Solutions Manual to
DESIGN OF MACHINE ELEMENTS
(First Revised Edition)

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CHAPTER 1

1.1 The series factor for R10 series is given by,

$\sqrt[10]{10} = 1.2589$

First number = 1

Second number = 1 (1.2589) = 1.2589 = (1.25)

Third number = (1.2589)(1.2589) = $(1.2589)^2$ = 1.5848 = (1.6)

Fourth number = $(1.2589)^2(1.2589)$ = $(1.2589)^3$ = 1.9951 = (2)

Fifth number = $(1.2589)^3(1.2589)$ = $(1.2589)^4$ = 2.5117 = (2.5)

Sixth number = $(1.2589)^4(1.2589)$ = $(1.2589)^5$ = 3.1620 = (3.16)

Seventh number = $(1.2589)^5(1.2589)$ = $(1.2589)^6$ = 3.9806 = (4)

Eighth number = $(1.2589)^6(1.2589)$ = $(1.2589)^7$ = 5.0112 = (5)

Ninth number = $(1.2589)^7(1.2589)$ = $(1.2589)^8$ = 6.3086 = (6.3)

Tenth number = $(1.2589)^8(1.2589)$ = $(1.2589)^9$ = 7.9418 = (8)

Eleventh number = $(1.2589)^9(1.2589)$ = $(1.2589)^{10}$ = 9.9980 = (10)

In above calculations, the rounded numbers are shown in bracket.

1.2

The series factor for R20 series is given by,

$\sqrt[20]{10} = 1.122$

Since every third term of R20 series is selected, the ratio factor (ϕ) is given by,

$\phi = (1.122)^3 = 1.4125$

First number = 200

Second number = 200 (1.4125) = 282.5 = (280)

Third number = 200(1.4125)(1.4125) = $200\,(1.4125)^2$ = 399.03 = (400)

Fourth number = $200(1.4125)^2$(1.4125) = $200\,(1.4125)^3$ = 563.63 = (560)

Fifth number = $200(1.4125)^3$(1.4125) = $200\,(1.4125)^4$ = 796.13 = (800)

Sixth number = $200(1.4125)^4$(1.4125) = $200\,(1.4125)^5$ = 1124.53 = (1120)

In above calculations, the rounded numbers are shown in bracket. The complete series is given by,

200, 280(282.5), 400(399.03), 560(563.63), 800(796.13), 1120(1124.53), …

1.3

Let us denote the ratio factor as (ϕ). The derived series is based on geometric progression. The power rating of seven models will as follows,

(1) $40\ (\phi)^0$,   (2) $40\ (\phi)^1$,   (3) $40\ (\phi)^2$,   4) $40\ (\phi)^3$,

(5) $40(\phi)^4$,   (6) $40(\phi)^5$,   (7) $40(\phi)^6$

The maximum load capacity is 630 kN. Therefore,

$40\ (\phi)^6 = 630$ or $\phi = \left(\dfrac{630}{40}\right)^{1/6} = 1.5832$

Load capacity of first model = (40) kN

Load capacity of second model = $40\,(1.5832)$ = 63.33 = (63) kN

Load capacity of third model = $40\,(1.5832)^2$ = 100.26 = (100) kN

Load capacity of fourth model = $40\,(1.5832)^3$ = 158.73 = (160) kN

Load capacity of fifth model = $40\,(1.5832)^4$ = 251.31 = (250) kN

Load capacity of sixth model = $40\,(1.5832)^5$ = 397.87 = (400) kN

Load capacity of seventh model = $40\,(1.5832)^6$ = 629.90 = (630) kN

1.4

Let us denote the ratio factor as (ϕ). The derived series is based on geometric progression. The speeds of different steps will as follows,

(1) $72\,(\phi)^0$, (2) $72\,(\phi)^1$, (3) $72(\phi)^2$, (4) $72\,(\phi)^3$,

(5) $72(\phi)^4$, (6) $72(\phi)^5$, (7) $72(\phi)^6$ (8) $72(\phi)^7$

(9) $72(\phi)^8$ (10) $72(\phi)^9$ (11) $72(\phi)^{10}$

The maximum speed is 720 r.p.m. Therefore,

$$72\,(\phi)^{10} = 720 \qquad \text{or} \qquad \phi = \left(\frac{720}{72}\right)^{1/10} = (10)^{1/10} = \sqrt[10]{10} = 1.2589$$

Speed of first step = 72 r.p.m.

Speed of second step = $72(1.2589) = 90.64 = (91)$ r.p.m.

Speed of third step = $72(1.2589)^2 = 114.11 = (114)$ r.p.m.

Speed of fourth step = $72(1.2589)^3 = 143.65 = (144)$ r.p.m.

Speed of fifth step = $72(1.2589)^4 = 180.84 = (181)$ r.p.m.

Speed of sixth step = $72(1.2589)^5 = 227.66 = (228)$ r.p.m.

Speed of seventh step = $72(1.2589)^6 = 286.60 = (287)$ r.p.m.

Speed of eighth step = $72(1.2589)^7 = 360.80 = (361)$ r.p.m.

Speed of ninth step = $72(1.2589)^8 = 454.22 = (454)$ r.p.m.

Speed of tenth step = $72(1.2589)^9 = 571.81 = (572)$ r.p.m.

Speed of eleventh step = $72(1.2589)^{10} = 719.85 = (720)$ r.p.m.

CHAPTER 3

3.1 From Tables 3.2 and 3.3b, the tolerances for the small end of connecting rod and bush are as follows:

Connecting rod (inner diameter) (15H6) = $\frac{15.011}{15.000}$ mm

Bush (outer diameter) (15r5) = $\frac{15.031}{15.023}$ mm

Maximum interference = 15.031 – 15 = 0.031 mm

Minimum interference = 15.023 - 15.011 = 0.012 mm

3.2 From Tables 3.2 and 3.3a,

Limiting dimensions of valve stem (5d8) = $\frac{4.970}{4.952}$ mm

Limiting dimensions of guide for valve stem (7H7) = $\frac{5.012}{5.000}$ mm

Maximum clearance = 5.012 - 4.952 = 0.06 mm

Minimum clearance = 5 - 4.97 = 0.03 mm

From Tables 3.2 and 3.3b,

Limiting dimensions of valve seat (20s5) = $\frac{20.044}{20.035}$ mm

Limiting dimensions of housing (20H6) = $\frac{20.013}{20.000}$ mm

Maximum interference = 20.044 – 20 = 0.044mm

Minimum interference = 20.035 – 20.013 = 0.022 mm

CHAPTER 4

4.1 Rod diameter:

$$\sigma_t = \frac{S_{yt}}{(fs)} = \frac{380}{2.5} = 152 \ \ N/mm^2$$

$$P = \left(\frac{\pi}{4} D^2\right)\sigma_t \qquad \therefore D = \sqrt{\frac{4P}{\pi \sigma_t}} = \sqrt{\frac{4(25 \text{ x} 10^3)}{\pi (152)}} = 14.47 \ \ \text{mm (i)}$$

Pin diameter:

$$\tau = \frac{S_{sy}}{(fs)} = \frac{0.577 S_{yt}}{(fs)} = \frac{0.577(380)}{2.5} = 87.7 \ \ N/mm^2$$

$$P = 2\left(\frac{\pi}{4} d^2\right)\tau \qquad \therefore d = \sqrt{\frac{2P}{\pi \tau}} = \sqrt{\frac{2(25 \text{ x} 10^3)}{\pi (87.7)}} = 13.47 \ \ \text{mm} \quad \text{(ii)}$$

4.2 $\tau_{max} = \frac{S_{sy}}{(fs)} = \frac{0.5 S_{yt}}{(fs)} = \frac{0.5(310)}{2.5} = 62 \ \ N/mm^2$

A = cross sectional area of bolt

$$\sigma_t = \frac{12000}{A} \qquad \text{and} \qquad \tau = \frac{6000}{A}$$

$$\tau_{max} = \sqrt{\left(\frac{\sigma_t}{2}\right)^2 + (\tau)^2} = \sqrt{\left(\frac{12000}{2A}\right)^2 + \left(\frac{6000}{A}\right)^2}$$

$$62 = \left(\frac{6000}{A}\right)\sqrt{2} \qquad \text{or} \qquad A = \frac{6000\sqrt{2}}{62}$$

$$\frac{\pi}{4} d^2 = \frac{6000\sqrt{2}}{62} \qquad d = 13.2 \text{ mm} \qquad \text{(Ans.)}$$

4.3

The maximum force in tie-rod is denoted by P. From Fig.4.71(a),

P sin(30) x 2500 = (50x10^3) x (2000) ∴ P = 80 000 N

Diameter of rod:

$$\sigma_t = \frac{S_{yt}}{(fs)} = \frac{250}{3} = 83.3 \ \mathrm{N/mm^2}$$

$$P = \left(\frac{\pi}{4} d_r^2\right)\sigma_t \qquad \text{or} \qquad 80\ 000 = \left(\frac{\pi}{4} d_r^2\right)83.3 \qquad d_r = 34.96 \text{ mm (i)}$$

Diameter of pin:

$$\tau = \frac{S_{sy}}{(fs)} = \frac{0.5 S_{yt}}{(fs)} = \frac{0.5(250)}{3} = 41.67 \ \mathrm{N/mm^2}$$

$$P = 2\left(\frac{\pi}{4} d_p^2\right)\tau \qquad \therefore\ 80\ 000 = 2\left(\frac{\pi}{4} d_p^2\right)(41.67) \qquad d_p = 34.96 \text{ mm (ii)}$$

4.4 $$\sigma_t = \frac{S_{ut}}{(fs)} = \frac{300}{2.5} = 120 \ \mathrm{N/mm^2}$$

$$\frac{P}{A} = \frac{15000}{(t)(5t)} = \left(\frac{3000}{t^2}\right) \mathrm{N/mm^2}$$

$$\frac{P e y}{I} = \frac{15000(7.5t)(2.5t)}{\left[\frac{1}{12}(t)(5t)^3\right]} = \left(\frac{27\ 000}{t^2}\right) \mathrm{N/mm^2}$$

From Eq.(4.24),

$$\sigma_t = \frac{P}{A} + \frac{P e y}{I} \qquad \text{or} \qquad 120 = \left(\frac{3000}{t^2}\right) + \left(\frac{27\,000}{t^2}\right) = \left(\frac{30\ 000}{t^2}\right)$$

t = 15.81 mm (Ans.)

4.5 $$(\sigma_1 - \sigma_2) = 50 \ \mathrm{N/mm^2}$$

$$(\sigma_1 - \sigma_3) = 200 \ \mathrm{N/mm^2} \qquad \text{(Maximum value)}$$

$$(\sigma_2 - \sigma_3) = 150 \ \mathrm{N/mm^2}$$

Maximum shear stress theory: Eq.(4.39)

$$(\sigma_1 - \sigma_3) = \frac{S_{yt}}{(fs)} \qquad \text{or} \qquad (200) = \frac{460}{(fs)} \qquad (fs) = 2.3 \qquad \text{(i)}$$

Distortion energy theory: Eq.(4.44)

$$\frac{S_{yt}}{(fs)} = \sqrt{\left(\sigma_1^2 - \sigma_1\,\sigma_2 + \sigma_2^2\right)}$$

$$\frac{460}{(fs)} = \sqrt{(200)^2 - (200)(150) + (150)^2} \qquad (fs) = 2.55 \qquad \text{(ii)}$$

4.6 $$\left(\frac{\sigma_x + \sigma_y}{2}\right) = \left(\frac{100+40}{2}\right) = 70\ \text{N/mm}^2$$

$$\left(\frac{\sigma_x - \sigma_y}{2}\right) = \left(\frac{100-40}{2}\right) = 30\ \text{N/mm}^2$$

From Eqs. (4.31) and (4.32),

$$\sigma_1,\, \sigma_2 = \left(\frac{\sigma_x + \sigma_y}{2}\right) \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + (\tau_{xy})^2} = 70 \pm \sqrt{(30)^2 + (80)^2}$$

$$\sigma_1 = 155.44\ \text{N/mm}^2 \qquad \sigma_2 = -15.44\ \text{N/mm}^2 \qquad \sigma_3 = 0$$

From Eq.(4.34),

$$\tau_{max} = \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + (\tau_{xy})^2} = \sqrt{(30)^2 + (80)^2} = 85.44\ \text{N/mm}^2$$

Maximum normal stress theory:

$$(fs) = \frac{S_{yt}}{\sigma_1} = \frac{380}{155.44} = 2.44 \qquad \text{(i)}$$

Maximum shear stress theory:

$$(fs) = \frac{S_{sy}}{\tau_{max}} = \frac{0.5S_{yt}}{\tau_{max}} = \frac{0.5(380)}{85.44} = 2.22 \qquad \text{(ii)}$$

Distortion energy theory: Eq.(4.44)

$$\sqrt{\left(\sigma_1^2 - \sigma_1\,\sigma_2 + \sigma_2^2\right)} = \sqrt{\left[(155.44)^2 - (155.44)(-15.44) + (-15.44)^2\right]} = 163.71\ \text{N/mm}^2$$

$$(fs) = \frac{S_{yt}}{(163.71)} = \frac{380}{163.71} = 2.32 \qquad \text{(iii)}$$

4.7 Refer to Fig.4.73.

$R = 4\ d \qquad R_i = 4d - 0.5d = (3.5d)$ mm

$R_o = 4d + 0.5d = (4.5d)$ mm

$$A = \frac{\pi}{4} d^2 = (0.7854 d^2)\ mm^2$$

$$M_b = (1x10^3)(4d) = (4000 d)\ N-mm$$

From Eq.(4.60),

$$R_N = \frac{\left(\sqrt{R_o} + \sqrt{R_i}\right)^2}{4} = \frac{\left(\sqrt{(4.5d)} + \sqrt{(3.5d)}\right)^2}{4} = (3.9843 d)\ mm$$

$e = R - R_N = 4d - 3.9843d = (0.0157\ d)$ mm

$h_i = R_N - R_i = 3.9843d - 3.5d = (0.4843d)$ mm

From Eq.(4.56),

$$\sigma_{bi} = \frac{M_b\ h_i}{A\ e\ R_i} = \frac{(4000d)(0.4843d)}{(0.7854d^2)(0.0157d)(3.5d)} = \left(\frac{44\ 886.51}{d^2}\right) N/mm^2$$

Direct tensile stress:

$$\sigma_t = \frac{P}{A} = \frac{1000}{(0.7854 d^2)} = \left(\frac{1273.24}{d^2}\right) N/mm^2$$

$$\frac{S_{yt}}{(fs)} = \frac{P}{A} + \frac{M_b\ h_i}{A\ e\ R_i} \qquad \therefore\ \frac{380}{(4.5)} = \frac{1273.24}{d^2} + \frac{44\ 886.51}{d^2}$$

d = 23.38 mm (Ans.)

4.8 Refer to Fig.4.74. At section XX,

$R_i = 4\ t \qquad b_i = 4\ t \qquad h = 6\ t \qquad R = 7\ t$

$R_o = 10\ t \qquad b_o = 4\ t \qquad t_i = t_o = t$

From Eq. (4.64),

$$R_N = \frac{[t(4t-t)+t(4t-t)+t(6t)]}{\left\{4t\ \log_e\left(\frac{4t+t}{4t}\right)+t\ \log_e\left(\frac{10t-t}{4t+t}\right)+4t\ \log_e\left(\frac{10t}{10t-t}\right)\right\}} = (6.3098\ t)\ \text{mm}$$

$$e = R - R_N = (7 - 6.3098)t = (0.6902\ t)\ \text{mm}$$

$$h_i = R_N - R_i = (6.3098 - 4)t = (2.3098t)\ \text{mm}$$

$$M_b = (100x10^3)(4t+R) = (100x10^3)(4t+7t) = (11x10^5)t \quad \text{N} - \text{mm}$$

$$A = 4t^2 + 4t^2 + 4t^2 = (12t^2)\ \text{mm}^2$$

From Eq.(4.56),

$$\sigma_{bi} = \frac{M_b\ h_i}{A\ e\ R_i} = \frac{(11x10^5\ t)(2.3098t)}{(12\ t^2)(0.6902t)(4t)} = \left(\frac{9.2031x10^5}{12\ t^2}\right)\ \text{N/mm}^2$$

Direct tensile stress:

$$\sigma_t = \frac{P}{A} = \frac{100x10^3}{(12t^2)} = \left(\frac{10^5}{12t^2}\right)\ \text{N/mm}^2$$

$$\frac{S_{ut}}{(fs)} = \frac{P}{A} + \frac{M_b\ h_i}{A\ e\ R_i} \qquad \therefore\ \frac{300}{(2.5)} = \frac{10^5}{12t^2} + \frac{9.2031x10^5}{12t^2}$$

t = 26.62 mm (Ans.)

4.9 Permissible stresses: -

$$\sigma_t = \frac{S_{yt}}{(fs)} = \frac{300}{5} = 60\ \text{N/mm}^2 \qquad \tau = \frac{S_{sy}}{(fs)} = \frac{0.5\ S_{yt}}{(fs)} = \frac{0.5\,x\,300}{5} = 30\ \text{N/mm}^2$$

Refer to Fig.4.1-solu, $(7.5\,x10^3)\,x100 = P\,x\,500$ or P = 1500 N

$R = \sqrt{(7500)^2 + (1500)^2} = 7648.53$ N From Eq.(4.51),

R = p (d x l) or 7648.53 = 10 (d x 1.5 d)

$\therefore\ d = 22.58\,\text{mm} \quad \text{and} \quad l = 1.5\,d = 1.5 \times 22.58 = 33.87\ \text{mm}$ (i)

$$\tau = \frac{R}{2\left(\frac{\pi}{4}d^2\right)} = \frac{7648.53}{2\left(\frac{\pi}{4}(22.58)^2\right)} = 9.55\ \text{N/mm}^2 \qquad \text{(ii)}$$

The dimensions of the boss of lever at the fulcrum are as follows,

inner diameter = 23 mm, outer diameter = 46 mm, length = 34 mm (iii)

For the lever, $d = 4\,b$ $M_b = (\,7500 \times 100\,)$ N- mm

$$\sigma_b = \frac{M_b\,y}{I} \quad \text{or} \quad 60 = \frac{(7500 \times 100)\,(2b)}{\left[\frac{1}{12}b\,(4b)^3\right]}$$

$\therefore$ $b = 16.74$ mm $d = 4\,b = 4 \times 16.74 = 66.94$ mm (iv)

4.10 $\sigma_t = \dfrac{S_{yt}}{(fs)} = \dfrac{200}{4} = 50\ \text{N/mm}^2$

Components of force P :-

$P_v = P\cos(30) = 5000\cos(30) = 4330.13$ N

$P_h = P\sin(30) = 5000\sin(30) = 2500$ N

$M_b = P_h \times 250 + P_v \times 125 = 2500 \times 250 + 4330.13 \times 125 = 1166\,266.25$ N-mm

$$\sigma_b = \frac{M_b\,y}{I} = \frac{1166\,266.25 \times t}{\left[\frac{1}{12}t\,(2t)^3\right]} = \frac{1749.4 \times 10^3}{t^3}\ \text{N/mm}^2 \qquad \text{(i)}$$

$$\sigma_t = \frac{P_V}{A} = \frac{4330.13}{2\,t^2} = \frac{2165.07}{t^2}\ \text{N/mm}^2 \qquad \text{(ii)}$$

$$\therefore\ 50 = \frac{1749.4 \times 10^3}{t^3} + \frac{2165.07}{t^2} \quad \text{or} \quad t^3 - 43.3\,t = 34988$$

The cubic equation is solved by trial and error

t	$t^3 - 43.3\,t$
35	41 359.5
34	37 831.8
33	34 508.1

$\therefore\ t = 33.5$ mm (Ans.)

4.11 $\sigma_t = \dfrac{S_{ut}}{(fs)} = \dfrac{400}{4} = 100\ \text{N/mm}^2$ At inner fibre,

$$\sigma_t = \frac{P}{A} + \frac{M_b\,y}{I} \qquad \text{or} \qquad 100 = \frac{25\text{x}10^3}{(t\,\text{x}\,2t)} + \frac{(25\text{x}10^3\,\text{x}140)\,t}{\left[\frac{1}{12}\,t\,(2t)^3\right]}$$

$t^3 - 125\,t = 52\,500$

The cubic equation is solved by trial and error.

t	$t^3 - 125\,t$
40	59 000
39	54 444
38.5	52 254

$\therefore$ $t = 38.5$ or 40 mm (Ans.)

