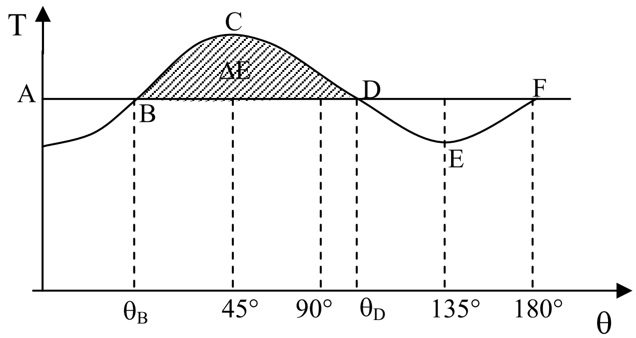
$$P = \frac{2\pi NT}{60} = \frac{2\pi\times180\times2000}{60} = 37.7 \text{ kW}$$

when, $T = T_{mean}$

$\Rightarrow 2000 + 950 \sin 2\theta - 570 \cos 2\theta = 2000$

$$\therefore \ \tan 2\theta = \frac{570}{950} = 0.6$$

$\therefore \ 2\theta = 31° \Rightarrow \theta = 15.5°$



$$\Delta E = \int_{\theta_B}^{\theta_D} (T - T_{mean})d\theta$$

$\theta_B = 15.5°$,

$\theta_D = 90° + 15.5° = 105.5°$

$$\Delta E = \int_{15.5°}^{105.5°} (2000 + 950 \sin 2\theta - 570 \cos 2\theta - 2000)\, d\theta$$

$$= \left[-950 \frac{\cos 2\theta}{2} - 570 \frac{\sin 2\theta}{2} \right]_{15.5°}^{105.5°}$$

$= 1107.8$ N.m

Also, $\Delta E = I\,\omega^2\, C_s$

$$\therefore \; 1107.8 = I \times \left(\frac{2\pi \times 180}{60} \right)^2 \times 0.02$$

$$\Rightarrow \quad I = 155.9 \text{ kg.m}^2$$

06. Ans: (c)

Sol: Given data,

$T = T_{mean} + 650 \sin 2\theta - 300 \cos 2\theta$ N.m

$I = 200$ kg.m^2,

$\theta = 45°$

$\Delta T = T - T_{mean}$

$= 650 \sin 2\theta - 300 \cos 2\theta$

$\Delta T = I\,\alpha$

$650 \sin 90° - 300 \cos 90° = 200 \times \alpha$

$\therefore \; \alpha = 3.25$ rad/s^2

Common Data for Solution of Q. 07 & 08

07. Ans: (b)

08. Ans: (d)

Sol: Given data,

$\rho = 7100$ kg/m^3 , $N = 150$ rpm,

$U = 2500$ N.m, $C_s = 0.2$,

$R = 0.5$ m , $k = 0.9$

$$U_0 = \frac{I\omega^2}{k} C_s$$

$$2500 = \frac{I \times \left(\frac{2\pi \times 150}{60} \right)^2}{0.9} \times 0.2$$

$\Rightarrow I = 45.6$ kg.m^2

Also,

$$\Rightarrow \; m = \frac{I}{R^2} = 2\pi R b t \times \rho$$

$$\Rightarrow \frac{45.6}{(0.5)^2} = 2\pi \times 0.5 \times b^2 \times 7100$$

$\Rightarrow b = t = 0.09$ m $= 90$ mm

09. Ans: (b)

Sol: Given data,

$m = 150$ kg, $N = 600$ rpm,

$\sigma = 10$ MPa, $\rho = 7260$ kg/m^2

$\sigma = \rho\, R^2\, \omega^2$

$$\therefore \; 10 \times 10^6 = 7260 \times R^2 \times \left(\frac{2\pi \times 600}{60} \right)^2$$

$\therefore \; R = 0.59$ m

$\therefore \; D = 2R = 1.18$ m