$b = 2\,t = 80$ mm

CHAPTER 5

5.1 At the hole of 3 mm diameter,

$$\sigma_o = \frac{P}{(w-d)\ t} = \frac{20x10^3}{(25-3)\ 15} = 60.61\ N/mm^2$$

$$\left(\frac{d}{w}\right) = \left(\frac{3}{25}\right) = 0.12 \qquad \text{From Fig.5.2,} \qquad K_t = 2.67$$

$$\sigma_{max} = K_t\ \sigma_o = 2.67(60.61) = 161.82\ N/mm^2 \qquad \text{(i)}$$

At the hole of 5 mm diameter,

$$\sigma_o = \frac{P}{(w-d)\ t} = \frac{20x10^3}{(25-5)\ 15} = 66.67\ N/mm^2$$

$$\left(\frac{d}{w}\right) = \left(\frac{5}{25}\right) = 0.2 \qquad \text{From Fig.5.2,} \qquad K_t = 2.51$$

$$\sigma_{max} = K_t\ \sigma_o = 2.51(66.67) = 167.33\ N/mm^2 \qquad \text{(ii)}$$

At the hole of 10 mm diameter,

$$\sigma_o = \frac{P}{(w-d)\ t} = \frac{20x10^3}{(25-10)\ 15} = 88.89\ N/mm^2$$

$$\left(\frac{d}{w}\right) = \left(\frac{10}{25}\right) = 0.4 \qquad \text{From Fig.5.2,} \qquad K_t = 2.25$$

$$\sigma_{max} = K_t\ \sigma_o = 2.25(88.89) = 200\ N/mm^2 \qquad \text{(iii)}$$

5.2 D = 0.25d +d +0.25 d = 1.5 d $\qquad \left(\frac{D}{d}\right) = 1.5$

From Fig.5.5, (D/d = 1.5 and K_t = 1.5)

$$\left(\frac{r}{d}\right) = 0.17 \qquad d = \frac{r}{0.17} = \frac{2}{0.17} = 11.76\ mm \qquad \text{(i)}$$

$$\sigma_b = \frac{32\ M_b}{\pi\ d^3} = \frac{32(15x10^3)}{\pi\ (11.76)^3} = 93.94\ N/mm^2$$

$$\sigma_{max} = K_t\ \sigma_o = 1.5(93.94) = 140.91\ N/mm^2 \qquad \text{(ii)}$$

$$(fs) = \frac{S_{ut}}{\sigma_{max}} = \frac{200}{140.91} = 1.42 \qquad \text{(iii)}$$

5.3 By symmetry, the reaction at each bearing is 2500 N. At fillet section,

$$M_b = 2500(25) = 62500\ N-mm$$

$$\sigma_b = \frac{32\ M_b}{\pi\ d^3} = \frac{32(62500)}{\pi\ (40)^3} = 9.947\ N/mm^2$$

$$\left(\frac{D}{d}\right) = \frac{60}{40} = 1.5 \qquad \text{and} \qquad \left(\frac{r}{d}\right) = \frac{2}{40} = 0.05$$

From Fig.5.5, $K_t = 2.05$

$$\sigma_{max} = K_t\ \sigma_o = 2.05(9.947) = 20.39\ N/mm^2 \qquad \text{(Ans.)}$$

5.4 $\sigma_{max} = \dfrac{S_{ut}}{(fs)} = \dfrac{350}{2.5} = 140\ \ N/mm^2$

$$\sigma_o = \frac{P}{d\ t} = \frac{20x10^3}{(30)(10)} = 66.67\ N/mm^2$$

$$K_t = \frac{\sigma_{max}}{\sigma_o} = \frac{140}{66.67} = 2.1 \qquad \text{and} \qquad \left(\frac{D}{d}\right) = \frac{45}{30} = 1.5$$

From Fig.5.3, (D/d = 1.5 and K_t = 2.1)

$\left(\dfrac{r}{d}\right) = 0.095$ r = 0.095 d = 0.095 (30) = 2.85 or 3 mm (Ans.)

5.5 $S_e^' = 0.5 S_{ut} = 0.5(600) = 300\ N/mm^2$

From Fig. 5.24 (Forged shaft and $S_{ut} = 600\ N/mm^2$**),** $K_a = 0.45$

For 25 mm diameter, $K_b = 0.85$

$K_f = 1 + q(K_t - 1) = 1 + 0.84(2.1 - 1) = 1.924$

$$K_d = \frac{1}{K_f} = \frac{1}{1.924} = 0.52$$

$S_e = K_a K_b K_d S_e^' = 0.45(0.85)(0.52)(300) = 59.67\ N/mm^2$

5.6 $S_e^' = 0.5 S_{ut} = 0.5(660) = 330\ N/mm^2$

From Fig. 5.24 (Machined surface and $S_{ut} = 660\ N/mm^2$**),** $K_a = 0.76$

For 40 mm diameter, $K_b = 0.85$

For 99% reliability, $K_c = 0.814$

$K_f = 1 + q(K_t - 1) = 1 + 0.90(1.6 - 1) = 1.54$

$$K_d = \frac{1}{K_f} = \frac{1}{1.54} = 0.649$$

$S_e = K_a K_b K_c K_d S_e^' = 0.76(0.85)(0.814)(0.649)(330) = 112.62\ N/mm^2$

5.7 $S_e^' = 0.5 S_{ut} = 0.5(540) = 270\ N/mm^2$

From Fig. 5.24 (Machined surface and $S_{ut} = 540\ N/mm^2$**),** $K_a = 0.78$

Assuming (7.5< d <50 mm), $K_b = 0.85$

$\left(\frac{D}{d}\right) = 1.5$ and $\left(\frac{r}{d}\right) = 0.1$

From Fig.5.5, $K_t = 1.72$

$$K_f = 1 + q(K_t - 1) = 1 + 0.9(1.72 - 1) = 1.648$$

$$K_d = \frac{1}{K_f} = \frac{1}{1.648} = 0.61$$

$$S_e = K_a K_b K_d S_e^{'} = 0.78(0.85)(0.61)(270) = 109.20 \text{ N/mm}^2$$

$$\sigma_b = \frac{S_e}{(fs)} = \frac{109.20}{2} = 54.6 \text{ N/mm}^2$$

$$\sigma_b = \frac{32 M_b}{\pi d^3} \quad \text{or} \quad 54.6 = \frac{32(5x10^3)(100)}{\pi d^3} \qquad d = 45.35 \text{ mm} \qquad \text{(Ans.)}$$

5.8 $S_e^{'} = 0.5 S_{ut} = 0.5(620) = 310 \text{ N/mm}^2$

From Fig. 5.24 (Ground surface), $K_a = 0.89$

Assuming (7.5< d <50 mm), $K_b = 0.85$

For 90% reliability, $K_c = 0.897$

$$S_e = K_a K_b K_c S_e^{'} = 0.89(0.85)(0.897)(310) = 210.36 \text{ N/mm}^2$$

$$S_{se} = 0.577 S_e = 0.577(210.36) = 121.38 \text{ N/mm}^2$$

$$\tau_a = \frac{S_{se}}{(fs)} = \frac{121.38}{2} = 60.69 \text{ N/mm}^2$$

$$(M_t)_{max} = 400 \text{ N} - \text{m} \qquad (M_t)_{min} = -200 \text{ N} - \text{m}$$

$$(M_t)_a = \frac{1}{2}\left[(M_t)_{max} - (M_t)_{min}\right] = \frac{1}{2}\left[(400) - (-200)\right] = 300 \text{ N} - \text{m}$$

$$\tau_a = \frac{16 (M_t)_a}{\pi d^3} \quad \text{or} \quad 60.69 = \frac{16(300x10^3)}{\pi d^3} \qquad d = 29.31 \text{ mm (Ans.)}$$

5.9 $\tau_{xym} = \dfrac{35+0}{2} = 17.5 \text{ N/mm}^2$ $\tau_{xya} = \dfrac{35-0}{2} = 17.5 \text{ N/mm}^2$

$\sigma_{xm} = \dfrac{30+(-15)}{2} = 7.5 \text{ N/mm}^2$ $\sigma_{xa} = \dfrac{30-(-15)}{2} = 22.5 \text{ N/mm}^2$

From Eqs. (5.50) and (5.51),

$$\sigma_m = \sqrt{(\sigma_{xm})^2 + 3(\tau_{xym})^2} = \sqrt{(7.5)^2 + 3(17.5)^2} = 31.22 \text{ N/mm}^2$$

$$\sigma_a = \sqrt{(\sigma_{xa})^2 + 3(\tau_{xya})^2} = \sqrt{(22.5)^2 + 3(17.5)^2} = 37.75 \text{ N/mm}^2$$

$\tan\theta = \dfrac{\sigma_a}{\sigma_m} = \dfrac{37.75}{31.22} = 1.2$ or $\theta = 50.4^0$

The modified Goodman diagram is shown in Fig.5.1-solu.

X is the point of intersection of following two lines,

$\dfrac{S_m}{540} + \dfrac{S_a}{200} = 1$ and $\dfrac{S_a}{S_m} = 1.2$

$\therefore$ $S_a = 152.83 \text{ N/mm}^2$ and $S_m = 127.36 \text{ N/mm}^2$

$(fs) = \dfrac{S_a}{\sigma_a} = \dfrac{152.83}{37.75} = 4.05$ (Ans.)

5.10 $\tau_{xym} = 70 \text{ N/mm}^2$ $\tau_{xya} = 35 \text{ N/mm}^2$

$\sigma_{xm} = 60 \text{ N/mm}^2$ $\sigma_{xa} = 80 \text{ N/mm}^2$

From Eqs. (5.50) and (5.51),

$$\sigma_m = \sqrt{(\sigma_{xm})^2 + 3(\tau_{xym})^2} = \sqrt{(60)^2 + 3(70)^2} = 135.28 \text{ N/mm}^2$$

$$\sigma_a = \sqrt{(\sigma_{xa})^2 + 3(\tau_{xya})^2} = \sqrt{(80)^2 + 3(35)^2} = 100.37 \text{ N/mm}^2$$

$\tan\theta = \dfrac{\sigma_a}{\sigma_m} = \dfrac{100.37}{135.28} = 0.742$ or $\theta = 36.57^0$

The modified Goodman diagram is similar to Fig.5.1-solu.

X is the point of intersection of following two lines,

$$\frac{S_m}{700} + \frac{S_a}{220} = 1 \qquad \text{and} \qquad \frac{S_a}{S_m} = 0.742$$

$$\therefore \qquad S_a = 154.54 \ N/mm^2 \ \text{and} \qquad S_m = 208.28 \ N/mm^2$$

$$(fs) = \frac{S_a}{\sigma_a} = \frac{154.54}{100.37} = 1.54 \qquad \text{(Ans.)}$$

CHAPTER 6

6.1 l = 2p = 2 x 6 = 12 mm

d_m = d – 0.5p = 30 – 0.5 x 6 = 27 mm

$$\tan\alpha = \frac{l}{\pi d_m} = \frac{12}{\pi(27)} = 0.1415 \quad \text{or} \quad \alpha = 8.052^0$$

$$\tan\phi = \mu = 0.1 \qquad \text{or} \quad \phi = 5.711^0$$

For square threads, Eq.(6.10)

$$\eta = \frac{\tan\alpha}{\tan(\phi + \alpha)} = \frac{0.1415}{\tan(5.711 + 8.052)} = 0.5776 \quad \text{or} \quad \eta = 57.76\ \% \qquad (\text{ i })$$

For Acme threads,

$$\mu \sec\theta = \frac{\mu}{\cos\theta} = \frac{0.1}{\cos(14.5)} = 0.10329$$

From Eq. (6.16),

$$\eta = \frac{\tan\alpha\ (1 - \mu \sec\theta \tan\alpha)}{(\mu \sec\theta + \tan\alpha)} = \frac{0.1415\ (1 - 0.10329 \text{ x } 0.1415)}{(0.10329 + 0.1415)} = 0.5696$$

$$\therefore \eta = 56.96\% \qquad (\text{ ii })$$

6.2 l = p = 6 mm $\qquad$ d_m = d – 0.5p = 36 – 0.5 x 6 = 33 mm

$$\tan\alpha = \frac{l}{\pi d_m} = \frac{6}{\pi(33)} \quad \text{or} \quad \alpha = 3.312^0$$

$$\tan\phi = \mu = 0.15 \qquad \text{or} \quad \phi = 8.531^0$$

$$M_t = \frac{W\ d_m}{2} \tan(\phi + \alpha) = \frac{(10 \text{x} 10^3)(33)}{2} \tan(8.531 + 3.312) = 34\ 599.55 \text{ N-mm}$$

$$(M_t)_c = \frac{\mu_c\ W\ (D_o + D_i)}{4} = \frac{(0.2)\ (10 \text{x} 10^3)\ (50 + 30)}{4} = 40\ 000 \text{ N-mm}$$

$$(M_t)_t = 34\ 599.55 + 40\ 000 = 74\ 599.55 \text{ N-mm} \quad \text{or} \quad 74.6 \text{ N – m} \qquad (\text{ i })$$

$$\eta_o = \frac{W\ l}{2\pi\ (M_t)_t} = \frac{(10 \text{x} 10^3)\ (6)}{2\ \pi\ (74\ 599.55)} = 0.128 \quad \text{or} \quad 12.8\ \% \qquad (\text{ ii })$$

6.3 $l = 2p = 2 \text{ x } 9 = 18$ mm

$d_m = d - 0.5p = 60 - 0.5 \text{ x } 9 = 55.5$ mm

$$\tan\alpha = \frac{l}{\pi d_m} = \frac{18}{\pi(55.5)} = 0.1032 \quad \text{or} \quad \alpha = 5.894^0$$

$$\theta = 14.5^0 \qquad \mu\sec\theta = \frac{0.15}{\cos(14.5)} = 0.1549$$

Raising load : From Eq.(6.13),

$$M_t = \frac{W\,d_m}{2} \text{ x } \frac{(\mu\sec\theta + \tan\alpha)}{(1 - \mu\sec\theta\tan\alpha)}$$

$$= \frac{(5 \text{x} 10^3)(55.5)}{2} \text{ x } \frac{(0.1549 + 0.1032)}{(1 - 0.1549 \text{ x } 0.1032)}$$

= 36 393.14 N-mm or 36.39 N-m (i)

Lowering load : From Eq.(6.15),

$$M_t = \frac{W\,d_m}{2} \text{ x } \frac{(\mu\sec\theta - \tan\alpha)}{(1 + \mu\sec\theta\tan\alpha)}$$

$$= \frac{(5 \text{x} 10^3)(55.5)}{2} \text{ x } \frac{(0.1549 - 0.1032)}{(1 + 0.1549 \text{ x } 0.1032)}$$

= 7060.51 N-mm or 7.06 N-m (ii)

From Eq.(6.16),

$$\eta = \frac{\tan\alpha\,(1 - \mu\sec\theta\tan\alpha)}{(\mu\sec\theta + \tan\alpha)} = \frac{0.1032\,(1 - 0.1549 \text{ x } 0.1032)}{(0.1549 + 0.1032)} = 0.3935$$

$\therefore \eta = 39.35\%$ (iii)

6.4 $d_c = d - p = 60 - 9 = 51$mm From Eq.(6.23),

$$z = \frac{4\,W}{\pi\,S_b\,(d^2 - d_c^2)} = \frac{4\,(50 \text{x} 10^3)}{\pi\,(10)\,(60^2 - 51^2)} = 6.37 \text{ or } 7 \text{ threads}$$

length of nut = 7 x 9 = 63 mm (i)

t = p/2 = 9/2 = 4.5 mm From Eq.(6.22),

$$\tau_n = \frac{W}{\pi\ d\ t\ z} = \frac{50\,x\,10^3}{\pi\ (60)(4.5)(7)} = 8.42\ N/mm^2 \qquad \text{(ii)}$$

6.5 l = 3p = 3 x 8 = 24 mm

d_m = d – 0.5p = 50 – 0.5 x 8 = 46 mm

$$\tan\alpha = \frac{l}{\pi d_m} = \frac{24}{\pi(46)} = 0.166 \quad \text{or} \quad \alpha = 9.429^0$$

$$\tan\phi = \mu = 0.12 \qquad \text{or} \quad \phi = 6.843^0$$

$\alpha > \phi$ The screw is not self locking.

$$M_t = \frac{W\ d_m}{2}\tan(\phi+\alpha) = \frac{(7500)(46)}{2}\tan(6.843 + 9.429) = 50\ 351.04\ \text{N-mm}$$

$$d_c = d - p = 50 - 8 = 42\,mm$$

$$\sigma_c = \frac{W}{\left(\frac{\pi}{4}\,d_c^2\right)} = \frac{7500}{\left(\frac{\pi}{4}\,(42)^2\right)} = 5.41\ N/mm^2$$

$$\tau = \frac{16\ (M_t)_t}{\pi\ d_c^3} = \frac{16\ (50\ 351.04)}{\pi\ (42)^3} = 3.46\,N/mm^2$$

$$\tau_{max} = \sqrt{\left(\frac{\sigma_c}{2}\right)^2 + \tau^2} = \sqrt{\left(\frac{5.41}{2}\right)^2 + (3.46)^2} = 4.39\,N/mm^2 \qquad (\ i\ )$$

$$z = \frac{48}{8} = 6\ \text{threads} \qquad t = p/2 = 8/2 = 4\ mm$$

From Eqs.(6.21) to (6.23),

$$\tau_s = \frac{W}{\pi d_c\,t\,z} = \frac{7500}{\pi(42)(4)(6)} = 2.37\,N/mm^2$$

$$\tau_n = \frac{W}{\pi\,d\,t\,z} = \frac{7500}{\pi(50)(4)(6)} = 1.99\,N/mm^2 \qquad (\ ii\ )$$

$$S_b = \frac{4\ W}{\pi\ z\ (d^2 - d_c^2)} = \frac{4\ (7500)}{\pi\ (6)\ (50^2 - 42^2)} = 2.16\ N/mm^2 \qquad (\ iii\ )$$

6.7 $d_m = d - 0.5p = 20 - 0.5 \times 5 = 17.5$ mm

$$\tan\alpha = \frac{l}{\pi d_m} = \frac{5}{\pi(17.5)} = 0.0909 \quad \text{or} \quad \alpha = 5.197^0$$

$$\tan\phi = \mu = 0.15 \quad \text{or} \quad \phi = 8.531^0$$

$$M_t = \frac{W\,d_m}{2}\tan(\phi+\alpha) = \frac{W\,(17.5)}{2}\tan(8.531+5.197) = 2.1376W \ \ N-mm$$

$$(M_t)_c = \frac{\mu_c\ W\,(D_O + D_i)}{4} = \mu_c\,W\,r_m = 0.15\,W\,(8) = 1.2\,W \quad N-mm$$

$$(M_t)_t = M_t + (M_t)_c = (2.1376+1.2)\,W = 3.3376\ W$$

$$\therefore\ 3.3376\,W = 50 \times 150 \quad \text{or} \quad W = 2247.12\ N$$

CHAPTER 7

7.1 $\sigma_t = \frac{S_{yt}}{(fs)} = \frac{400}{5} = 80\,N/mm^2$

$\sigma_t = \frac{P}{\left(\frac{\pi}{4}d_c^2\right)}$ or $80 = \frac{(7.5 x 10^3)}{\left(\frac{\pi}{4}d_c^2\right)}$ $\therefore d_c = 10.93$ mm

$d = \frac{d_c}{0.8} = \frac{10.93}{0.8} = 13.66\,mm$ or 14 mm (Ans.)

7.2 $P = \frac{\pi}{4}D^2 p = \frac{\pi}{4}(250)^2(1.5) = 73631.08$ N Also,

$P = \frac{\pi}{4}d_c^2\,n\,\sigma_t$ or $73631.08 = \frac{\pi}{4}d_c^2\ (12)(30)$

$\therefore d_c = 16.14$ mm

$d = \frac{d_c}{0.84} = \frac{16.14}{0.84} = 19.21\,mm$ or 20 mm (i)

$t = \frac{\pi d}{n} = \frac{\pi(400)}{12} = 104.72$ mm (ii)

5 d = 5(20) = 100 mm

10 d = 10(20) = 200 mm $\therefore 5d < t < 10d$ (o.k.)

7.3 $\tau = \frac{S_{sy}}{(fs)} = \frac{0.5(380)}{2} = 95\ N/mm^2$ Refer to Fig.7.1-solu.

$P_1' = P_2' = P_3' = P_4' = \frac{3000}{4} = 750$ N

e = 200 + 50 = 250 N

$$r_1 = r_2 = r_3 = r_4 = \sqrt{50^2 + 50^2} = 70.71 \text{ mm}$$

$$P_1^{''} = \frac{(P\,e)\,r_1}{4r^2} = \frac{3000 \text{ x } 250 \text{ x } 70.71}{4 \text{ x } 70.71^2} = 2651.68 \text{ N}$$

Force on bolt 2 or 4 is maximum. As shown in Fig.7.1-solu, the angle between vectors $P_2^{'}$ and $P_2^{''}$ is 45^0

$$P_2 = \sqrt{(P_2^{'} + P_2^{''}\cos 45)^2 + (P_2^{''}\sin 45)^2}$$

$$= \sqrt{\left[(750 + 2651.68 \cos 45)^2 + (2651.68 \sin 45)^2\right]}$$

$$= 3225.9 \text{ N}$$

$$d = \sqrt{\frac{4(3225.9)}{\pi\,(95)}} = 6.58 \text{ mm} \qquad \text{(Ans.)}$$

7.4 $\tau = \dfrac{S_{sy}}{(fs)} = \dfrac{0.5(400)}{3} = 66.67 \text{ N/mm}^2$ Refer to Fig.7.2-solu.

$$P_1^{'} = P_2^{'} = P_3^{'} = \frac{P}{3} = \frac{5000}{3} = 1666.67 \text{ N} \qquad e = 250 \text{ mm}$$

$$P_1^{''} = P_3^{''} = \frac{(P \text{ x } e)\ r_1}{(r_1^2 + r_3^2)} = \frac{(5000 \text{ x } 250)(75)}{(75^2 + 75^2)} = 8333.33 \text{ N}$$

As shown in Fig.7.2-solu, the vectors $P_1^{'}$ and $P_1^{''}$ are perpendicular to each other.

$$P_1 = P_3 = \sqrt{(8333.33)^2 + (1666.67)^2} = 8498.36 \text{ N}$$

$$d = \sqrt{\frac{4P_1}{\pi\,\tau}} = \sqrt{\frac{4(8498.36)}{\pi\,(66.67)}} = 12.74 \text{ mm} \qquad \text{(Ans.)}$$

7.5 Two bolts at A are denoted by 1 and two bolts at B by 2.

$$P_1^{'} = P_2^{'} = \frac{P}{4} = \frac{5000}{4} = 1250\,\mathrm{N}$$

$$\tau = \frac{P_1^{'}}{A} = \left(\frac{1250}{A}\right)\ \mathrm{N/mm} \qquad (\,i\,) \qquad \text{From Eq.(7.10),}$$

$$P_1^{''} = \frac{P\,e\,l_1}{2(l_1^2 + l_2^2)} = \frac{5000(250)(375)}{2(375^2 + 75^2)} = 1602.56\,\mathrm{N}$$

$$\sigma_t = \frac{P_1^{''}}{A} = \left(\frac{1602.56}{A}\right)\ \mathrm{N/mm} \quad (\,ii\,)$$

$$\sigma_{max} = \frac{\sigma_t}{2} + \sqrt{\left(\frac{\sigma_t}{2}\right)^2 + \tau^2} = \left(\frac{1602.56}{2A}\right) + \sqrt{\left(\frac{1602.56}{2A}\right)^2 + \left(\frac{1250}{A}\right)^2}$$

$$= \frac{2286.05}{A} \qquad \therefore \frac{2286.05}{A} = \frac{S_{yt}}{(fs)} = \frac{380}{5} \qquad \therefore A = 30.08\ \mathrm{mm}^2$$

$$\frac{\pi}{4} d_c^2 = 30.08 \qquad d_c = 6.19\ \mathrm{mm}$$

$$d = \frac{d_c}{0.8} = \frac{6.19}{0.8} = 7.74\,\mathrm{mm}\ \text{ or }\ 8\ \mathrm{mm} \qquad \text{(Ans.)}$$

7.6 Two bolts at A are denoted by 1 and two bolts at B by 2. The direct tensile force in each bolt is given by,

$$P_1^{'} = P_2^{'} = \frac{P}{4} = \frac{10\,000}{4} = 2500\,\mathrm{N} \qquad \text{From Eq.(7.10),}$$

$$P_1^{''} = \frac{P\,e\,l_1}{2(l_1^2 + l_2^2)} = \frac{10\,000(550)(325)}{2(325^2 + 75^2)} = 8033.71\,\mathrm{N}$$

$$P_2 = P_1^{'} + P_1^{''} = 2500 + 8033.71 = 10\,533.71\,\mathrm{mm}$$

$$\sigma_t = \frac{S_{yt}}{(fs)} = \frac{400}{6} = 66.67 \text{ N/mm}^2$$ Also,

$$\sigma_t = \frac{P_2}{\left(\frac{\pi}{4} d_c^2\right)} \qquad 66.67 = \frac{10\ 533.71}{\left(\frac{\pi}{4} d_c^2\right)} \qquad d_c = 14.18 \text{ mm}$$

$$d = \frac{d_c}{0.8} = \frac{14.18}{0.8} = 17.73 \text{ or } 18 \text{ mm}$$ (Ans.)

7.7 Two bolts at A are denoted by 1 and two bolts at B by 2.

$$P_2 = \frac{P l l_2}{2(l_1^2 + l_2^2)} = \frac{10000(300)(225)}{2(75^2 + 225^2)} = 6000 \text{ N}$$

$$\sigma_t = \frac{S_{yt}}{(fs)} = \frac{400}{5} = 80 \text{ N/mm}^2$$ Also,

$$\sigma_t = \frac{P_2}{\left(\frac{\pi}{4} d_c^2\right)} \qquad 80 = \frac{6000}{\left(\frac{\pi}{4} d_c^2\right)} \qquad d_c = 9.77 \text{ mm}$$

$$d = \frac{d_c}{0.8} = \frac{9.77}{0.8} = 12.22 \text{ or } 13 \text{ mm}$$ (Ans.)

7.8 $$\sigma_t = \frac{S_{yt}}{(fs)} = \frac{380}{5} = 76 \text{ N/mm}^2$$

$$a = \frac{750}{2} = 375 \text{ mm} \qquad b = \frac{600}{2} = 300 \text{ mm}$$

$l = r - a = 750 - 375 = 375$ mm From Eq.(7.18),

$$P_1 = \frac{2 P l \left[a + b \cos\left(\frac{180}{n}\right)\right]}{4\left[2a^2 + b^2\right]}$$ Therefore,

$$P_1 = \frac{2\,(50 \times 10^3)(375)\left[\;375 + 300\cos\left(\frac{180}{4}\right)\right]}{4\left[2 \times 375^2 + 300^2\right]} = 14826.57 \text{ N}$$

$$\sigma_t = \frac{P_1}{\left(\frac{\pi}{4}\, d_c^2\right)} \qquad 76 = \frac{14826.57}{\left(\frac{\pi}{4}\, d_c^2\right)} \qquad d_c = 15.76 \text{ mm}$$

$$d = \frac{d_c}{0.8} = \frac{15.76}{0.8} = 19.7 \text{ or } 20\,\text{mm} \qquad (\,i\,)$$

From Eq.(7.16),

$$P_1 = \frac{2\,P\,l\,[\,a + b\,]}{4\left[2\,a^2 + b^2\right]} = \frac{2\,(50 \times 10^3)(375)(375+300)}{4(2 \times 375^2 + 300^2)} = 17045.45 \text{ N}$$

$$\sigma_t = \frac{P_1}{\left(\frac{\pi}{4}\, d_c^2\right)} \qquad 76 = \frac{17045.45}{\left(\frac{\pi}{4}\, d_c^2\right)} \qquad d_c = 16.9 \text{ mm}$$

$$d = \frac{d_c}{0.8} = \frac{16.9}{0.8} = 21.12 \text{ or } 22\,\text{mm} \qquad (\,ii\,)$$

7.9 It can be proved that the maximum principal stress (σ_{max}) in the tie rods is 1.207 times of direct tensile stress (σ_t).

$$\sigma_{max} = 1.207\ \sigma_t = \frac{1.207\,P}{\left(\frac{\pi}{4}\, d_c^2\right)} \qquad \therefore \frac{380}{5} = \frac{1.207\ (4500)}{\left(\frac{\pi}{4}\, d_c^2\right)}$$

$$d_c = 9.54 \text{ mm} \qquad d = \frac{d_c}{0.8} = \frac{9.54}{0.8} = 11.92\,\text{mm} \qquad \text{(Ans.)}$$

7.10 $k_c' = 2k_b'$ From Eqs. (7.23) and (7.24),

$$\Delta P = P\left[\frac{k_b'}{k_b' + k_c'}\right] = P\left[\frac{k_b'}{k_b' + 2k_b'}\right] = \frac{P}{3} = \left(\frac{7.5x10^3}{3}\right) N$$

$$P_b = P_i + \Delta P = 10\ 000 + \frac{7500}{3} = 12\ 500\ N$$

$$A = \frac{P_b\ (fs)}{S_{yt}} = \frac{12\ 500(3)}{400} = 93.75\ mm^2$$ (Ans.)

From Table7.1, the standard size of bolt is M16.

7.11 $S_e' = 0.5S_{ut} = 0.5(630) = 315\,N/mm^2$

For 50% reliability, $K_c = 1$

$$K_d = \frac{1}{K_f} = \frac{1}{3}$$

$$S_e = K_c\,K_d\,S_e' = 1(1/3)(315) = 105\ N/mm^2$$

$k_c' = 3k_b'$ From Eqs. (7.23) and (7.24),

$$\Delta P = P\left[\frac{k_b'}{k_b' + k_c'}\right] = P\left[\frac{k_b'}{k_b' + 3k_b'}\right] = \frac{P}{4} = o.25P$$

$$P_b = P_i + \Delta P = P_i + 0.25\ P$$

$$(P_b)_{max} = P_i + 0.25\ P = 4500 + 0.25(5000) = 5750\ N$$

$$(P_b)_{min} = P_i + 0.25\ P = 4500 + 0.25(0) = 4500\ N$$

$$(P_b)_m = \frac{1}{2}[5750 + 4500] = 5125\ N$$

$$(P_b)_a = \frac{1}{2}[5750 - 4500] = 625\ N$$ From Eq.(7.30),

$$S_a = \frac{S_{ut} - (P_i / A)}{1 + (S_{ut} / S_e)} = \frac{630 - (4500/36.6)}{1 + (630/105)} = 72.44 \ \mathrm{N/mm^2}$$

$$\frac{S_a}{(fs)} = \frac{(P_b)_a}{A} \qquad \text{or} \qquad \frac{72.44}{(fs)} = \frac{625}{36.6}$$

$$(fs) = 4.24 \qquad \text{(Ans.)}$$

CHAPTER 8

8.1 From Eq.(8.7),

$P = 1.414\ h\,l\,\tau \qquad \therefore\ 35 x 10^3 = 1.414(10)\,l(75)$ or $l = 33$ mm

Adding 15 mm length for starting and stopping of the weld run,

$l = 33 + 15 = 48$ mm (Ans.)

8.2 $P = w\,t\,\sigma_t = 80(10)(100) = 80\,000\ N$ (i)

The strength of the transverse fillet weld is denoted by P_1.

From Eq.(8.9),

$P_1 = 0.707\ h\,l\,\sigma_t = 0.707(10)(80)(100) = 56\,560\ N$ (ii)

The strength of double parallel fillet weld is denoted by P_2.

$P_2 = 1.414\,h\,l\,\tau = 1.414(10)\ l\ (70) = (989.8)\,l \quad N$ (iii)

The strength of the welded joint is equal to the strength of the plate.

$80\,000 = 56\,560 + (989.8)\,l$ or $l = 23.68$ mm (Ans.)

8.3 $l_1 + l_2 = \dfrac{120 x 10^3}{1 x 10^3} = 120\,mm$ (i)

The resisting forces at welds l_1 and l_2 are denoted by P_1 and P_2 respectively.

$P_1 x 100 = P_2 x 50$ or $(1000 x l_1) x 100 = (1000 x l_2) x 50$

$\therefore 2l_1 = l_2$ (ii)

From (i) and (ii), $l_1 = 40\,\text{mm}$ and $l_2 = 80$ mm (Ans.)

8.4 $A = 2(50\ t) = 100\ t\ \ \text{mm}^2$

$$\tau_1 = \frac{P}{A} = \frac{10\,000}{100\,t} = \left(\frac{100}{t}\right)\ \text{N/mm}^2$$

e = 150 + 25=175 mm

$$M = P\,x\,e = 10\,000\,x\,175 = 175\,x\,10^4\ \ \text{N} - \text{mm}$$

Refer to Fig.8.1-solu.

r = distance of farthest point = $\sqrt{25^2 + 25^2} = 35.36\,\text{mm}$

From Eq.(8.25),

$$J_1 = J_2 = A_1\left(\frac{l_1^2}{12} + r_1^2\right) = 50\,t\left(\frac{50^2}{12} + 25^2\right) = 41667\,t\ \ \text{mm}^4$$

$$J = J_1 + J_2 = 2\ J_1 = 83333\,t\ \text{mm}^4$$

$$\tau_2 = \frac{M\ r}{J} = \frac{(175\,x\,10^4)(35.36)}{(83\,333)\,t} = \left(\frac{742.56}{t}\right)\text{N/mm}^2$$

$$\tau_{max} = \sqrt{\left(\frac{742.56}{t}\cos 45 + \frac{100}{t}\right)^2 + \left(\frac{742.56}{t}\sin 45\right)^2} = \frac{816.34}{t}\ \ \text{N/mm}^2$$

$\dfrac{816.34}{t} = 95$ t = 8.59 mm (Ans.)

8.5 There are two horizontal welds W_1 and W_2 and one vertical weld W_3.

From Fig.8.2-solu, $\bar{y} = 100$ mm Taking moment about vertical weld and treating the weld as line,

$(100 + 200 + 100)\ \bar{x} = 100 \text{ x } 50 + 100 \text{ x } 50 + 200 \text{ x } 0$ $\bar{x} = 25$ mm

The areas of welds are as follows,

$A_1 = 100$ t $\qquad A_2 = 100$ t $\qquad A_3 = 200$t

$A = A_1 + A_2 + A_3 = (400\ t)\quad mm^2$

$$\tau_1 = \frac{P}{A} = \frac{50\,000}{400\,t} = \left(\frac{125}{t}\right)\ N/mm^2 \qquad (\ i\ )$$

A is the farthest point from the centre of gravity G. Its distance r is given by,

$$r = \sqrt{100^2 + (100-25)^2} = 125\ mm \qquad \text{Also} \quad \tan\,\theta = \frac{100}{75}$$

$$\therefore \theta = 53.13^0 \qquad \phi = 90 - \theta = 90 - 53.13 = 36.87^0$$

The secondary shear stress τ_2 is inclined at 36.87^0 with horizontal.

$e = (\ 100 - \bar{x}\ ) + 200 = (\ 10 - 25\ ) + 200 = 275$ mm

$$\overline{GG_1} = \overline{GG_2} = \sqrt{25^2 + 100^2} = 103.08\ mm \quad \text{or} \quad r_1 = r_2 = 103.08mm$$

$$r_3 = \overline{GG_3} = \bar{x} = 25\ mm$$

$$J_1 = J_2 = A_1\left(\frac{l_1^2}{12} + r_1^2\right) = 100\,t\left(\frac{100^2}{12} + 103.08^2\right) = 1145881.97\ t\quad mm^4$$

$$J_3 = A_3\left(\frac{l_3^2}{12} + r_3^2\right) = 200\,t\left(\frac{200^2}{12} + 25^2\right) = 791666.67\ t\quad mm^4$$

$J = 2\,J_1 + J_3 = (\ 3\ 083\ 430.61)\ t\quad mm^4$

$$\tau_2 = \frac{M\ r}{J} = \frac{(50\,000)(275)(125)}{(3\ 083\ 430.61)\,t} = \left(\frac{557.41}{t}\right)\quad N/mm^2 \qquad (ii)$$

Refer to Fig.8.3-solu,

Vertical component of τ_2 =

$$= \tau_2 \sin\phi = \left(\frac{557.41}{t}\right)\sin(36.87) = \frac{334.45}{t}\ \text{N/mm}^2$$

Horizontal component of τ_2 =

$$= \tau_2 \cos\phi = \left(\frac{557.41}{t}\right)\cos(36.87) = \frac{445.93}{t}\ \text{N/mm}^2$$

Resultant shear stress –

$$\tau = \sqrt{\left(\frac{445.93}{t}\right)^2 + \left(\frac{334.45}{t} + \frac{125}{t}\right)^2} = \left(\frac{640.27}{t}\right)\ \text{N/mm}^2$$

$$\frac{640.27}{t} = 70 \qquad t = 9.15\ \text{mm}$$

$$h = \frac{t}{0.707} = \frac{9.15}{0.707} = 12.94\,\text{mm} \qquad \text{(Ans.)}$$

8.6 A = 2 (50 t) = (100 t) mm^2

$$\tau_1 = \frac{P}{A} = \frac{2500}{100\,t} = \left(\frac{25}{t}\right)\ \text{N/mm}^2$$

$$I = 2\left(\frac{t\,(50)^3}{12}\right) = (20833.33\,t)\ \text{mm}^4$$

$$\sigma_b = \frac{M_b\, y}{I} = \frac{(2500 \times 150)(25)}{20833.33\,t} = \left(\frac{450}{t}\right)\ \text{N/mm}^2$$

$$\tau = \sqrt{\left(\frac{\sigma_b}{2}\right)^2 + \tau_1^2} = \sqrt{\left(\frac{450}{2\,t}\right)^2 + \left(\frac{25}{t}\right)^2} = \frac{226.38}{t}\ \text{N/mm}^2$$

$$\frac{226.38}{t} = 50 \qquad t = 4.53\ \text{mm}$$

$$h = \frac{t}{0.707} = \frac{4.53}{0.707} = 6.4\,\text{mm}$$ (Ans.)

8.7 From Eq.(8.32),

$$\tau = \frac{M_t}{2\pi\, t\, r^2} \qquad \therefore 70 = \frac{3000 \text{ x } 10^3}{2\pi\, t\,(37.5)^2} \qquad t = 4.85 \text{ mm}$$

$$h = \frac{t}{0.707} = \frac{4.85}{0.707} = 6.86\,\text{mm}$$ (Ans.)

8.8 $\tau_1 = \frac{P}{A} = \frac{P}{\pi d\, t} = \frac{5000}{\pi(25)t} = \frac{63.66}{t} \quad \text{N/mm}^2$

$$I_{xx} = \pi\, t\, r^3 = \pi\, t\,(12.5)^3 \text{ mm}^4$$

$$\sigma_b = \frac{M_b\, y}{I} = \frac{(5000 \text{ x } 100)(12.5)}{\pi\, t\,(12.5)^3} = \left(\frac{1018.59}{t}\right) \text{N/mm}^2$$

$$\tau = \sqrt{\left(\frac{\sigma_b}{2}\right)^2 + \tau_1^2} = \sqrt{\left(\frac{1018.59}{2t}\right)^2 + \left(\frac{63.66}{t}\right)^2} = \frac{513.26}{t} \text{ N/mm}^2$$

$$\frac{513.26}{t} = 95 \qquad t = 5.4 \text{ mm}$$

$$h = \frac{t}{0.707} = \frac{5.4}{0.707} = 7.64\,\text{mm}$$ (Ans.)

CHAPTER 9

9.7 $$\tau = \frac{S_{sy}}{(fs)} = \frac{0.5S_{yt}}{(fs)} = \frac{0.5(380)}{4} = 47.5 \ N/mm^2$$

For motor shaft,

$$M_t = \frac{60 \times 10^6 (kW)}{2\pi n} \times (1.5) = \frac{60 \times 10^6 (10)(1.5)}{2\pi(1440)} = 99\,471.84 \ N-mm$$

$$\tau = \frac{16 M_t}{\pi d^3} \qquad \therefore 47.5 = \frac{16(99\,471.84)}{\pi \ d^3} \qquad \therefore d = 22.01 \text{ mm} \qquad \text{(i)}$$

For pump shaft,

$$M_t = \frac{60 \times 10^6 (kW)}{2\pi n} \times (1.5) = \frac{60 \times 10^6 (10)(1.5)}{2\pi(480)} = 298\,415.52 \ N-mm$$

$$\tau = \frac{16 M_t}{\pi d^3} \qquad \therefore 47.5 = \frac{16(298\,415.52)}{\pi d^3} \qquad \therefore d = 31.75 \text{ mm} \qquad \text{(ii)}$$

9.8 $$\tau = \frac{S_{sy}}{(fs)} = \frac{0.5S_{yt}}{(fs)} = \frac{0.5(300)}{3} = 50 \ N/mm^2$$

$$M_t = \frac{60 \times 10^6 (kW)}{2\pi n} = \frac{60 \times 10^6 (12.5)}{2\pi(300)} = 397\,887.36 \ N-mm$$ Also,

$$M_t = (P_1 - P_2)\,R \qquad \therefore 397\,887.36 = (P_1 - P_2)\,225$$

$$\therefore (P_1 - P_2) = 1768.39 \text{ N} \qquad \text{(a)} \qquad \text{and} \qquad \left(\frac{P_1}{P_2}\right) = 2 \qquad \text{(b)}$$

From Eqs. (a) and (b),

$P_1 = 3536.78$ N and $P_2 = 1768.39$ N $\therefore (P_1 + P_2 + W) = 5605.17$ N

From Fig. 9.1-solu (b),

$(P_1 + P_2 + W) \times 200 = R_b \times 750 \qquad \therefore R_b = 1494.71$ N

$M_b = R_b \text{ x } 550 = 1494.71 \text{ x } 550 = 822\,091.6$ N-mm

$$\tau_{max} = \frac{16}{\pi d^3} \sqrt{(M_b)^2 + (M_t)^2}$$

$$50 = \frac{16}{\pi d^3} \sqrt{(822091.6)^2 + (397887.36)^2} \qquad \therefore\ d = 45.31 \text{ mm} \qquad \text{(Ans.)}$$

9.9 From Eq. (9.8), $\sigma_1 = \dfrac{16}{\pi d^3} [M_b + \sqrt{(M_b)^2 + (M_t)^2}]$

$$= \frac{16}{\pi (40)^3} \left[(1250 \text{ x} 10^3) + \sqrt{(1250 \text{ x} 10^3)^2 + (250 \text{ x} 10^3)^2} \right]$$

$= 200.91$ N/mm^2

From Eq. (9.10), $\tau_{max} = \dfrac{16}{\pi d^3} [\sqrt{(M_b)^2 + (M_t)^2}]$

$$= \frac{16}{\pi (40)^3} \left[\sqrt{(1250 \text{ x} 10^3)^2 + (250 \text{ x} 10^3)^2} \right]$$

$= 101.44$ N/mm^2

According to maximum principal stress theory,

$$(fs) = \frac{S_{yt}}{\sigma_1} = \frac{580}{200.91} = 2.89 \qquad \text{(i)}$$

According to maximum shear stress theory,

$S_{sy} = 0.5\, S_{yt} = 0.5\,(580) = 290$ N/mm^2

$$(fs) = \frac{S_{sy}}{\tau_{max}} = \frac{290}{101.44} = 2.86 \qquad \text{(ii)}$$

9.10 $\tau = \frac{S_{sy}}{(fs)} = \frac{0.5 S_{yt}}{(fs)} = \frac{0.5(380)}{4} = 47.5\ N/mm^2$ $C = \frac{d_i}{d_o} = 0.8$

$$M_t = \frac{60 \times 10^6\ (kW)}{2\pi n} = \frac{60 \times 10^6\ (50)}{2\pi(600)} = 795\,774.72\ \ N-mm$$

From Eq. (9.19),

$$\tau = \frac{16 M_t}{\pi d_o^3\ (1 - C^4)} \qquad \therefore 47.5 = \frac{16(795\ 774.72)}{\pi d_o^3\ (1 - 0.8^4)} \qquad \therefore d_o = 52.48\ mm$$

$d_i = C\ d_o = 0.8\ (52.48) = 41.98\ \ mm$ (Ans.)

9.11 $0.30\ S_{yt} = 0.30\ (480) = 144\ N/mm^2$

$0.18\ S_{ut} = 0.18\ (620) = 111.6\ N/mm^2$ (minimum)

The gears are keyed to the shaft.

$$\tau_{max} = 0.75(111.6) = 83.7\ N/mm^2$$

Refer to Fig.9.2-solu. The resultant bending and turning moments are given by,

$$(M_b)_{max} = \sqrt{(69334)^2 + (114400)^2} = 133\ 770.56\ N-mm$$

$$M_t = (1144) \times 125 = 143000\ N-mm$$

From Eq. (9.15),

$$d^3 = \frac{16}{\pi \tau_{max}} \sqrt{(k_b M_b)^2 + (k_t M_t)^2}$$

$$= \frac{16}{\pi\ (87.3)} \sqrt{(2 \times 133\ 770.56)^2 + (1.5 \times 143\ 000)^2}$$

$\therefore d = 27.15$ mm (Ans.)

9.12 From Eq. (9.13),

$$\theta = \frac{584\ M_t\ l}{G\ d^4} \quad \text{or} \quad 0.25 = \frac{584\ (143\ 000)\ (1000)}{(79\ 300\ )\ d^4}$$

d = 45.3 mm (Ans.)

9.13 The deflections at gear A and gear B are calculated by the principle of superimposition.

Vertical Plane:

(i) Deflection due to a force of 208 N [Fig. 9.3-solu (a), Eq. (27) of Table 9.4]:

a = 200 mm b = 400 mm l = 600 mm

$$(\delta_A)_1 = \frac{P\ b\ x\ (x^2 + b^2 - l^2)}{6\ E\ I\ l} \qquad x = 200\ \text{mm}$$

$$= \frac{(208)\ (400)\ (200)\ (200^2 + 400^2 - 600^2)}{6\ E\ I\ (600)}$$

$$= -\frac{7.3955\ x\ 10^8}{E I}\ \text{mm} \qquad \text{(i)}$$

From Eq. (28) of Table 9.4,

$$(\delta_B)_1 = \frac{P\ a\ (l - x)\ (x^2 + a^2 - 2 l x)}{6\ E\ I\ l} \qquad x = 400\ \text{mm}$$

$$= \frac{(208)\ (200)\ (600 - 400)\ (400^2 + 200^2 - 2x600x400)}{6\ E\ I\ (600)}$$

$$= -\frac{6.4711\ x\ 10^8}{E I}\ \text{mm} \qquad \text{(ii)}$$

(ii) Deflection due to a force of 416 N [Fig. 9.3-solu (b), Eq. (27) of Table 9.4]:

a = 400 mm   b = 200 mm   l = 600 mm

$$(\delta_A)_2 = \frac{P\ b\ x\ (x^2 + b^2 - l^2)}{6\ E\ I\ l} \qquad x = 200\ \text{mm}$$

$$= \frac{(416)\ (200)\ (200)\ (200^2 + 200^2 - 600^2)}{6\ E\ I\ (600)}$$

$$= -\frac{12.942\ x\ 10^8}{E\,I}\ \text{mm} \qquad \text{(iii)}$$

$$(\delta_B)_2 = \frac{P\ b\ x\ (x^2 + b^2 - l^2)}{6\ E\ I\ l} \qquad x = 400\ \text{mm}$$

$$= \frac{(416)\ (200)\ (400)\ (400^2 + 200^2 - 600^2)}{6\ E\ I\ (600)}$$

$$= -\frac{14.791\ x\ 10^8}{E\,I}\ \text{mm} \qquad \text{(iv)}$$

Horizontal Plane:

(iii) Deflection due to a force of 572 N [Fig. 9.3-solu (c), Eq. (27) of Table 9.4]:

a = 200 mm   b = 400 mm   l = 600 mm

$$(\delta_A)_1 = \frac{P\ b\ x\ (x^2 + b^2 - l^2)}{6\ E\ I\ l} \qquad x = 200\ \text{mm}$$

$$= \frac{(572)\ (400)\ (200)\ (200^2 + 400^2 - 600^2)}{6\ E\ I\ (600)}$$

$$= -\frac{20.338\ x\ 10^8}{E\,I}\ \text{mm} \qquad \text{(i)}$$

From Eq. (28) of Table 9.4,

$$(\delta_B)_1 = \frac{P\ a\ (l-x)\ (x^2 + a^2 - 2lx)}{6\ E\ I\ l} \qquad x = 400 \text{ mm}$$

$$= \frac{(572)\ (200)\ (600-400)\ (400^2 + 200^2 - 2x600x400)}{6\ E\ I\ (600)}$$

$$= -\frac{17.796 \text{ x } 10^8}{E I} \text{ mm} \qquad \text{(ii)}$$

(ii) Deflection due to a force of 1144 N [Fig. 9.3-solu (d), Eq. (27) of Table 9.4]:

a = 400 mm   b = 200 mm   l = 600 mm

$$(\delta_A)_2 = \frac{P\ b\ x\ (x^2 + b^2 - l^2)}{6\ E\ I\ l} \qquad x = 200 \text{ mm}$$

$$= \frac{(-1144)\ (200)\ (200)\ (200^2 + 200^2 - 600^2)}{6\ E\ I\ (600)}$$

$$= +\frac{35.591 \text{ x } 10^8}{E I} \text{ mm} \qquad \text{(iii)}$$

$$(\delta_B)_2 = \frac{P\ b\ x\ (x^2 + b^2 - l^2)}{6\ E\ I\ l} \qquad x = 400 \text{ mm}$$

$$= \frac{(-1144)\ (200)\ (400)\ (400^2 + 200^2 - 600^2)}{6\ E\ I\ (600)}$$

$$= +\frac{40.676 \text{ x } 10^8}{E I} \text{ mm} \qquad \text{(iv)}$$

Vertical deflection at A is denoted by $(\delta_A)_v$.

$$(\delta_A)_v = (\delta_A)_1 + (\delta_A)_2$$

$$= -\frac{7.3955 \text{ x } 10^8}{E I} + \frac{-12.942 \text{ x } 10^8}{E I}$$

$$= -\frac{20.3375 \text{ x } 10^8}{E\,I}$$

Vertical deflection at B is denoted by $(\delta_B)_v$.

$$(\delta_B)_v = (\delta_B)_1 + (\delta_B)_2$$

$$= -\frac{6.4711 \text{ x } 10^8}{E\,I} + \frac{-14.791 \text{ x } 10^8}{E\,I}$$

$$= -\frac{21.2621 \text{ x } 10^8}{E\,I}$$

Horizontal deflection at A is denoted by $(\delta_A)_h$.

$$(\delta_A)_h = (\delta_A)_1 + (\delta_A)_2$$

$$= -\frac{20.338 \text{ x } 10^8}{E\,I} + \frac{35.591 \text{ x } 10^8}{E\,I}$$

$$= +\frac{15.253 \text{ x } 10^8}{E\,I}$$

Horizontal deflection at B is denoted by $(\delta_B)_h$.

$$(\delta_B)_h = (\delta_B)_1 + (\delta_B)_2$$

$$= -\frac{17.796 \text{ x } 10^8}{E\,I} + \frac{40.676 \text{ x } 10^8}{E\,I}$$

$$= +\frac{22.88 \text{ x } 10^8}{E\,I}$$

The radial deflection at gear A and B consists of two components-vertical deflection $(\delta\ )_v$ and horizontal component $(\delta\ )_h$. The_radial deflections are given by,

$$\delta_A = \sqrt{[(\delta_A)_v]^2 + [(\delta_A)_h]^2}$$

$$= \sqrt{\left(\frac{20.3375x10^8}{EI}\right)^2 + \left(\frac{15.253x10^8}{EI}\right)^2}$$

$$= \frac{25.4218\,x\,10^8}{E\;I}\ \text{mm}$$

$$\delta_B = \sqrt{[(\delta_B)_v]^2 + [(\delta_B)_h]^2}$$

$$= \sqrt{\left(\frac{21.2621x10^8}{EI}\right)^2 + \left(\frac{22.88x10^8}{EI}\right)^2}$$

$$= \frac{31.2341\ x\ 10^8}{E\;I}\ \text{mm}$$

$$\delta_{max} = \frac{31.2341x10^8}{EI} \qquad (0.01x10) = \frac{31.2341x10^8}{(207\,000)\left(\frac{\pi\ d^4}{64}\right)}$$

d = 41.87 mm (Ans.)

9.14 $0.30\ S_{yt} = 0.30\ (380) = 114\ N/mm^2$

$0.18\ S_{ut} = 0.18\ (600) = 108\ N/mm^2$ (minimum)

$\tau_{max} = 0.75(108) = 81\ N/mm^2$

Refer to Fig.9.4-solu (b). The resultant bending moments are given by,

$$(M_b)_a = \sqrt{(136\ 709)^2 + (33\ 333.33)^2} = 140\ 714.11\ N - mm$$

$$(M_b)_b = \sqrt{(89\ 871)^2 + (100\ 000)^2} = 134\ 449.98\ N - mm$$

$$M_t = (1500 - 500)\,x150 = 150\ 000\,N - mm$$

$$d^3 = \frac{16}{\pi\,\tau_{max}}\sqrt{(k_b M_b)^2 + (k_t M_t)^2}$$

$$= \frac{16}{\pi\ (81)}\sqrt{(1.5\,x140\ 714.11)^2 + (150\ 000)^2}$$

$\therefore$ d = 25.35 mm (Ans.)

$$\theta = \frac{584\ M_t\ l}{G\ d^4} \quad \text{or} \quad 0.5 = \frac{584\ (150\ 000)\ (200)}{(79\ 300\ )\ d^4}$$

d = 25.78 mm (Ans.)

9.15 $\sigma_c = \dfrac{S_{yc}}{(fs)} = \dfrac{300}{2.8} = 107.14\ N/mm^2$

$$\tau = \frac{S_{sy}}{(fs)} = \frac{0.577\,S_{yt}}{(fs)} = \frac{0.577\,(300)}{2.8} = 61.82\ N/mm^2$$

$$M_t = \frac{60\,x\,10^6\ (kW)}{2\,\pi\,n} = \frac{60\,x\,10^6\ (25)}{2\,\pi\,(300)} = 795774.72\ N-mm$$

From Eq.(9.27),

$$l = \frac{2\,M_t}{\tau\,d\,b} = \frac{2\,(795774.72)}{(61.82)(40)(22)} = 29.26\ mm \qquad (i)$$

From Eq.(9.28),

$$l = \frac{4\,M_t}{\sigma_c\ d\ h} = \frac{4\,(795774.72)}{(107.14)(40)(14)} = 53.05\ mm \qquad (ii)$$

$\therefore$ l = 53.05 mm (Ans.)

9.16 $\sigma_c = \dfrac{S_{yc}}{(fs)} = \dfrac{380}{3} = 126.67\ N/mm^2$

$$\tau = \frac{S_{sy}}{(fs)} = \frac{0.577\,S_{yt}}{(fs)} = \frac{0.577\,(380)}{3} = 73.09\ N/mm^2$$

$$b = h = \frac{d}{4} = \frac{50}{4} = 12.5\ mm$$

$$M_t = \frac{60\,x10^6\,(kW)}{2\pi n} = \frac{60\,x10^6\,(10)}{2\pi(200)} = 477\ 464.83\ \ N-mm$$

From Eq.(9.27),

$$l = \frac{2M_t}{\tau d b} = \frac{2(477\ 464.83)}{(73.09)(50)(12.5)} = 20.9\ mm \qquad (i)$$

From Eq.(9.28),

$$l = \frac{4M_t}{\sigma_c\, d\, h} = \frac{4(477\ 464.83)}{(126.67)(50)(12.5)} = 24.12\ mm \qquad (ii)$$

$\therefore$ size of key = 12.5x12.5x25 mm (Ans.)

9.17 $\sigma_c = \dfrac{S_{yc}}{(fs)} = \dfrac{230}{3} = 76.67\ N/mm^2$

$$\tau = \frac{S_{sy}}{(fs)} = \frac{0.5S_{yt}}{(fs)} = \frac{0.5(230)}{3} = 38.33\ N/mm^2$$

$$M_t = \frac{60\,x10^6\,(kW)}{2\pi n} = \frac{60\,x10^6\,(15)}{2\pi(360)} = 397887.36\ \ N-mm$$

From Eq.(9.27),

$$l = \frac{2M_t}{\tau d b} = \frac{2(397887.36)}{(38.33)(45)(14)} = 32.95\ mm \qquad (i)$$

From Eq.(9.28),

$$l = \frac{4M_t}{\sigma_c\, d\, h} = \frac{4(397887.36)}{(76.67)(45)(9)} = 51.26\ mm \qquad (ii)$$

9.18 From Eq. (9.32),

$$M_t = \frac{1}{8} p_m \, l \, n (D^2 - d^2) = \frac{1}{8}(6.5)(50)(8)(40^2 - 36^2) = 98\,800 \text{ N} - \text{mm}$$

$$kW = \frac{2\,\pi\, n\, M_t}{60x10^6} = \frac{2\,\pi\,(700)\,(98\,800)}{60x10^6} = 7.24 \text{ kW} \qquad \text{(Ans.)}$$

9.19 $$\tau = \frac{S_{sy}}{(fs)} = \frac{0.577 S_{yt}}{(fs)} = \frac{0.577(380)}{2.5} = 87.7 \text{ N/mm}^2$$

$$M_t = \frac{60\,x10^6\,(kW)}{2\pi n} x\ 2.25 = \frac{60\,x10^6\,(45)}{2\pi(1440)} x\,2.25 = 671\,434.92 \text{ N} - \text{mm}$$

From Eq. (9.41),

$$d^2 = \frac{8\, M_t}{\pi\, D\, N\, \tau} = \frac{8\,(671\,434.92)}{\pi\,(150)(8)(87.7)} \qquad d = 4.03 \text{ mm} \qquad \text{(Ans.)}$$

9.20 From Eq. (9.42),

$$R_f = \frac{2}{3}\frac{(R_o^3 - R_i^3)}{(R_o^2 - R_i^2)} = \frac{2}{3}\frac{(80^3 - 47.5^3)}{(80^2 - 47.5^2)} = 65.13 \text{ mm}$$

From Eq. (9.43),

$$M_t = \mu\, P_i\, N\, R_f = 0.15(10x10^3)(6)(65.13) = 586\,170 \text{ N} - \text{mm}$$

$$kW = \frac{2\,\pi\, n\, M_t}{60x10^6} = \frac{2\,\pi\,(100)\,(586\,170)}{60x10^6} = 6.14 \text{ kW} \qquad \text{(Ans.)}$$

9.21 $$\tau = \frac{S_{sy}}{(fs)} = \frac{0.5 S_{yt}}{(fs)} = \frac{0.5(400)}{5} = 40 \text{ N/mm}^2$$

$$M_t = \frac{60\,x10^6\,(kW)}{2\pi n} x1.5 = \frac{60\,x10^6\,(7.5)}{2\pi(720)} x1.5 = 149\,207.76 \text{ N} - \text{mm}$$

Diameter of shaft:

$$\tau = \frac{16\,M_t}{\pi d^3} \quad \text{or} \quad 40 = \frac{16(149\ 207.76)}{\pi d^3}$$

$\therefore d = 26.68$ mm or 30 mm (i)

Diameter of bolts:

For 30 mm diameter shaft, N = 3 (ii)

D = 3d = 3 x 30 = 90 mm

From Eq. (9.41),

$$d_1^2 = \frac{8\,M_t}{\pi D N \tau} = \frac{8(149\ 207.76)}{\pi\,(90)(3)(40)}$$

$d_1 = 5.93$ or 6 mm (iii)

9.22 Permissible stresses for shafts and keys :

$$\tau = \frac{S_{sy}}{(fs)} = \frac{0.5 S_{yt}}{(fs)} = \frac{0.5(240)}{3} = 40\ \text{N/mm}^2$$

$$\sigma_c = \frac{S_{yc}}{(fs)} = \frac{S_{yt}}{(fs)} = \frac{240}{3} = 80\ \text{N/mm}^2$$

Permissible stress for pins : $\tau = 35\ \text{N/mm}^2$

$$\sigma_t = \frac{S_{yt}}{(fs)} = \frac{240}{3} = 80\ \text{N/mm}^2$$

Shaft diameter:

$$M_t = \frac{60 \times 10^6\,(kW)}{2\pi n} = \frac{60 \times 10^6\,(5)}{2\pi(720)} = 66\ 314.56\ \text{N-mm}$$

$$\tau = \frac{16\,M_t}{\pi d^3} \qquad 40 = \frac{16(66\ 314.56)}{\pi d^3}$$

$\therefore d = 20.36$ mm or 22 mm (i)

Dimensions of key:

$$b = h = \frac{d}{4} = \frac{22}{4} = 5.5 \text{ or } 6 \text{ mm} \qquad l_h = 1.5d = 33 \text{ mm}$$

Size of key: 6 x 6 x 33 mm (ii)

From Eq.(9.27), $\tau = \frac{2M_t}{d\,b\,l} = \frac{2(66\ 314.56)}{(22)(6)(33)} = 30.45 \text{ N/mm}^2$

From Eq.(9.28), $\sigma_c = \frac{4M_t}{d\ h\ l} = \frac{4(66\ 314.56)}{(22)(6)(33)} = 60.90 \text{ N/mm}^2$

$\therefore \tau < 40 \text{ N/mm}^2$ and $\sigma_c < 80 \text{ N/mm}^2$

Dimensions of bushes: N = 4

D = 4d = 4 x 22 = 88 mm

From Eq. (9.50),

$$D_b^2 = \frac{2M_t}{D\,N} = \frac{2(66314.56)}{(88)(4)} \qquad D_b = 19.41 \text{ or } 20 \text{ mm}$$

$l_b = D_b = 20$ mm (iv)

Diameter of pins : $P = \frac{2\ M_t}{D\,N} = \frac{2(66314.56)}{(88)\ (4)} = 376.79 \text{ N}$

$$M_b = P\left(\frac{l_b}{2} + 5\right) = 376.79\left(\frac{20}{2} + 5\right) = 5651.81 \text{ N} - \text{mm}$$

$$\sigma_b = \frac{32\ M_b}{\pi\ d_1^3} \qquad \text{or} \qquad 80 = \frac{32\ (5651.81)}{\pi\ d_1^3}$$

$d_1 = 8.96$ or 9 mm (iii)

9.23 The deflections at gear A and gear B are calculated by the principle of superimposition.

Vertical Plane:

(i) Deflection due to a force of 200 N [Fig. 9.5-solu (a), Eq. (27) of Table 9.4]:

a = 300 mm b = 700 mm l = 1000 mm

$$(\delta_A)_A = \frac{P\ b\ x\ (x^2 + b^2 - l^2)}{6\ E\ I\ l} \qquad x = 300 \text{ mm}$$

$$= \frac{(200)\ (700)\ (300)\ (300^2 + 700^2 - 1000^2)}{6\ E\ I\ (1000)}$$

$$= -\frac{0.294 \text{ x } 10^{10}}{E\, I} \text{ mm} \qquad \text{(i)}$$

From Eq. (28) of Table 9.4,

$$(\delta_B)_A = \frac{P\ a\ (l-x)\ (x^2 + a^2 - 2lx)}{6\ E\ I\ l} \qquad x = 600 \text{ mm}$$

$$= \frac{(200)\ (300)\ (1000-600)\ (600^2 + 300^2 - 2\text{x}1000\text{x}600)}{6\ E\ I\ (1000)}$$

$$= -\frac{0.3 \text{x } 10^{10}}{E\, I} \text{ mm} \qquad \text{(ii)}$$

(ii) Deflection due to a force of 3500 N [Fig. 9.5-solu (b), Eq. (27) of Table 9.4]:

a = 600 mm b = 400 mm l = 1000 mm

$$(\delta_A)_B = \frac{P\ b\ x\ (x^2 + b^2 - l^2)}{6\ E\ I\ l} \qquad x = 300 \text{ mm}$$

$$= \frac{(3500)\ (400)\ (300)\ (300^2 + 400^2 - 1000^2)}{6\ E\ I\ (1000)}$$

$$= -\frac{5.25 \text{ x } 10^{10}}{E I} \text{ mm} \qquad \text{(iii)}$$

$$(\delta_B)_B = \frac{P\ b\ x\ (x^2 + b^2 - l^2)}{6\ E\ I\ l} \qquad x = 600 \text{ mm}$$

$$= \frac{(3500)\ (400)\ (600)\ (600^2 + 400^2 - 1000^2)}{6\ E\ I\ (1000)}$$

$$= -\frac{6.72 \text{ x } 10^{10}}{E I} \text{ mm} \qquad \text{(iv)}$$

Vertical deflection at A is denoted by (δ_A) .

$$(\delta_A) = (\delta_A)_A + (\delta_A)_B$$

$$= -\frac{0.294 \text{ x } 10^{10}}{E I} + \frac{-5.25 \text{ x } 10^{10}}{E I}$$

$$= -\frac{5.544 \text{ x } 10^{10}}{E I}$$

$$= -\frac{5.544\text{x}10^{10}}{207\ 000\left(\frac{\pi (50)^4}{64}\right)} = 0.873 \text{ mm} = (0.873\text{x}10^{-3}) \text{ m}$$

Vertical deflection at B is denoted by (δ_B).

$$(\delta_B) = (\delta_B)_A + (\delta_B)_B$$

$$= -\frac{0.3 \text{ x } 10^{10}}{E I} + \frac{-6.72 \text{ x } 10^{10}}{E I}$$

$$= -\frac{7.02 \text{ x } 10^{10}}{E I}$$

$$= -\frac{7.02\text{x}10^{10}}{207\ 000\left(\frac{\pi(50)^4}{64}\right)} = 1.105 \text{ mm} = (1.105\text{x}10^{-3}) \text{ m}$$

From Eq. (9.57),

$$\omega_n = \sqrt{\frac{g\ (W_1\,\delta_1 + W_2\,\delta_2)}{(W_1\,\delta_1^2 + W_2\,\delta_2^2)}}$$

$$= \sqrt{\frac{(9.81)\left[(200)(0.873)(10^{-3}) + (3500)(1.105)(10^{-3})\right]}{\left[(200)(0.873)^2(10^{-3})^2 + (3500)(1.105)^2(10^{-3})^2\right]}}$$

$$= \sqrt{\frac{9.81(4042.1)(10)^{-3}}{4426.01(10)^{-6}}}$$

$= 94.65$ rad/s (1 revolution = 2π radians)

$$= \frac{94.65(60)}{2\pi} = 903.86 \quad \text{r.p.m.}$$ (Ans.)

CHAPTER 10

10.1 The permissible shear stress is given by,

$\tau = 0.5\, S_{ut} = 0.5(1000) = 500$ N/mm^2

From Eq. (10.7),

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C} = \frac{4(6)-1}{4(6)-4} + \frac{0.615}{6} = 1.2525$$

From Eq. (10.13),

$$\tau = K\left(\frac{8PC}{\pi d^2}\right) \quad \text{or} \quad 500 = (1.2525)\left\{\frac{8(500)(6)}{\pi d^2}\right\}$$

$\therefore d = 4.37$ or 5 mm (1)

D = Cd = 6(5) = 30 mm (2)

From Eq. (10.8),

$$\delta = \frac{8PD^3N}{Gd^4} \quad \text{or} \quad 20 = \frac{8(500)(30)^3 N}{(81370)(5)^4}$$

$\therefore N = 9.42$ or 10 coils (3)

The spring has square and ground ends. The number of inactive coils is 2. Therefore,

$N_t = N + 2 = 10 + 2 = 12$ coils (4)

The actual deflection of the spring is given by,

$$\delta = \frac{8PD^3N}{Gd^4} = \frac{8(500)(30)^3(10)}{(81370)(5)^4} = 21.24 \text{ mm}$$

solid length of spring = $N_t\, d$ = 12(5) = 60 mm

There is a gap of 1 mm between consecutive coils when the spring is subjected to the maximum force. The total number of coils is 12.

The total axial gap between the coils is (12-1) x 1 = 11 mm.

free length = solid length + total axial gap + δ

= 60 + 11 + 21.24

= 92.24 (5)

pitch of coil = $\dfrac{\text{freelength}}{(N_t - 1)} = \dfrac{92.24}{(12-1)} = 8.39$ mm (6)

10.2 There are six springs in parallel. The force acting on each spring is given by,

$P = \dfrac{1500}{6} = 250N$

The permissible shear stress for the spring wire is given by,

$\tau = 0.5\ S_{ut} = 0.5\ (1200) = 600\ N/mm^2$

$K = \dfrac{4C-1}{4C-4} + \dfrac{0.615}{C} = \dfrac{4x6-1}{4x6-4} + \dfrac{0.615}{6} = 1.2525$

From Eq. (10.13),

$\tau = K \left(\dfrac{8PC}{\pi d^2}\right)$ or $600 = (1.2525) \left\{\dfrac{8(250)(6)}{\pi d^2}\right\}$

$\therefore$ d = 2.82 or 3 mm (1)

D = C d = 6 (3) = 18 mm (2)

From Eq. (10.8),

$\delta = \dfrac{8PD^3N}{Gd^4}$ or $10 = \dfrac{8(250)(18)^3 N}{(81370)(3)^4}$

$\therefore$ N = 5.65 or 6 coils (3)

The springs have square and ground ends. The number of inactive coils is 2. Therefore,

$N_t = N + 2 = 6+2 = 8$ (4)

The actual deflection of the spring is given by,

$$\delta = \frac{8PD^3N}{Gd^4} = \frac{8(250)(18)^3(6)}{(81370)(3)^4} = 10.62 \text{ mm}$$

solid length = $N_t d$ = 8(3) = 24 mm (5)

There is a gap of 1 mm between the adjacent coils when the spring is subjected to the maximum force of 250N. The total number of coils is 8. Therefore, the total axial gap is (8-1) x1 = 7 mm.

free length = solid length + total axial gap + δ

= 24 + 7 + 10.62

= 41.62 (6)

The required stiffness of the spring is given by,

$$k = \frac{P}{\delta} = \frac{250}{10} = 25 \text{ N/mm} \quad (7)$$

The actual stiffness of spring is given by,

$$k = \frac{Gd^4}{8D^3N} = \frac{(81370)(3)^4}{8(18)^3(6)} = 23.54 \text{ N/mm} \quad (8)$$

10.3 The length of scale of the pointer is 75 mm. In order words, the spring deflection is 75 mm when the force is 500 N.

The permissible shear stress for spring wire is given by,

$\tau = 0.5\, S_{ut} = 0.5\,(1400) = 700 \text{ N/mm}^2$

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C} = \frac{4 \text{ x } 6-1}{4 \text{ x } 6-4} + \frac{0.615}{6} = 1.2525$$

From Eq. (10.13),

$$\tau = K\left(\frac{8PC}{\pi d^2}\right) \qquad \text{or} \qquad 700 = 1.2525\left\{\frac{8(500)(6)}{\pi d^2}\right\}$$

$\therefore$ d = 3.7 or 4 mm (i)

D = Cd = 6 (4) = 24 mm (ii)

From Eq. (10.8),

$$\delta = \frac{8PD^3N}{Gd^4} \qquad \text{or} \qquad 75 = \frac{8(500)(24)^3 N}{(81370)(4)^4}$$

$\therefore$ N = 28.25 or 29 coils (iii)

The required spring rate is given by,

$$k = \frac{P}{\delta} = \frac{500}{75} = 6.67 \ \mathrm{N/mm} \qquad \text{(iv)}$$

The actual spring rate is given by,

$$k = \frac{Gd^4}{8D^3N} = \frac{(81370)(4)^4}{8(24)^3(29)} = 6.5 \ \mathrm{N/mm} \qquad \text{(v)}$$

10.4 The kinetic energy of the moving wagon is absorbed by the springs. The kinetic energy of the wagon is given by,

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}(1000)(2)^2 = 2000 \text{ J or N-m} = (2000 \times 10^3) \text{ N-mm} \qquad \text{(a)}$$

Suppose P is the maximum force acting on each spring and causing it to compress by 150 mm. The strain energy absorbed by two springs is given by,

$$E = 2\left[\frac{1}{2}\,P\,\delta\right] = 2\left[\frac{1}{2}P(150)\right] = (150P)\ \text{N-mm} \qquad \text{(b)}$$

The strain energy absorbed by two springs is equal to the kinetic energy of the wagon. Therefore,

$$(150\,P) = 2000 \times 10^3$$

$$P = 13\,333.33\ \text{N} \qquad \text{(i)}$$

The permissible shear stress for spring wire is given by,

$$\tau = 0.5\,(1500) = 750\ \text{N / mm}^2$$

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C} = \frac{4(6)-1}{4(6)-4} + \frac{0.615}{6} = 1.2525$$

From Eq. (10.13),

$$\tau = K\left(\frac{8PC}{\pi d^2}\right) \qquad \text{or} \qquad 750 = (1.2525)\left\{\frac{8(13333.33)(6)}{\pi d^2}\right\}$$

$$\therefore d = 18.44 \text{ or } 19\ \text{mm} \qquad \text{(ii)}$$

$$D = Cd = 6\,(19) = 114\ \text{mm} \qquad \text{(iii)}$$

From Eq, (10.8),

$$\delta = \frac{8\,PD^3\,N}{Gd^4} \qquad \text{or} \qquad 150 = \frac{8(13333.33)(114)^3\,N}{(81370)(19)^4}$$

$$\therefore N = 10.07 \text{ or } 11 \text{ coils} \qquad \text{(iv)}$$

10.5 The permissible shear stress for spring wire is given by,

$\tau = 0.5\ S_{ut} = 0.5\ (1000) = 500\ N/mm^2$

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C} = \frac{4x8-1}{4x8-4} + \frac{0.615}{8} = 1.184$$

From Eq. (10.13),

$$\tau = K\left(\frac{8PC}{\pi d^2}\right) \qquad \text{or} \qquad 500 = 1.184\left\{\frac{8(1000)(8)}{\pi d^2}\right\}$$

$\therefore$ d = 6.95 or 7 mm (1)

D = C d = 8 (7) = 56 mm (2)

From Eq. (10.8),

$$\delta = \frac{8PD^3N}{Gd^4} \qquad \text{or} \qquad 25 = \frac{8(1000-500)(56)^3 N}{(81370)(7)^4}$$

$\therefore$ N = 6.95 or 7 coils (3)

The spring has square and ground ends. The number of inactive coils is 2.

Therefore,

$N_t = N + 2 = 7 + 2 = 9$ (4)

solid length = $N_t d$ = 9(7) = 63 mm (5)

The actual deflection of the spring is given by,

$$\delta = \frac{8PD^3N}{Gd^4} = \frac{8(1000)(56)^3(7)}{(81370)(7)^4} = 50.34\ \text{mm}$$

Gap = (9 – 1)(2) = 16 mm

free length = solid length + total axial gap + δ

= 63 + 16 + 50.34

$$= 129.34 \text{ mm} \qquad (6)$$

The required spring rate is given by,

$$k = \frac{P}{\delta} = \frac{1000-500}{25} = 20 \text{ N/mm} \qquad (7)$$

The actual spring rate is given by,

$$k = \frac{Gd^4}{8D^3N} = \frac{(81370)(7)^4}{8(56)^3(7)} = 19.87 \text{ N/mm} \qquad (8)$$

10.6 $P_1 = \frac{\pi}{4}(40)^2(1.2) = 1507.96 \text{ N}$ $\qquad \delta_1 = 20 \text{ mm}$

$\delta_2 = 20 + 12 = 32 \text{ mm}$

$$\frac{P_2}{P_1} = \frac{\delta_2}{\delta_1} \qquad \therefore \qquad \frac{P_2}{1507.96} = \frac{32}{20} \qquad P_2 = 2412.74 \text{ N}$$

The permissible shear stress for the spring wire is given by,

$\tau = 0.5\, S_{ut} = 0.5\,(1400) = 700 \text{ N/mm}^2$

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C} = \frac{4(6)-1}{4(6)-4} + \frac{0.615}{6} = 1.2525$$

From Eq. (10.13),

$$\tau = K\left(\frac{8PC}{\pi d^2}\right) \qquad \text{or} \qquad 700 = 1.2525\left\{\frac{8(2412.74)(6)}{\pi d^2}\right\}$$

$\therefore d = 8.12 \text{ or } 9 \text{ mm}$ (i)

D= Cd = 6(9) = 54 mm (ii)

From Eq. (10.8),

$$\delta = \frac{8PD^3N}{Gd^4} \qquad \text{or} \qquad 20 = \frac{8(1507.96)(54)^3 N}{(81370)(9)^4}$$

$\therefore$ N = 5.62 or 6 coils (iii)

10.7 $$M_t = \frac{60x10^6(kW)}{2\pi n} = \frac{60x10^6(25)}{2\pi(1000)} = 238\ 732.41\ N-mm$$

There are two pairs of contacting surfaces and the torque transmitted by each pair is (238 732.41/2) or 119 366.2 N-mm. Assuming uniform-wear theory (Chapter 11), the total normal force P_t required to transmit the torque is given by,

$$P_t = \frac{4(M_t)_f}{\mu(D+d)} = \frac{4(119\ 366.2)}{0.35(2x190)} = 3589.96\ N$$

Since there are six springs, the force exerted by each spring is

$$P = \frac{3589.96}{6} = 598.33\ N$$

From Eq. (10.7),

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C} = \frac{4(6)-1}{4(6)-4} + \frac{0.615}{6} = 1.2525$$

From Eq. (10.13),

$$\tau = K\left(\frac{8PC}{\pi d^2}\right) \quad \text{or} \quad \tau = (1.2525)\left[\frac{8(598.33)(6)}{\pi d^2}\right]$$

or $$\tau = \frac{11450.12}{d^2}\ N/mm^2 \qquad \text{(a)}$$

The permissible shear stress is denoted by τ_d in order to differentiate it from induced stress τ. It is given by,

$$\tau_d = 0.5\ S_{ut} \qquad \text{(b)}$$

Equations (a) and (b) are solved by the trial and error method.

From Table 10.1 (Grade-2),

d (mm)	S_{ut}	$\tau_d = 0.5\ S_{ut}$	$\tau = \dfrac{11450.12}{d^2}$
2.5	1640	820	1832.02
3.0	1570	785	1272.24
3.6	1510	755	883.50
4.0	1480	740	715.63

Therefore, $d = 4$ mm (Ans.)

10.8 $$P_{max} = \left(\frac{\pi}{4}d^2\right)p_{max} = \left(\frac{\pi}{4}(25)^2\right)(1) = 490.87\ \text{N}$$

Assume $D = 15$ mm

Trial 1

$d = 3.6$ mm

From Table 10.2, $S_{ut} = 1400\ \ \text{N/mm}^2$

$\tau_d = 0.5\ S_{ut} = 0.5(1400) = 700\ \ \text{N/mm}^2$

$$C = \frac{D}{d} = \frac{15}{3.6} = 4.167$$

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C} = \frac{4(4.167)-1}{4(4.167)-4} + \frac{0.615}{4.167} = 1.3844$$

$$\tau = K\left(\frac{8PD}{\pi d^3}\right) \quad \text{or} \quad \tau = (1.3844)\left[\frac{8(490.87)(15)}{\pi(3.6)^3}\right] = 556.35\ \text{N/mm}^2$$

Therefore,

$\tau < \tau_d$

The design is safe.

Trial 2

d = 3 mm

From Table 10.2, $S_{ut} = 1430 \quad N/mm^2$

$\tau_d = 0.5\ S_{ut} = 0.5(1430) = 715\ \ N/mm^2$

$$C = \frac{D}{d} = \frac{15}{3} = 5$$

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C} = \frac{4(5)-1}{4(5)-4} + \frac{0.615}{5} = 1.3105$$

$$\tau = K\left(\frac{8PD}{\pi d^3}\right) \quad \text{or} \quad \tau = (1.3105)\left[\frac{8(490.87)(15)}{\pi(3)^3}\right] = 910.06\ N/mm^2$$

Therefore,

$\tau > \tau_d$

The design is not safe.

From Trial No. 1 and 2,

d = 3.6 mm and D = 15 mm (i), (ii)

$$P_{min} = \left(\frac{\pi}{4}\ d^2\right)p_{min} = \left(\frac{\pi}{4}\ (25)^2\right)(0.25) = 122.72\ N$$

$$k = \frac{P_{max} - P_{min}}{lift} = \frac{490.87 - 122.72}{6} = 61.36\ N/mm \qquad \text{(iii)}$$

$$k = \frac{Gd^4}{8D^3N} \qquad 61.36 = \frac{(81370)(3.6)^4}{8(15)^3 N}$$

N = 8.25 or 9 (iv)

10.9 C = 5 From Eq. (10.7) and (10.5),

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C} = \frac{4(5)-1}{4(5)-4} + \frac{0.615}{5} = 1.311$$

$$K_s = 1 + \frac{0.5}{C} = 1 + \frac{0.5}{5} = 1.1$$

$$P_m = \frac{1}{2}(P_{max} + P_{min}) = \frac{1}{2}(300+50) = 175 \text{ N}$$

$$P_a = \frac{1}{2}(P_{max} - P_{min}) = \frac{1}{2}(300-50) = 125 \text{ N}$$

From Eq. (10.18) and (10.19),

$$\tau_m = K_s\left(\frac{8P_m D}{\pi d^3}\right) = (1.1)\left(\frac{8(175)(25)}{\pi(5)^3}\right) = 98.04 \text{ N/mm}^2$$

$$\tau_a = K\left(\frac{8P_a D}{\pi d^3}\right) = (1.311)\left(\frac{8(125)(25)}{\pi(5)^3}\right) = 83.46 \text{ N/mm}^2$$

From. Eq. (10.21), the relationships for oil-hardened and tempered steel wire are as follows,

$S'_{se} = 0.22\ S_{ut} = 0.22(1440) = 316.8$ N/mm^2

$S_{sy} = 0.45\ S_{ut} = 0.45(1440) = 648$ N/mm^2

$$\frac{1}{2}S'_{se} = \frac{1}{2}(316.8) = 158.4 \text{ N/mm}^2$$

From Eq. (10.22),

$$\frac{\tau_a}{\left(\frac{S_{sy}}{fs}\right) - \tau_m} = \frac{\frac{1}{2}S'_{se}}{S_{sy} - \frac{1}{2}S'_{se}}$$

$$\frac{83.46}{\left(\frac{648}{fs}\right) - 98.04} = \frac{158.4}{648 - 158.4}$$

(fs)= 1.82 (Ans.)

10.10 Suppose suffix 'i' and 'o' refer to inner and outer spring respectively.

$D_i = 64$ mm $\quad d_i = 8$ mm $\quad N_i = 10$ coils

$D_o = 80$ mm $\quad d_o = 10$ mm $\quad N_o = 15$ coils

Stiffness of springs:

From Eq. (10.9),

$$k_o = \frac{G\ d_o^4}{8\ D_o^3\ N_o} = \frac{(81370)(10)^4}{8\ (80)^3\ (15)} = 13.24\ \text{N/mm} \qquad \text{(i)}$$

$$k_i = \frac{G\ d_i^4}{8\ D_i^3\ N_i} = \frac{(81370)(8)^4}{8\ (64)^3\ (10)} = 15.89\ \text{N/mm}$$

$$k = k_o + k_i = 13.24 + 15.89 = 29.13\ \text{N/mm} \qquad \text{(ii)}$$

10.11 From Eq. (10.32),

$$\sigma_b = \frac{12\ M}{b\ t^2} \qquad \text{or} \qquad 750 = \frac{12\ (1000)}{(10\,t)\ t^2}$$

$t = 1.17$ or 1.2 mm (i)

$b = 10\ t = 12$ mm (ii)

$\theta = 2.5$ revolutions $= 2.5\ (2\ \pi) = 5\ \pi$ radians

From Eq. (10.33),

$$\theta = \frac{12\ M\ l}{E\ b\ t^3} \qquad \text{or} \qquad 5\ \pi = \frac{12\ (1000)\, l}{(207\,000)(12)(1.2)^3}$$

$\therefore \quad l = 5618.68$ mm or 5.62 m (iii)

10.12 $2\ L = 1x10^3$ mm L = 500 mm

From Eq. (10.41),

$$\sigma_b = \frac{6PL}{nbt^2} \qquad \text{or} \qquad (350) = \frac{6P(500)}{(8)(50)(7.5)^2}$$

P = 2625 N

2 P = 5250 N (Ans.)

10.13 $2\ P = 10x10^3$ N P = 5000 N

$2\ L = 1x10^3$ mm L = 500 mm

From Eq. (10.41),

$$\sigma_b = \frac{6PL}{nbt^2} \qquad \text{or} \qquad (350) = \frac{6(5000)(500)}{(10)(50)t^2}$$

t = 9.26 or 10 mm (i)

From Eq. (10.38),

$$\delta = \frac{12\ P\ L^3}{E\ b\ t^3(3n_f + 2n_g)} = \frac{12\ (5\ 000)(500)^3}{(207\ 000)(50)(10)^3(3x2 + 2x8)}$$

$\delta = 32.94$ mm (ii)

10.14 $2\ P = 30x10^3$ N P = 15 000 N

$2\ L = 1x10^3$ mm L = 500 mm

$$\sigma_b = \frac{S_{yt}}{(fs)} = \frac{1500}{2} = 750\ N/mm^2$$

From Eq. (10.41),

$$\sigma_b = \frac{6PL}{n\,b\,t^2} \qquad \text{or} \qquad (750) = \frac{6(15000)(500)}{(10)\,b\,t^2}$$

$b\,t^2 = 6000$

Let $\quad b = 32$ mm $\qquad t^2 = \dfrac{6000}{32} \qquad$ or $\qquad t = 13.69$ or 14 mm

Cross-section = 32x14 mm (i)

From Eq. (10.38),

$$\delta = \frac{12\ P\ L^3}{E\ b\ t^3\,(3n_f + 2n_g)} = \frac{12\ (15\ 000)(500)^3}{(207\ 000)(32)(14)^3\,(3\,x\,2 + 2\,x\,8)}$$

$\delta = 56.27$ mm (ii)

CHAPTER 11

11.1 Uniform wear theory: From Eq. (11.8),

$$M_t = \frac{\mu P}{4}(D+d) = \frac{(0.25)(15 x 10^3)}{4}(250+125) = 351\ 562.5 \text{ N-mm}$$

$$kW = \frac{2\pi n M_t}{60 \text{ x } 10^6} = \frac{2\ \pi\ (500)(351\ 562.5)}{60 \text{ x } 10^6} = 18.41 \qquad \text{(i)}$$

Uniform pressure theory: From Eq. (11.5),

$$M_t = \frac{\mu P}{3}\frac{(D^3 - d^3)}{(D^2 - d^2)} = \frac{(0.25)(15x10^3)}{3}\frac{(250^3 - 125^3)}{(250^2 - 125^2)} = 364\ 583.33 \text{ N-mm}$$

$$kW = \frac{2\pi n M_t}{60 \text{ x } 10^6} = \frac{2\ \pi\ (500)(364\ 583.33)}{60 \text{ x } 10^6} = 19.09 \qquad \text{(ii)}$$

11.2 There are two pairs of contacting surfaces. Therefore, the torque transmitted by one pair of contacting surfaces is given by,

$$M_t = \frac{531x10^3}{2} = 265\ 500 \text{ N} - \text{mm}$$

From Eq. (11.7),

$$M_t = \frac{\pi \mu p_a d}{8}(D^2 - d^2) \qquad (265\ 500) = \frac{\pi (0.3)(0.3)\ d}{8}(270^2 - d^2)$$

$$d(270^2 - d^2) = 7\ 512\ 113.314$$

The above equation is solved by trial and error method. It is a cubic equation.

d	166	167	168
d ($270^2 - d^2$)	7 527 104	7 516 837	7 505 568

d = 167 mm (i)

Check:

$$M_t = \frac{\pi \mu p_a d}{8}(D^2 - d^2) = \frac{\pi(0.3)(0.3)(167)}{8}(270^2 - 167^2)$$

$= 265\ 660.95$ N-mm (> 265 500 N-mm) (O.K.)

From Eq. (11.8),

$$P = \frac{4\ M_t}{\mu\ (D + d)} = \frac{4(265\ 500)}{0.3(270 + 167)} = 8100.69\ \text{N} \qquad \text{(ii)}$$

11.3 There are two steel plates and one bronze plate. The total number of plates is 3.

number of disks = z +1 = 3

or $z = 2$

From Eq. (11.6),

$$P = \frac{\pi p_a d}{2}(D - d) = \frac{\pi\ (0.4)(200)}{2}(250 - 200) = 6283.19\ \text{N} \qquad \text{(i)}$$

From Eq. (11.10),

$$M_t = \frac{\mu\ P\ z}{4}(D + d) = \frac{(0.1)(6283.19)(2)}{4}(250 + 200) = 141\ 371.78\ \text{N-mm}$$

$$\text{kW} = \frac{2 \pi n\ M_t}{60\ \text{x}\ 10^6} = \frac{2\ \pi\ (720)(141\ 371.78)}{60\ \text{x}\ 10^6} = 10.66 \qquad \text{(ii)}$$

11.4 From Eq. (11.6),

$$P = \frac{\pi p_a d}{2}(D - d) = \frac{\pi\ (0.5)(100)}{2}(200 - 100) = 7853.98\ \text{N}$$

$$M_t = \frac{60\text{x}10^6\ (\text{kW})}{2\ \pi\ n} = \frac{60\text{x}10^6\ (15)}{2\ \pi\ (1440)} = 99\ 471.84\ \text{N} - \text{mm}$$

From Eq. (11.8),

$$z = \frac{4\ M_t}{\mu\ P\ (D+d)} = \frac{4(99\ 471.84)}{0.15(7853.98)(200+100)} = 1.13\ \text{ or }\ 2$$

Number of plates = z +1 = 2 +1 = 3

Two steel plates and one bronze plate (Ans.)

11.5 $\frac{D+d}{2} = 300$ D + d = 600 mm (a)

From Eq.(11.19),

$b = \frac{D-d}{2\sin\alpha}$ $100 = \frac{D-d}{2\ \sin(12.5^0)}$ D – d = 43.29 mm (b)

From (a) and (b),

D = 321.64 mm d = 278.36 mm

From Eq. (11.6),

$$P = \frac{\pi p_a d}{2}(D-d) = \frac{\pi\ (0.07)(278.36)}{2}(321.64-278.36) = 1324.68\ \text{N} \quad \text{(i)}$$

From Eq. (11.18),

$$M_t = \frac{\mu\ P(D+d)}{4\ \sin\alpha} = \frac{(0.2)(1324.68)(321.64+278.36)}{4\ \sin(12.5^o)} = 183\ 609.64\ \text{N}-\text{mm}$$

$$kW = \frac{2\pi n\ M_t}{60\ x\ 10^6} = \frac{2\ \pi\ (500)(183\ 609.64)}{60\ x\ 10^6} = 9.61 \quad \text{(ii)}$$

11.6 $\omega_2 = \frac{2\pi n_2}{60} = \frac{2\pi(720)}{60} = 75.40\ \text{rad/s}$

$\omega_1 = 0.75\ \omega_1 = 0.75(75.40) = 56.55\ \text{rad/s}$

$$M_t = \frac{60\ x\ 10^6\ (kW)}{2\pi n_2} = \frac{60\ x\ 10^6\ (18.5)}{2\pi(720)} = 245\ 363.87\ \text{N-mm}$$

From Eq. (11.23),

$$m = \frac{1000\ M_t}{\mu\, r_g\, r_d\, z\, (\omega_2^2 - \omega_1^2)} = \frac{1000\,(245\ 363.87)}{0.25(140)(165)(4)\,(75.4^2 - 56.55^2)}$$

$$= 4.27 \text{ kg} \qquad \text{(Ans.)}$$

CHAPTER 12

12.1 $v_1 = 95 \text{ km/hr} = \dfrac{95 \times 10^3}{60 \times 60} \text{ m/s} = 26.39 \text{ m/s}$ and $v_2 = 0$

$$\text{deceleration} = \frac{(v_1 - v_2)}{t} \qquad 6 = \frac{(26.39 - 0)}{t}$$

$t = 4.4$ s (i)

$$v_{ave} = \frac{1}{2} v_1 = \frac{1}{2}(26.39) \text{ m/s}$$

$$\text{distance} = v_{ave}\, t = \frac{1}{2}(26.39)(4.4) = 58.06 \text{ m} \qquad \text{(ii)}$$

KE of the vehicle = E_v

$$E_v = \frac{1}{2} m\,(v_1^2 - v_2^2) = \frac{1}{2}\left(\frac{13.5 \times 10^3}{9.81}\right)(26.39)^2 \qquad E_t = 1.1\,E_v$$

$$(E_t) \text{ per brake} = \frac{E_t}{4} = \left(\frac{1}{4}\right)(1.1)\left(\frac{1}{2}\right)\left(\frac{13.5 \times 10^3}{9.81}\right)(26.39)^2$$

$$= 131\,779 \text{ J} \qquad \text{(iii)}$$

$$\omega_{ave} = \frac{v_{ave}}{r} = \frac{26.39}{2(0.375)} \text{ rad/s}$$

$$\theta = \omega_{ave}\, t = \frac{26.39}{2(0.375)}(4.4) = 154.82 \text{ rad}$$

$$M_t = \frac{E_t}{\theta} = \frac{131\,779}{154.82} = 851.18 \text{ N} - \text{m} \qquad \text{(iv)}$$

$$\Delta_t = \frac{E_t}{m\,c} = \frac{131\,779}{10(460)} = 28.65^0 \qquad \text{(v)}$$

12.2 From Eq. (12.12),

$$h = \frac{4 R \sin\theta}{2\theta + \sin 2\theta} = \frac{4(150)\sin(45^0)}{\left(\frac{2x45\ \pi}{180}\right) + \sin(90^0)} = 165 \text{ mm} \qquad \text{(Ans.)}$$

12.3 From Eq. (12.6),

$$N = \frac{M_t}{\mu R} = \frac{(15 x 10^3)}{0.3(150)} = 333.33 \text{ N}$$

The free-body diagram of forces for clockwise rotation of the drum is shown in Fig. 12.1-solu. Taking moments about the hinge-pin,

$\mu N(60) + P(650) - N(200) = 0$ or

0.3(333.33)(60) + P(650) – 333.33(200) = 0

$\therefore$ P = 93.33 N (i)

N = l w p   333.33 = w^2 (1)

w = l = 18.26 mm (ii)

$$R_X = \mu N = 0.3(333.33) = 100 \text{ N}$$

$$R_Y = N - P = 333.33 - 93.33 = 240 \text{ N}$$

$$R = \sqrt{(100)^2 + (240)^2} = 260 \text{ N} \qquad \text{(iii)}$$

Initial velocity = $v_1 = \omega\, r = \left(\frac{2\ \pi\ n}{60}\right) r = \left[\frac{2\ \pi\ (50)}{60}\right](0.15) = 0.7854$ m/s

Final velocity = 0

$$v_{ave} = \frac{1}{2} v_1 = \frac{1}{2}(0.7854) = 0.3927 \text{ m/s}$$

Rate of heat generated = $\mu\ N\ v_{ave} = 0.3(333.33)(0.3927)$

= 39.27 N-m/s or W (iv)

12.4 R = 150 mm h = 125 mm C = 177 mm

$\theta_1 = 0$ $\theta_2 = 90^0$ $\phi_{max} = 90^0$ $\sin\phi_{max} = 1$

w = 50 mm p_{max} = 0.8 N/mm^2 μ = 0.4

From Eq. (12.19),

$$M_f = \frac{\mu\, p_{max}\, R\, w\left[4R(\cos\theta_1 - \cos\theta_2) - h(\cos 2\theta_1 - \cos 2\theta_2)\right]}{4\sin\phi_{max}}$$

$$= \frac{0.4(0.8)(150)(50)\left[4(150)(1-\cos\ 90^0) - 125(1-\cos 180^0)\right]}{4(1)}$$

= 210 000 N-mm

From Eq. (12.20),

$$M_n = \frac{p_{max}\, R\, w\, h\left[2(\theta_2 - \theta_1) - (\sin 2\theta_2 - \sin 2\theta_1)\right]}{4\sin\phi_{max}}$$

$$= \frac{0.8(150)(50)(125)\left[2\left(\frac{90\pi}{180}\right) - \sin(180^0)\right]}{4(1)}$$

= 589 048.62 N-mm

From Eq. (12.22),

$$P = \frac{M_n - M_f}{C} = \frac{589\ 048.62 - 210\ 000}{177} = 2141.52 \text{ N} \qquad \text{(i)}$$

` From Eq. (12.21), the torque $(M_t)_R$ for the right hand shoe is given by

$$(M_t)_R = \frac{\mu R^2 p_{max}\, w(\cos\theta_1 - \cos\theta_2)}{\sin\phi_{max}}$$

$$= \frac{0.4(150)^2(0.8)(50)(1-\cos 90^0)}{1}$$

= 360 000 N-mm

The maximum intensity of pressure for the left hand shoe is unknown. For identical shoes, it can be seen from the expressions of M_n and M_f, that both are proportional to (p_{max}). For left hand shoe, the maximum intensity of pressure is taken as (p'_{max}).

Therefore, for the left hand shoe,

$$M'_f = \frac{210000\ p'_{max}}{p_{max}} = \frac{(210000)\,p'_{max}}{(0.8)} = 262\ 500\,p'_{max}$$

Similarly,

$$M'_n = \frac{589\ 048.62\ p'_{max}}{p_{max}} = \frac{(589\ 048.62)\,p'_{max}}{(0.8)} = 736\ 310.78\,p'_{max}$$

For the left-hand shoe,

$$P = \frac{M'_n + M'_f}{C} \qquad \text{or} \qquad 2141.52 = \frac{(262\ 500 + 736\ 310.78)\,p'_{max}}{177}$$

$$\therefore \qquad p'_{max} = 0.3795\ \text{N/mm}^2$$

Since the shoes are identical,

$$(M_t)_L = 360000\left(\frac{p'_{max}}{p_{max}}\right) = 360000\left(\frac{0.3795}{0.8}\right) = 170\ 775\ \text{N}-\text{mm}$$

The total torque-absorbing capacity of the brake is given by,

$$M_t = 360\ 000 + 170\ 775 = 530\ 775\ \text{N-mm}$$

$$M_t = 530.78\ \text{N-m} \qquad \text{(ii)}$$

12.5 From Eq. (12.27),

$$P_1 = R\,w\,p_{max} = 250(60)(0.25) = 3750\ \text{N} \qquad \text{(i)}$$

$$e^{\mu\theta} = e^{0.4\left(\frac{225}{180}\right)\pi} = 4.81 \qquad \frac{P_1}{P_2} = 4.81$$

$$P_2 = \frac{P_1}{4.81} = \frac{3750}{4.81} = 779.63\ \text{N} \qquad \text{(i)}$$

P x 750 = P_2 x 250 = 779.63(250)

P = 259.88 N (ii)

$$M_t = (P_1 - P_2)R = (3750 - 779.63)(0.25) = 742.59\ \text{N} - \text{m} \qquad \text{(iii)}$$

CHAPTER 13

13.1 $$v = \frac{\pi d n}{60(1000)} = \frac{\pi (300)(720)}{60(1000)} = 11.31 \ m/s$$

$$(P_1 - P_2) = \frac{1000(kW)}{v} = \frac{1000(35)}{11.31} = 3094.61 \ N$$

$$P_1 = P_2 + 3094.61 \qquad \text{(a)}$$

$$m v^2 = 2(11.31)^2 = 255.83$$

$$\alpha_s = 180 - 2 \sin^{-1}\left(\frac{D-d}{2C}\right) = 180 - 2 \sin^{-1}\left(\frac{900-300}{2 \times 2000}\right) = 162.75^0$$

$$e^{f\alpha} = e^{(0.35)\left(\frac{162.75}{180}\right)\pi} = 2.70$$

From Eq. (13.6),

$$\frac{P_1 - m v^2}{P_2 - m v^2} = e^{f\alpha} \qquad \text{or} \qquad \frac{P_1 - 255.83}{P_2 - 255.83} = 2.70$$

$$P_1 - 2.70 \ P_2 + 434.91 = 0 \qquad \text{(b)}$$

From (a) and (b),

$$P_1 = 5170.80 \ N \qquad \text{and} \qquad P_2 = 2076.19 \ N \qquad \text{(i)}$$

From Eq. (13.3),

$$L = 2C + \frac{\pi(D+d)}{2} + \frac{(D-d)^2}{4\,C}$$

$$= 2(2000) + \frac{\pi(900+300)}{2} + \frac{(900-300)^2}{4\,(2000)}$$

$$= 5929.96 \ mm \qquad \text{(ii)}$$

13.2 $$v = \frac{\pi d n}{60(1000)} = \frac{\pi(250)(1000)}{60(1000)} = 13.09 \ \text{m/s}$$

$$(P_1 - P_2) = \frac{1000(\text{kW})}{v} = \frac{1000(7.5)}{13.09} = 572.96 \ \text{N}$$

$$P_1 = P_2 + 572.96 \qquad \text{(a)}$$

$$m v^2 = 0.55(13.09)^2 = 94.24$$

$$\alpha_s = 180 + 2 \sin^{-1}\left(\frac{D+d}{2C}\right) = 180 + 2 \sin^{-1}\left(\frac{500+250}{2 \text{x} 1500}\right) = 208.96^0$$

$$e^{f\alpha} = e^{(0.3)\left(\frac{208.96}{180}\right)\pi} = 2.99$$

From Eq. (13.6),

$$\frac{P_1 - m v^2}{P_2 - m v^2} = e^{f\alpha} \qquad \text{or} \qquad \frac{P_1 - 94.24}{P_2 - 94.24} = 2.99$$

$$P_1 - 2.99 P_2 + 187.54 = 0 \qquad \text{(b)}$$

From (a) and (b),

$P_1 = 955.12$ N and $P_2 = 382.16$ N (i)

From Eq. (13.5),

$$L = 2C + \frac{\pi(D+d)}{2} + \frac{(D+d)^2}{4C}$$

$$= 2(1500) + \frac{\pi(500+250)}{2} + \frac{(500+250)^2}{4(1500)}$$

$$= 4271.85 \ \text{mm} \qquad \text{(ii)}$$

13.3 $$d = \frac{60(1000)v}{\pi n} = \frac{60(1000)(13)}{\pi(1000)} = 248.28 \ \text{mm (or 250 mm)}$$

$$d = 250 \ \text{mm} \qquad \text{(i)}$$

$$D = \frac{250\,(1000)}{(500)} = 500 \text{ mm} \qquad \text{(i)}$$

The correct belt velocity is given by,

$$v = \frac{\pi\, d\, n}{60\,(1000)} = \frac{\pi\,(250)\,(1000)}{60\,(1000)} = 13.09 \text{ m / s}$$

From Eq. (13.5),

$$L = 2\,C + \frac{\pi\,(D+d)}{2} + \frac{(D+d)^2}{4\,C}$$

$$= 2\,(1500) + \frac{\pi\,(500+250)}{2} + \frac{(500+250)^2}{4\,(1500)}$$

$$= 4271.85 \text{ mm} \qquad \text{(ii)}$$

$$\alpha_s = 180 + 2\sin^{-1}\left(\frac{D+d}{2C}\right) = 180 + 2\sin^{-1}\left(\frac{500+250}{2\,x\,1500}\right) = 208.96^0$$

$$e^{f\,\alpha} = e^{(0.3)\left(\frac{208.96}{180}\right)\pi} = 2.99$$

$$m = (0.95x10^{-3})(100)\left(\frac{b}{10}\right)\left(\frac{6}{10}\right) = (5.7x10^{-3})\,b$$

$$m\,v^2 = (5.7x10^{-3})\,b\,(13.09)^2 = (0.977\,b)$$

From Eq. (13.6),

$$\frac{P_1 - m\,v^2}{P_2 - m\,v^2} = e^{f\,\alpha} \qquad \text{or} \qquad \frac{P_1 - 0.977\,b}{P_2 - 0.977\,b} = 2.99$$

$$P_1 - 2.99\,P_2 + 1.944\,b = 0 \qquad \text{(a)}$$

From Eq. (13.8),

$$P_1 - P_2 = \frac{1000(kW)}{v} = \frac{1000(7.5)}{13.09} = 572.96 \qquad \text{(b)}$$

$$P_1 = \sigma\,A = 1.75(6\,b) = (10.5\,b) \qquad \text{(c)}$$

From (a), (b) and (c),

b = 90.4 mm (ii)

P_1 = 949.2 N P_2 = 376.24 N (iii)

13.4 Assume v = 18 m/s

$$d = \frac{60(1000)v}{\pi n} = \frac{60(1000)(18)}{\pi(1440)} = 238.73 \text{ mm (or } 250 \text{ mm)}$$

d = 250 mm (i)

$$D = \frac{250(1440)}{(360)} = 1000 \text{ mm} \qquad \text{(i)}$$

The correct belt velocity is given by,

$$v = \frac{\pi d n}{60(1000)} = \frac{\pi(250)(1440)}{60(1000)} = 18.85 \text{ m / s}$$

$\therefore$ 17.8 < v < 22.9 m/s (o.k.)

Maximum power = 10 (load factor) = 10 (1.2) = 12 kW

$$\alpha_s = 180 - 2\sin^{-1}\left(\frac{D-d}{2C}\right) = 180 - 2\sin^{-1}\left(\frac{1000-250}{2 \text{ x } 2000}\right) = 158.39^0$$

Assuming linear interpolation of values in Table 13.2,

$$F_d = 1.08 + \frac{(1.13-1.08)}{(160-150)}(160-158.39) = 1.088$$

Corrected power = 1.088(12) = 13.056 kW

$$\text{Corrected belt rating} = (0.0118)\left(\frac{18.85}{5.08}\right) = 0.04379$$

$$\text{(width x number of plies)} = \left(\frac{13.056}{0.04379}\right) = 298.15$$

4 ply $\quad w = \left(\frac{298.15}{4}\right) = 74.54$ or 76 mm (standard size)

Belt specification = 4 ply x 76 mm wide belting (ii)

From Eq. (13.3),

$$L = 2C + \frac{\pi(D+d)}{2} + \frac{(D-d)^2}{4C}$$

$$= 2(2000) + \frac{\pi(1000+250)}{2} + \frac{(1000-250)^2}{4\,(2000)}$$

= 6033.81 or 6035 mm (iii)

13.5 Assume $\quad v = 18$ m/s

$$d = \frac{60(1000)\,v}{\pi n} = \frac{60(1000)(18)}{\pi(800)} = 429.72 \text{ mm (or 450 mm standard size)}$$

d = 450 mm (i)

$$D = \frac{450(800)}{(400)} = 900 \text{ mm}$$ (i)

The correct belt velocity is given by,

$$v = \frac{\pi d n}{60(1000)} = \frac{\pi(450)(800)}{60(1000)} = 18.85 \text{ m / s}$$

$\therefore \quad 17.8 < v < 22.9$ m/s (o.k.)

Maximum power = 30 (load factor) = 30 (1.3) = 39 kW

$$\alpha_s = 180 - 2\sin^{-1}\left(\frac{D-d}{2C}\right) = 180 - 2\sin^{-1}\left(\frac{900-450}{2 \text{ x } 3000}\right) = 171.4^0$$

Assuming linear interpolation of values in Table 13.2,

$$F_d = 1 + \frac{(1.04-1)}{(180-170)}(180-171.4) = 1.034$$

Corrected power = 1.034(39) = 40.33 kW

Corrected belt rating = $(0.0147)\left(\frac{18.85}{5.08}\right) = 0.0545$

(width x number of plies) = $\left(\frac{40.33}{0.0545}\right) = 740$

4 ply w = $\left(\frac{740}{4}\right) = 185$ mm

5 ply w = $\left(\frac{740}{5}\right) = 148$ or 152 mm (standard size)

Belt specification = 5 ply x 152 mm wide belting (ii)

From Eq. (13.3),

$$L = 2C + \frac{\pi(D+d)}{2} + \frac{(D-d)^2}{4C}$$

$$= 2(3000) + \frac{\pi(900+450)}{2} + \frac{(900-450)^2}{4\,(3000)}$$

= 8137.45 or 8138 mm (iii)

13.6 In this application, an induction motor is driving a compressor of 20 kW capacity for 15 hr per day. From Table 13.15, the correction factor according to service (F_a) is 1.2. Therefore,

Design power = F_a (transmitted power) = 1.2(20) = 24 kW

Plot a point with coordinates 24 kW and 1440 r.p.m. speed in Fig. 13.24. It is observed that the point is located in the region of C – section belt. Therefore, for this application the cross-section of V-belt is C. From Table13.12, the minimum pitch diameter for the smaller pulley of C section is 315 mm.

Speed ratio = $\frac{1440}{480} = 3$

d = 315 mm and D = 3(315) = 945 mm (ii)

From Eq. (13.3),

$$L = 2C + \frac{\pi(D+d)}{2} + \frac{(D-d)^2}{4C}$$

$$= 2(1200) + \frac{\pi(945+315)}{2} + \frac{(945-315)^2}{4\,(1200)}$$

= 4461.89 mm

From Table 13.14, the preferred pitch length for C- section belt is 4060 or 4600 mm. It is assumed that the pitch length of the belt is 4600 mm.

Belt specification = C section 4600 mm pitch length V belt (i)

Substituting this value of pitch length in Eq.(13.3),

$$L = 2C + \frac{\pi(D+d)}{2} + \frac{(D-d)^2}{4C}$$

$$4600 = 2C + \frac{\pi(945+315)}{2} + \frac{(945-315)^2}{4C}$$

Simplifying the above expression,

$$C^2 - 1310.4C + 49\,612.5 = 0$$

$$C = \frac{1310.4 \pm \sqrt{1310.4^2 - 4(49\,612.5)}}{2} = 1271.38\,\text{mm}$$

The correct center distance is 1271.38 mm. (iii)

From Table 13.21 (C-section and 4600 mm pitch length),

F_c = 1.05

From Eq. (13.1),

$$\alpha_s = 180 - 2\sin^{-1}\left(\frac{D-d}{2C}\right) = 180 - 2\sin^{-1}\left(\frac{945-315}{2 \text{ x } 1271.38}\right) = 151.31^0$$

From Table 13.22, F_d is approximately 0.93.

From Table 13.18, (1440 r.p.m., 315 mm pulley, C-section) (speed ratio = 3)

P_r = 14.76 + 1.27 = 16.03 kW

From Eq.(13.18),

$$\text{Number of belts} = \frac{P \text{ x } F_a}{P_r \text{ x } F_c \text{ x } F_d} = \frac{20\ (1.2)}{16.03(1.05)(0.93)}$$

Number of belts = 1.53 or 2 belts (iv)

13.7 In this application, an induction motor is driving a centrifugal pump for a service of 24 hr per day. From Table 13.15, the correction factor according to service (F_a) is 1.3. Therefore,

Design power = F_a (transmitted power) = 1.3(15) = 19.5 kW

Plot a point with coordinates 19.5 kW and 1440 r.p.m. speed in Fig. 13.24. It is observed that the point is located on the border of B and C – section belts. We will select B cross-section V-belt. From Table13.12, the minimum pitch diameter for the smaller pulley of B section is 200 mm.

$$\text{Speed ratio} = \frac{1440}{360} = 4$$

d = 200 mm and D = 4(200) = 800 mm (ii)

From Eq. (13.3),

$$L = 2C + \frac{\pi(D+d)}{2} + \frac{(D-d)^2}{4\,C}$$

$$= 2(1000) + \frac{\pi(800+200)}{2} + \frac{(800-200)^2}{4\,(1000)}$$

= 3660.80 mm

From Table 13.14, the preferred pitch length for B- section belt is 3600 or 4060 mm.

It is assumed that the pitch length of the belt is 3600 mm.

Belt specification = B section 3600 mm pitch length V belt (i)

Substituting this value of pitch length in Eq.(13.3),

$$L = 2C + \frac{\pi(D+d)}{2} + \frac{(D-d)^2}{4\,C}$$

$$3600 = 2C + \frac{\pi(800+200)}{2} + \frac{(800-200)^2}{4C}$$

Simplifying the above expression,

$$C^2 - 1014.6C + 45\,000 = 0$$

$$C = \frac{1014.6 \pm \sqrt{1014.6^2 - 4(45\,000)}}{2} = 968.12\,\text{mm}$$

The correct center distance is 968.12 mm. (iii)

From Table 13.21 (B-section and 3600 mm pitch length),

F_c = 1.1

From Eq. (13.1),

$$\alpha_s = 180 - 2\sin^{-1}\left(\frac{D-d}{2C}\right) = 180 - 2\sin^{-1}\left(\frac{800-200}{2\,x\;968.12}\right) = 143.90^0$$

From Table 13.22, F_d is approximately 0.90.

From Table 13.17, (1440 r.p.m., 200 mm pulley, B-section) (speed ratio = 4)

$P_r = 5.90 + 0.46 = 6.36$ kW

From Eq.(13.18),

$$\text{Number of belts} = \frac{P \times F_a}{P_r \times F_c \times F_d} = \frac{15\,(1.3)}{6.36\,(1.1)\,(0.90)}$$

Number of belts = 3.097 or 3 belts (iv)

13.8 $e = \dfrac{(P_1\, a + P_2\, b)}{W} = \dfrac{1500(75) + 500(250)}{100 \text{x} 9.81} = 242.1$ mm (Ans.)

CHAPTER 14

14.1 From Table 14.1, the pitch dimension (p) of I.S.O. 10B chain is 15.875 mm. When both shafts rotate at same speed, the number of teeth on driving and driven sprockets is same.

$z_2 = z_1 = 19$ teeth $\qquad p = 15.875$ mm $\qquad a = 550$ mm

From Eq. (14.6),

$$L_n = 2\left(\frac{a}{p}\right) + \left(\frac{z_1 + z_2}{2}\right) + \left(\frac{z_2 - z_1}{2\,\pi}\right)^2 \text{x} \left(\frac{p}{a}\right)$$

$$= 2\left(\frac{550}{15.875}\right) + \left(\frac{19+19}{2}\right) + 0$$

$$= 88.29 \text{ or } 88 \text{ links} \qquad \text{(i)}$$

From Eq. (14.7),

$$a = \frac{p}{4}\left\{\left[L_n - \left(\frac{z_1 + z_2}{2}\right)\right] + \sqrt{\left[L_n - \left(\frac{z_1 + z_2}{2}\right)\right]^2 - 8\left[\frac{z_2 - z_1}{2\,\pi}\right]^2}\right\}$$

Substituting, $\qquad z_2 = z_1$

$$a = \frac{p}{2}\left\{\left[L_n - \left(\frac{z_1 + z_2}{2}\right)\right]\right\} = \frac{15.875}{2}\left\{\left[88 - \left(\frac{19+19}{2}\right)\right]\right\}$$

$$= 547.69 \text{ mm} \qquad \text{(ii)}$$

14.2 Refer to Table 14.2. The kW rating of simple chain 08B at a speed of 200 r.p.m. is 1.18 kW.

For smooth operation without shock, (Table 14.3)

$K_s = 1$

From Table 14.4 (single strand),

$K_1 = 1$

From Table 14.5 (19 teeth),

$K_2 = 1.11$

From Eq. (14.8),

$$(\text{kW to be transmitted}) = (\text{kW rating of chain})\frac{K_1\ K_2}{K_s} = (1.18)\frac{(1)(1.11)}{1}$$

$$= 1.31 \qquad \text{(i)}$$

From Table 14.1, (chain 08B) p =12.7 mm

$$v = \frac{z\ p\ n}{60x10^3} = \frac{(19)(12.7)(200)}{60x10^3} = 0.8\ m/s \qquad \text{(ii)}$$

$$P_1 = \frac{1000\ kW}{v} = \frac{1000\ (1.31)}{0.8} = 1637.5\ \ N \qquad \text{(iii)}$$

From Table 14.1, the breaking load for simple 08B chain is 17 800 N.

$$(fs) = \frac{17\ 800}{1637.5} = 10.87 \qquad \text{(iv)}$$

14.3 Table 14.1 (chain 06B) p = 9.525 mm

From Eq. (14.2),

$$D_1 = \frac{p}{\sin\left(\frac{180}{z_1}\right)} = \frac{9.525}{\sin\left(\frac{180}{21}\right)} = 63.91\text{ mm} \qquad \text{(i)}$$

$$D_2 = \frac{p}{\sin\left(\frac{180}{z_2}\right)} = \frac{9.525}{\sin\left(\frac{180}{35}\right)} = 106.26\text{ mm} \qquad \text{(i)}$$

$$v = \frac{z\ p\ n}{60x10^3} = \frac{(21)(9.525)(500)}{60x10^3} = 1.667\,m/s \qquad \text{(ii)}$$

$$P_1 = \frac{1000\ kW}{v} = \frac{1000\ (1)}{1.667} = 599.88\ \ N \qquad \text{(iii)}$$

$$\text{Torque} = P_1\left(\frac{D_2}{2}\right) = (599.88)\left(\frac{106.26}{2}\right) = 31.87x10^3\ \text{N-mm}$$

$$= 31.87\ \text{N-m} \qquad \text{(iv)}$$

14.4 Assume $z_1 = 17$ (i)

$$z_2 = z_1\left(\frac{1400}{350}\right) = (17)\left(\frac{1400}{350}\right) = 68 \qquad \text{(i)}$$

For moderate shock with electric motor, (Table 14.3)

$K_s = 1.3$

From Table 14.4 (two strands),

$K_1 = 1.7$

From Table 14.5 (17 teeth),

$K_2 = 1$

From Eq. (14.8),

$$\text{kW rating of chain} = \frac{(\text{kW to be transmitted})\ x\ K_s}{K_1\ x\ K_2} = \frac{(15)\ (1.3)}{(1.7)(1)} = 11.47\ \text{kW}$$

Refer to Table 14.2. The required kW rating is 11.47 kW at 1400 r.p.m. Therefore, chain No.10 B (kW rating = 11.67) is suitable for the above application.

Recommended chain = 10B (ii)

From Table 14.1 p = 15.875 mm

From Eq. (14.2),

$$D_1 = \frac{p}{\sin\left(\frac{180}{z_1}\right)} = \frac{15.875}{\sin\left(\frac{180}{17}\right)} = 86.39 \text{ mm} \qquad \text{(iii)}$$

$$D_2 = \frac{p}{\sin\left(\frac{180}{z_2}\right)} = \frac{15.875}{\sin\left(\frac{180}{68}\right)} = 343.74 \text{ mm} \qquad \text{(iii)}$$

a = 40 p = 40 (15.875) = 635 mm

From Eq. (14.6),

$$L_n = 2\left(\frac{a}{p}\right) + \left(\frac{z_1 + z_2}{2}\right) + \left(\frac{z_2 - z_1}{2\pi}\right)^2 x \left(\frac{p}{a}\right)$$

$$= 2\left(\frac{635}{15.875}\right) + \left(\frac{17+68}{2}\right) + \left(\frac{68-17}{2\pi}\right)^2 x \left(\frac{15.875}{635}\right)$$

$$= 124.15 \text{ or } 124 \text{ links} \qquad \text{(iv)}$$

From Eq. (14.7),

$$a = \frac{p}{4}\left\{\left[L_n - \left(\frac{z_1+z_2}{2}\right)\right] + \sqrt{\left[L_n - \left(\frac{z_1+z_2}{2}\right)\right]^2 - 8\left[\frac{z_2-z_1}{2\pi}\right]^2}\right\}$$

$$= \frac{15.875}{4}\left\{\left[124 - \left(\frac{17+68}{2}\right)\right] + \sqrt{\left[124 - \left(\frac{17+68}{2}\right)\right]^2 - 8\left[\frac{68-17}{2\pi}\right]^2}\right\}$$

$$= 633.81 \text{ mm} \qquad \text{(v)}$$

CHAPTER 15

15.1 From Eq. (15.6),

$$L_{10} = \left(\frac{C}{P}\right)^p = \left(\frac{22.8}{10}\right)^3 = 11.85 \text{ million revolutions} \qquad \text{(i)}$$

$$L_{10h} = \frac{L_{10}\, x10^6}{60\ n} = \frac{(11.85)\, x10^6}{60\ (1450)} = 136.23 \text{ hr} \qquad \text{(ii)}$$

$$L_{50h} = 5\ L_{10h} = 5\ (136.23) = 681.17 \text{ hr} \qquad \text{(iii)}$$

15.2 $M_t = \mu\ F_r \left(\frac{D_i}{2}\right) = 0.0012\ (25x10^3)\left(\frac{40}{2}\right) = 600$ N-mm

$$(kW)_f = \frac{2\ \pi\ n\ M_t}{60x10^6} = \frac{2\ \pi\ (1440)\ (600)}{60x10^6} = 0.09 \qquad \text{(Ans.)}$$

15.3 From Eq. (15.2),

$$P = X\ F_r + Y\ F_a = 0.56(2500)+1.6(1000) = 3000 \text{ N}$$

$$L_{10} = \left(\frac{C}{P}\right)^p = \left(\frac{7350}{3000}\right)^3 \text{ million revolutions}$$

$$L_{10h} = \frac{L_{10}\, x10^6}{60\ n} = \left(\frac{7350}{3000}\right)^3 \frac{10^6}{60(720)} = 340.42 \text{ hr} \qquad \text{(Ans.)}$$

15.4 Consider the work cycle of one minute duration.

Element No.	P (N)	Element time (sec.)	Speed (r.p.m.)	Revolutions N in element time
1	3000	18	720	216
2	7000	30	1440	720
3	5000	12	900	180
Total		60	total	1116

Average speed of rotation = 1116 r.p.m. (i)

From Eq. (15.13),

$$P_e = \sqrt[3]{\left[\frac{N_1 P_1^3 + N_2 P_2^3 + N_3 P_3^3}{N_1 + N_2 + N_3}\right]}$$

$$= \sqrt[3]{\left[\frac{216(3000)^3 + 720(7\,000)^3 + 180(5000)^3}{1116}\right]}$$

$$= 6271.57 \text{ N} \qquad \text{(ii)}$$

According to the load-life relationship,

$$L_{10} = \left(\frac{C}{P_e}\right)^3 = \left(\frac{16.6 x 10^3}{6271.57}\right)^3 = 18.54 \quad \text{million rev.}$$

$$L_{10h} = \frac{L_{10} \text{ x } 10^6}{60 \text{ n}} = \frac{18.54 \text{ x } 10^6}{60 \text{ (1116)}} = 276.94 \text{ hr} \qquad \text{(iii)}$$

15.5 $$P_e = \sqrt[3]{\left[\frac{N_1 P_1^3 + N_2 P_2^3}{N_1 + N_2}\right]}$$

$$= \sqrt[3]{\left[\frac{5(2500)^3 + 10(1500)^3}{5+10}\right]}$$

$$= 1953.8 \text{ N}$$

$$C = P_e\ (L_{10})^{1/3} = 1953.8(20)^{1/3} = 5303.43\ \text{N} \qquad \text{(Ans.)}$$

15.6 $$L_{95} = \frac{60\,n\,L_{95h}}{10^6} = \frac{60(720)(10\ 000)}{10^6} = 432 \text{ million rev}$$

From Eq. (15.17),

$$\left(\frac{L_{95}}{L_{10}}\right) = \left[\frac{\log_e\left(\frac{1}{R_{95}}\right)}{\log_e\left(\frac{1}{R_{90}}\right)}\right]^{1/1.17} = \left[\frac{\log_e\left(\frac{1}{0.95}\right)}{\log_e\left(\frac{1}{0.90}\right)}\right]^{1/1.17} = 0.5405$$

$$L_{10} = \frac{L_{95}}{0.5405} = \frac{432}{0.5405} = 799.26 \text{ million revolutions}$$

$$C = P\ (L_{10})^{1/3} = 3000(799.26)^{1/3} = 27\ 840.94\ \text{N} \qquad \text{(i)}$$

$$R_s = (R)^N = (0.95)^4 = 0.8145 \quad \text{or} \quad 81.45\% \qquad \text{(ii)}$$

15.7 $R_s = (R)^N \qquad 0.82 = (R)^4 \qquad R = 0.95$

From Example 15.6,

$$\left(\frac{L_{95}}{L_{10}}\right) = 0.5405 \quad \text{or}$$

$$L_{10} = \frac{L_{95}}{0.5405} = \frac{5}{0.5405} = 9.25 \text{ million revolutions}$$

$$C = P\ (L_{10})^{1/3} = 2500(9.25)^{1/3} = 5247.92\ \text{N} \qquad \text{(Ans.)}$$

CHAPTER 16

16.1 From Eq. (16.10),

$$W = \frac{\pi P_i}{2}\left[\frac{R_o^2 - R_i^2}{\log_e\left(\frac{R_o}{R_i}\right)}\right] = \frac{\pi(5)}{2}\left[\frac{200^2 - 125^2}{\log_e\left(\frac{200}{125}\right)}\right] = 407\ 317.71\ \text{N}$$

W = 407.32 kN (i)

From Eq. (16.9),

$$Q = \frac{\pi P_i h_o^3}{6\mu \log_e\left(\frac{R_o}{R_i}\right)} = \frac{\pi(5)(0.15)^3}{6(30 \times 10^{-9}) \log_e\left(\frac{200}{125}\right)} = 626\ 642.63\ \ \text{mm}^3/\text{s}$$

= 626 642.63 (10^{-3}) (10^{-3}) 60 litre/min

= 37.598 or 37.6 litre/min (ii)

From Eq. (16.11),

$(kW)_p = Q(P_i – P_o)\ (10^{-6})=(626\ 642.63)[5 – 0]\ (10^{-6})$

= 3.13 (iii)

From Eq. (16.12),

$$(kW)_f = \left(\frac{1}{58.05 \times 10^6}\right)\frac{\mu n^2 (R_o^4 - R_i^4)}{h_o}$$

$$= \left(\frac{1}{58.05 \times 10^6}\right)\frac{(30 \times 10^{-9})(720)^2\left[(200)^4 - (125)^4\right]}{(0.15)}$$

= 2.42 (iv)

The total energy loss is given by

$(kW)_t = (kW)_p + (kW)_f = 3.13 + 2.42 = 5.55$ kW or kJ/s

$Q = 626\ 642.63\ mm^3/s$

$= 626\ 642.63(10^{-3})$ c.c./s

$= 626\ 642.63(10^{-3})\ (0.86)$ gm/s

$= 626\ 642.63(10^{-3})\ (0.86)\ (10^{-3})$ kg/s

$= 0.5389$ kg/s

$H = m\ C_p\ \Delta_t$ or $5.55 = 0.5389\ (1.75)\ \Delta_t$

$\Delta_t = 5.88^0C$ (v)

16.2 $W = (500x50)(P_i) + (2x500x225)(0.5\ P_i) = 137\ 500\ P_i$

$$P_i = \frac{W}{137\ 500} = \frac{500x10^3}{137\ 500} = 3.64\ N/mm^2 \text{ or MPa} \qquad (i)$$

From Eq. (16.7),

$$Q_1 = \frac{\Delta p\, b\, h^3}{12\, \mu\, l} = \frac{3.64\ (500)(0.2)^3}{12(500\, x\, 10^{-9})(225)} = (10.785x10^3)\ mm^3/s$$

$Q = 2\ Q_1(10^{-6})(60)$ litres/min

$= 2\ (10.785x10^3)(10^{-6})(60)$

$= 1.29$ l/min (ii)

16.3 For each pad $W = \frac{300}{4} = 75$ kN

From Eq. (16.10),

$$P_i = \frac{2W\log_e\left(\frac{R_o}{R_i}\right)}{\pi(R_o^2 - R_i^2)} = \frac{2(75 \times 10^3)\log_e\left(\frac{100}{25}\right)}{\pi(100^2 - 25^2)}$$

$= 7.06$ N/mm^2 or MPa (i)

From Eq. (16.4)

$$z_k = \left[0.22\,t - \frac{180}{t}\right] = \left[0.22(250) - \frac{180}{(250)}\right] = 54.28 \text{ cSt}$$

$z = \rho z_k = 0.88(54.28) = 47.77$ cP

$\mu = \frac{z}{10^9} = (47.77)(10^{-9})$ N-s/mm^2

From Eq.(16.9),

$$Q = \frac{\pi P_i h_o^3}{6\mu\log_e\left(\frac{R_o}{R_i}\right)} = \frac{\pi(7.06)(0.1)^3}{6(47.77)(10^{-9})\log_e\left(\frac{100}{25}\right)} = 55820.36 \text{ mm}^3\text{/s}$$

$Q_t = 4\,Q$

$= 4\,(55820.36)$ mm^3/s

$= 4\,(55820.36)\,(10^{-6})\,(60)$ l/min

$= 13.4$ l/min (ii)

16.4 Consider the flow of lubricant through a slot of length $R\,d\theta$ and thickness h_o as shown in Fig.16.1-solu.

$Q = \frac{\Delta p\, b\, h^3}{12\mu l}$ (a)

$\Delta_p = dp$ $\quad b = 2\pi\ R\ \sin\theta$ $\quad l = R\,d\theta$ $\quad h = h_o$

Substituting above values in Eq. (a),

$$dp = -\frac{6\,\mu Q}{\pi\ h_o^3}\,\frac{d\theta}{\sin\theta}$$ Intrgrating,

$$p = -\frac{6\,\mu Q}{\pi\ h_o^3}\,\log\left[\tan\left(\frac{\theta}{2}\right)\right] + C \qquad \text{(b)}$$

The first boundary condition is,

$p = 0$ when $\theta = \phi_1$

$$C = \frac{6\,\mu Q}{\pi\ h_o^3}\,\log\left[\tan\left(\frac{\phi_1}{2}\right)\right] \qquad \text{(c)}$$

From (b) and (c),

$$p = \frac{6\,\mu Q}{\pi\ h_o^3}\,\log_e\left\{\frac{\tan\left(\frac{\phi_1}{2}\right)}{\tan\left(\frac{\theta}{2}\right)}\right\} \qquad \text{(d)}$$

The second boundary condition is,

$p = P_i$ when $\theta = \phi_2$

Substituting above condition in Eq. (d),

$$P_i = \frac{6\,\mu Q}{\pi\ h_o^3}\,\log_e\left\{\frac{\tan\left(\frac{\phi_1}{2}\right)}{\tan\left(\frac{\phi_2}{2}\right)}\right\} \qquad \text{or}$$

$$Q = \frac{\pi\ P_i\ h_o^3}{6\ \mu\ \log_e\left[\frac{\tan(\phi_1/2)}{\tan(\phi_2/2)}\right]} \qquad \text{(i)}$$

The load carrying capacity is given by,

$$W = \pi\,(R\sin\phi_2)^2\,P_i + \int_{\phi_2}^{\phi_1}(2\pi R\sin\theta)\,R\,d\theta\,(p\cos\theta)$$

Substituting value of p from Eq. (d),

$$W = \pi P_i R^2\sin^2\phi_2 + \frac{6\,\mu Q R^2}{h_o^3}\int_{\phi_2}^{\phi_1}\log\left[\frac{\tan(\phi_1/2)}{\tan(\theta/2)}\right]\sin 2\theta\,d\theta \qquad \text{(e)}$$

Define I as,

$$I = \int\log\left[\frac{\tan(\phi_1/2)}{\tan(\theta/2)}\right]\sin 2\theta\,d\theta = \int u\ dv$$

where,

$$u = \log\left[\frac{\tan(\phi_1/2)}{\tan(\theta/2)}\right] \qquad \text{and} \qquad dv = \sin 2\theta\,d\theta$$

$$\therefore\ du = \frac{\tan(\theta/2)}{\tan(\phi_1/2)}\,x\,\frac{\tan(\phi_1/2)}{[-\tan^2(\theta/2)]}\,x\sec^2(\theta/2)\,x\,\frac{1}{2} = -\frac{1}{\sin\theta}$$

$$v = -\frac{\cos 2\theta}{2}$$

Since,

$$I = \int u\ dv = u\,v - \int v\ du$$

$$= -\frac{1}{2}\cos 2\theta\,\log\left[\frac{\tan(\phi_1/2)}{\tan(\theta/2)}\right] - \frac{1}{2}\int\frac{\cos 2\theta}{\sin\theta}\,d\theta$$

$$= -\frac{1}{2}\cos 2\theta\,\log\left[\frac{\tan(\phi_1/2)}{\tan(\theta/2)}\right] - \frac{1}{2}\left[\int\frac{d\theta}{\sin\theta} - 2\int\sin\theta\ d\theta\right]$$

$$= -\frac{1}{2}\cos 2\theta\,\log\left[\frac{\tan(\phi_1/2)}{\tan(\theta/2)}\right] - \frac{1}{2}\left[\log\tan\left(\frac{\theta}{2}\right) + 2\cos\theta\right]$$

Substituting limits,

$$I = \left[-\frac{1}{2}\cos 2\theta \,\log\left[\frac{\tan(\phi_1/2)}{\tan(\theta/2)}\right] - \frac{1}{2}\log\tan\left(\frac{\theta}{2}\right) - \cos\theta \right]_{\phi_2}^{\phi_1}$$

$$= +\frac{1}{2}\cos 2\phi_2 \;\log\left[\frac{\tan(\phi_1/2)}{\tan(\phi_2/2)}\right] - \frac{1}{2}\log\left[\frac{\tan(\phi_1/2)}{\tan(\phi_2/2)}\right] - (\cos\phi_1 - \cos\phi_2)$$

$$= -\log_e\left[\frac{\tan(\phi_1/2)}{\tan(\phi_2/2)}\right]\sin^2\phi_2 \;-(\cos\phi_1 - \cos\phi_2)$$

Substituting above expression in Eq.(e),

$$W = \frac{\pi\, P_i\, R^2 (\cos\phi_2 - \cos\phi_1)}{\log_e\left[\dfrac{\tan(\phi_1/2)}{\tan(\phi_2/2)}\right]} \qquad \text{(ii)}$$

16.5 $p = \dfrac{W}{l\,d} = \dfrac{50x10^3}{150x150} = 2.222 \;\; N/mm^2$

$\dfrac{h_o}{c} = \dfrac{0.03}{0.15} = 0.2 \qquad\qquad \dfrac{l}{d} = \dfrac{150}{150} = 1$

From Table 16.1, S = 0.0446

$$n_s = S\left(\frac{c}{r}\right)^2 \frac{p}{\mu} = (0.0446)\left(\frac{0.15}{75}\right)^2 \frac{2.222}{(8x10^{-9})} = 49.55 \;\; \text{rev/s}$$

n = 60 (49.55) = 2973 r.p.m. (Ans.)

16.6 $p = \dfrac{W}{l\,d} = \dfrac{50x10^3}{100x100} = 5 \;\; N/mm^2$

$$S = \left(\frac{r}{c}\right)^2 \frac{\mu\, n_s}{p} = \left(\frac{50}{0.12}\right)^2 \frac{(16x10^{-9})(1440/60)}{(5)} = 0.0133$$

The values of dimensionless performance parameters are obtained by linear interpolation from Table (16.1). For (l/d =1)

$$\left(\frac{h_o}{c}\right) = 0.03 + \frac{(0.1 - 0.03)}{(0.0188 - 0.00474)}(0.0133 - 0.00474) = 0.07262$$

$$h_o = 0.07262\ c = 0.07262(0.12) = 0.008714 \text{ mm} \quad \text{or} \quad 0.0087 \text{ mm} \qquad \text{(i)}$$

$$\left(\frac{r}{c}\right)f = 0.514 + \frac{(1.05 - 0.514)}{(0.0188 - 0.00474)}(0.0133 - 0.00474) = 0.84$$

$$f = 0.84\left(\frac{c}{r}\right) = 0.84\left(\frac{0.12}{50}\right) = 2.016x10^{-3} \qquad \text{(ii)}$$

$$(kW)_f = \frac{2\ \pi\ n_s\ f\ W\ r}{10^6} = \frac{2\ \pi\ (1440/60)\ (2.016x10^{-3})\ (50x10^3)\ (50)}{10^6} = 0.76 \qquad \text{(iii)}$$

16.7 l = d

$$p = \frac{W}{l\,d} \qquad (2.5) = \frac{25x10^3}{l^2}$$

l = d = 100 mm (i)

Refer to Chapter-3 for values of tolerances. The hole and shaft limits for H7e7 running fit are as follows:

Hole limits: (100.00) and (100.035) mm

Shaft limits: (100 - 0.072) and (100 - 0.107) mm

If the manufacturing processes are centered, the average diameter of the bearing and journal will be 100.0175 and 99.9105 mm respectively.

$$c = \left(\frac{1}{2}\right)(100.0175 - 99.9105) = 0.0535 \text{ mm}$$

$$S = \left(\frac{r}{c}\right)^2 \frac{\mu\, n_s}{p} = \left(\frac{50}{0.0535}\right)^2 \frac{(20x10^{-9})(900/60)}{(2.5)} = 0.1048$$

The values of dimensionless performance parameters are obtained by linear interpolation from Table (16.1). For (l/d =1)

$$\left(\frac{h_o}{c}\right) = 0.2 + \frac{(0.1048 - 0.0446)}{(0.121 - 0.0446)}(0.4 - 0.2) = 0.3576$$

$$h_o = 0.3576\,c = 0.3576\,(0.0535) = 0.0191\text{ mm} \qquad \text{(ii)}$$

$$\left(\frac{Q}{r\,c\,n_s\,l}\right) = 4.62 - \frac{(0.1048 - 0.0446)}{(0.121 - 0.0446)}(4.62 - 4.33) = 4.391$$

$Q = 4.391\ r\ c\ n_s\ l = 4.391(50)(0.0535)(15)(100)$

$= 17618.89\ \text{mm}^3/\text{s}$

$= 17618.89\ (60\text{x}10^{-6})$ litres/min

$= 1.057$ litres/min (iii)

16.8 $h_o = 5\left[\sum \text{surface roughness}\right] = 5(0.8 + 0.4) = 6\ \mu\text{m}$ (i)

$$c = \frac{1}{2}(50.02 - 49.93) = 0.045\text{ mm}$$

$$p = \frac{W}{l\,d} = \frac{8000}{50\text{x}50} = 3.2\ \text{N/mm}^2$$

$$S = \left(\frac{r}{c}\right)^2 \frac{\mu\,n_s}{p} = \left(\frac{25}{0.045}\right)^2 \frac{(12\text{x}10^{-9})(1440/60)}{(3.2)} = 0.02777$$

The values of dimensionless performance parameters are obtained by linear interpolation from Table (16.1). For (l/d =1)

$$\left(\frac{h_o}{c}\right) = 0.1 + \frac{(0.0278 - 0.0188)}{(0.0446 - 0.0188)}(0.2 - 0.1) = 0.1349$$

$$h_o = 0.1349\ c = 0.1349\,(0.045) = 0.00607\text{ mm or } 6.07\ \mu\text{m} \qquad \text{(ii)}$$

$$\left(\frac{r}{c}\right)f = 1.05 + \frac{(0.0278 - 0.0188)}{(0.0446 - 0.0188)}(1.7 - 1.05) = 1.277$$

$$r\,f = 1.277\,c = 1.277\,(0.045) = 0.05747$$

$$(kW)_f = \frac{2\,\pi\, n_s\; f\;\; W\, r}{10^6} = \frac{2\,\pi\,(1440/60)\;(0.05747)\;(8000)}{10^6} = 0.069 \qquad \text{(iii)}$$

CHAPTER 17

17.1 $z_p = 20$ $z_g = 100$ $m = 6$ mm

From Eq. (17.5),

$$a = \frac{m(z_p + z_g)}{2} = \frac{6(20+100)}{2} = 360 \text{ mm} \qquad \text{(i)}$$

$d_p^{'} = m\, z_p = 6(20) = 120$ mm

$d_g^{'} = m\, z_g = 6(100) = 600$ mm (ii)

addendum (h_a) = m = 6 mm

dedendum (h_f) = 1.25 m = 1.25(6) = 7.5 mm (iii)

tooth thickness = 1.5708 m = 1.5708(6) = 9.4248 mm

clearance (c) = 0.25 m = 0.25(6) = 1.5 mm (iv)

$$i = \frac{z_g}{z_p} = \frac{100}{20} = 5 \qquad \text{(vi)}$$

17.2 $z_p = 25$ $n_p = 1200$ r.p.m. $n_g = 200$ r.p.m. $m = 4$ mm

$$i = \frac{n_p}{n_g} = \frac{1200}{200} = 6$$

$$z_g = i\ z_p = 6(25) = 150$$

From Eq. (17.5),

$$a = \frac{m(z_p + z_g)}{2} = \frac{4(25+150)}{2} = 350 \text{ mm} \qquad \text{(Ans.)}$$

17.3 $a = 495$ mm $i = 4.5$ $m = 6$ mm

From Eq. (17.5),

$$a = \frac{m(z_p + z_g)}{2} \qquad 495 = \frac{6(z_p + z_g)}{2}$$

$$z_p + z_g = 165 \qquad \text{(a)}$$

$$\frac{z_g}{z_p} = 4.5 \qquad \text{(b)}$$

Solving (a) and (b),

$z_p = 30$ $\qquad z_g = 135$ $\qquad$ (Ans)

17.4 $d_1^{'} = m\ z_1 = 4(20) = 80\ \text{mm}$

$$d_3^{'} = m\ z_3 = 4(30) = 120\ \text{mm}$$

Forces between gears 1 and 2:

$$(M_t)_1 = \frac{60\ x\ 10^6\ (kW)}{2\ \pi\ n} = \frac{60\ x\ 10^6\ (5)}{2\ \pi(720)} = 66\ 314.56\ \text{N} - \text{mm}$$

$$P_t = \frac{2\ (M_t)_1}{d_1^{'}} = \frac{2(66\ 314.56)}{80} = 1657.86\ \text{N}$$

$$P_r = P_t\ \tan\alpha = 1657.86\ \tan(20) = 603.41\ \text{N} \qquad \text{(i)}$$

Forces between gears 3 and 4:

$$(M_t)_3 = \frac{z_2}{z_1}\ (M_t)_1 = \left(\frac{50}{20}\right)(66314.56) = 165\ 786.4$$

$$P_t = \frac{2\ (M_t)_3}{d_3^{'}} = \frac{2(165\ 786.4)}{120} = 2763.11\ \text{N}$$

$$P_r = P_t\ \tan\alpha = 2763.10\ \tan(20) = 1005.69\ \text{N} \qquad \text{(ii)}$$

17.5 Torques:

$$(M_t)_A = \frac{60 \text{ x } 10^6 \text{ (kW)}}{2\ \pi\ n} = \frac{60 \text{ x } 10^6 \text{ (10)}}{2\ \pi(1440)} = 66\ 314.56 \text{ N} - \text{mm}$$

$$(M_t)_B = \frac{z_2}{z_1}(M_t)_A = \left(\frac{100}{20}\right)(66314.56) = 331\ 572.8 \text{ N} - \text{mm}$$

$$(M_t)_C = \frac{z_4}{z_3}(M_t)_B = \left(\frac{150}{25}\right)(331\ 572.8) = 1\ 989\ 436.79 \text{ N} - \text{mm}$$

$$(M_t)_D = \frac{z_6}{z_5}(M_t)_C = \left(\frac{150}{25}\right)(1\ 989\ 436.8) = 11\ 936\ 620.73 \text{ N} - \text{mm} \qquad \text{(i)}$$

Gear tooth forces:

Forces between gears 1 and 2:

$$d_1^{'} = m\ z_1 = 5(20) = 100 \text{ mm}$$

$$P_t = \frac{2\ (M_t)_A}{d_1^{'}} = \frac{2(66\ 314.56)}{100} = 1326.29 \text{ N}$$

$$P_r = P_t \tan\alpha = 1326.29 \tan(20) = 482.73 \text{ N}$$

Forces between gears 3 and 4:

$$d_3^{'} = m\ z_3 = 6(25) = 150 \text{ mm}$$

$$P_t = \frac{2\ (M_t)_B}{d_3^{'}} = \frac{2(331\ 572.8)}{150} = 4420.97 \text{ N}$$

$$P_r = P_t \tan\alpha = 4420.97 \tan(20) = 1609.1 \text{ N}$$

Forces between gears 5 and 6:

$$d_5^{'} = m\ z_5 = 6(25) = 150 \text{ mm}$$

$$P_t = \frac{2\ (M_t)_C}{d_5^{'}} = \frac{2(1\ 989\ 436.79)}{150} = 26\ 525.82 \text{ N}$$

$$P_r = P_t \tan\alpha = 26\,525.82 \tan(20) = 9654.61 \text{ N} \qquad \text{(ii)}$$

Reactions at B_1 and B_2 :

Free body diagram of forces is shown in Fig.17.1-solu. It is observed that tangential components on gears 2 and 3 are in same direction. The radial components on gear 2 and 3 are in opposite directions. Refer to Fig. 17.2-solu (a).

Taking moments about bearing B_1,

$$(B_2)_h \text{ x } 350 = 4420.97 \text{ x } 100 + 1326.29 \text{ x } 250 \qquad (B_2)_h = 2210.48 \text{ N}$$

Taking moments about bearing B_2 ,

$$(B_1)_h \text{ x } 350 = 1326.29 \text{ x } 100 + 4420.97 \text{ x } 250 \qquad (B_1)_h = 3536.78 \text{ N}$$

Refer to Fig. 17.2-solu (b).

Taking moments about bearing B_1,

$$(B_2)_v \text{ x } 350 + 482.73 \text{ x } 250 = 1609.1 \text{ x } 100 \qquad (B_2)_v = 114.94 \text{ N}$$

Taking moments about bearing B_2 ,

$$(B_1)_v \text{ x } 350 + 482.73 \text{ x } 100 = 1609.1 \text{ x } 250 \qquad (B_1)_v = 1011.43 \text{ N}$$

Resultant reactions:

$$B_1 = \sqrt{3536.78^2 + 1011.43^2} = 3678.56 \text{ N}$$

$$B_2 = \sqrt{2210.48^2 + 114.94^2} = 2213.47 \text{ N} \qquad \text{(iii)}$$

Reactions at C_1 and C_2 :

Free body diagram of forces is shown in Fig.17.3-solu. It is observed that tangential components on gears 4 and 5 are in same direction. The radial components on gear 4 and 5 are in opposite directions. Refer to Fig. 17.4-solu (a).

Taking moments about bearing C_1,

$(C_2)_h \text{ x } 350 = 4420.97 \text{ x } 250 + 26525.82 \text{ x } 100 \qquad (C_2)_h = 10736.64 \text{ N}$

Taking moments about bearing C_2 ,

$(C_1)_h \text{ x } 350 = 26525.82 \text{ x } 250 + 4420.97 \text{ x } 100 \qquad (C_1)_h = 20210.15 \text{ N}$

Refer to Fig. 17.4-solu (b).

Taking moments about bearing C_1,

$(C_2)_v \text{ x } 350 + 1609.1 \text{ x } 250 = 9654.61 \text{ x } 100 \qquad (C_2)_v = 1609.1 \text{ N}$

Taking moments about bearing C_2 ,

$(C_1)_v \text{ x } 350 + 1609.1 \text{ x } 100 = 9654.61 \text{ x } 250 \qquad (C_1)_v = 6436.41 \text{ N}$

Resultant reactions:

$$C_1 = \sqrt{20210.15^2 + 6436.41^2} = 21210.32 \text{ N}$$

$$C_2 = \sqrt{10736.64^2 + 1609.1^2} = 10856.55 \text{ N} \qquad \text{(iv)}$$

17.6 Torques:

$$(M_t)_1 = \frac{60 \text{ x } 10^6 \text{ (kW)}}{2 \pi n} = \frac{60 \text{ x } 10^6 \text{ (50)}}{2 \pi (300)} = 1\,591\,549.43 \text{ N} - \text{mm}$$

$$(M_t)_2 = \frac{z_2}{z_1} (M_t)_1 = \left(\frac{60}{30}\right)(1\,591\,549.4) = 3\,183\,098.86 \text{ N} - \text{mm}$$

Gear tooth forces:

Forces between gears 1 and 2:

$$d_1' = m\, z_1 = 8(30) = 240 \text{ mm}$$

$$P_t = \frac{2\,(M_t)_1}{d_1'} = \frac{2(1\,591\,549.43)}{240} = 13\,262.91 \text{ N}$$

$$P_r = P_t \tan\alpha = 13\,262.91 \tan(20) = 4827.31\,\text{N}$$

Forces between gears 3 and 4:

$$d_3' = m\,z_3 = 8(25) = 200\ \text{mm}$$

$$P_t = \frac{2\,(M_t)_2}{d_3'} = \frac{2(3\,183\,098.83)}{200} = 31\,830.99\ \text{N}$$

$$P_r = P_t \tan\alpha = 31\,830.99\ \tan(20) = 11\,585.53\ \text{N} \qquad \text{(i)}$$

Reactions at B_1 and B_2 :

Free body diagram of forces is shown in Fig.17.5-solu.

Refer to Fig. 17.6-solu (a).

Taking moments about bearing B_1,

$$(B_2)_v \times 625 + 31830.99 \times 150 = 4827.31 \times 500 \qquad (B_2)_v = -\,3777.59\ \text{N}$$

Taking moments about bearing B_2 ,

$$(B_1)_v \times 625 = 4827.31 \times 125 + 31830.99 \times 775 \qquad (B_1)_v = 40435.89\ \text{N}$$

Refer to Fig. 17.6-solu (b).

Taking moments about bearing B_1,

$$(B_2)_h \times 625 + 11585.53 \times 150 = 13262.91 \times 500 \qquad (B_2)_h = 7829.80\ \text{N}$$

Taking moments about bearing B_2 ,

$$(B_1)_h \times 625 = 13262.91 \times 125 + 11585.53 \times 775 \qquad (B_1)_h = 17018.64\ \text{N}$$

Resultant reactions:

$$B_1 = \sqrt{40435.89^2 + 17018.64^2} = 43\,871.35\ \text{N}$$

$$B_2 = \sqrt{3777.59^2 + 7829.80^2} = 8693.44\ \text{N} \qquad \text{(ii)}$$

17.7 From Table17.3 Lewis form factor Y for 24 teeth is 0.337

From Eq.(17.16),

$$S_b = m\ b\ \sigma_b\ Y = 3(30)\left(\frac{600}{3}\right)(0.337) = 6066\ N \qquad \text{(i)}$$

$$d_p^{'} = m\ z_p = 3(24) = 72\ mm$$

$$v = \frac{\pi\ d_p^{'}\ n_p}{60\ x\ 10^3} = \frac{\pi\ (72)\ (1200)}{60\ x\ 10^3} = 4.52\ m/s$$

$$C_v = \frac{3}{3+v} = \frac{3}{3+4.52} = 0.3987 \qquad \text{(ii)}$$

$$S_b = P_{eff}\ (fs)$$

$$S_b = \frac{C_s}{C_v}\ P_t\ (fs) \qquad 6066 = \frac{(1.5)}{(0.3987)}\ P_t\ (1.5)$$

$$P_t = 1074.90\ N$$

$$M_t = P_t\left(\frac{d_p^{'}}{2}\right) = 1074.90\left(\frac{72}{2}\right)\ N-mm$$

$$kW = \frac{2\ \pi\ n\ M_t}{60x10^6} = \frac{2\ \pi\ (1200)(1074.90)(72/2)}{60x10^6} = 4.86 \qquad \text{(iii)}$$

17.8 $$M_t = \frac{60\ x\ 10^6\ (kW)}{2\ \pi\ n_p} = \frac{60\ x\ 10^6\ (5)}{2\ \pi\ (500)} = 95\ 492.97\ N-mm$$

$$P_t = \frac{2\ M_t}{d_p^{'}} = \frac{2\ (95\ 492.97)}{100} = 1909.86\ N$$

$$v = \frac{\pi\ d_p^{'}\ n_p}{60\ x\ 10^3} = \frac{\pi\ (100)\ (500)}{60\ x\ 10^3} = 2.618\ m/s$$

$$C_v = \frac{3}{3+v} = \frac{3}{3+2.618} = 0.534$$

$$P_{eff} = \frac{C_s}{C_v} P_t = \frac{1.5\ (1909.86)}{0.534} = 5364.78\ N$$

It is assumed that gear is weaker than pinion and Lewis form factor for gear is approximately 0.42.

$$S_b = m\ b\ \sigma_b\ Y = m(10m)\left(\frac{300}{3}\right)(0.42) = \left(420\ m^2\right) N$$

$S_b = P_{eff}\ (fs)$ $\quad$ $420\ m^2 = 5364.78\ (1.5)$ $\quad$ $m = 4.38$ mm

The first preference value of module is 5 mm.

m = 5 mm $\qquad$ (i)

$$z_p = \frac{d'_p}{m} = \frac{100}{5} = 20 \qquad z_g = \frac{d'_g}{m} = \frac{300}{5} = 60 \qquad \text{(ii)}$$

Check for design:

Fro Table 17.3,

$Y_p = 0.32$ (for 20 teeth) $\qquad$ $Y_g = 0.421$ (for 60 teeth)

$$(\sigma_b\ Y)_p = 0.32(200) = 64$$

$$(\sigma_b\ Y)_g = 0.421(100) = 42.1$$

Therefore, gear is weaker than pinion.

17.9 $$M_t = \frac{60 \times 10^6\ (kW)}{2\ \pi\ n_p} = \frac{60 \times 10^6\ (7.5)}{2\ \pi\ (1000)} = 71\,619.72\ N-mm$$

$$d'_p = m\ z_p = 4(25) = 100\ mm$$

$$P_t = \frac{2\ M_t}{d_p^{'}} = \frac{2\ (71\ 619.72)}{100} = 1432.39\ \text{N}$$

$$v = \frac{\pi\ d_p^{'}\ n_p}{60\ \text{x}\ 10^3} = \frac{\pi\ (100)\ (1000)}{60\ \text{x}\ 10^3} = 5.236\ \text{m/s}$$

$$C_v = \frac{3}{3 + v} = \frac{3}{3 + 5.236} = 0.3643$$

$$P_{eff} = \frac{C_s}{C_v}\ P_t = \frac{2\ (1432.39)}{0.3643} = 7863.79\ \text{N} \qquad \text{(i)}$$

From Table17.3 Lewis form factor Y for 25 teeth is 0.34

$$P_{eff} = S_b = m\ b\ \sigma_b\ Y$$

$$7863.79 = 4\ (45)\ \sigma_b\ (0.34)$$

$$\sigma_b = 128.49\ \text{N/mm}^2 \qquad \text{(ii)}$$

17.10 $$Q = \frac{2\ z_g}{z_g + z_p} = \frac{2\ (60)}{60 + 25} = 1.4118$$

$$K = 0.16\left(\frac{BHN}{100}\right)^2 = 0.16\left(\frac{220}{100}\right)^2 = 0.7744$$

$$d_p^{'} = m\ z_p = 5(25) = 125\ \text{mm}$$

$$S_w = b\ Q\ d_p^{'}\ K = 45(1.4118)(125)(0.7744) = 6149.8\ \text{N} \qquad \text{(i)}$$

$$v = \frac{\pi\ d_p^{'}\ n_p}{60\ \text{x}\ 10^3} = \frac{\pi\ (125)\ (500)}{60\ \text{x}\ 10^3} = 3.2725\ \text{m/s}$$

$$C_v = \frac{3}{3 + v} = \frac{3}{3 + 3.2725} = 0.4783$$

$$S_w = \frac{C_s}{C_v}\ P_t\ (fs) \qquad 6149.8 = \frac{1.75}{0.4783}\ P_t\ (2)$$

$$P_t = 840.41 \text{ N} \qquad \text{(ii)}$$

$$M_t = P_t\left(\frac{d_p'}{2}\right) = 840.41\left(\frac{125}{2}\right) = 52525.88 \text{ N} - \text{mm}$$

$$kW = \frac{2\,\pi\,n\,M_t}{60x10^6} = \frac{2\,\pi\,(500)(52525.88)}{60x10^6} = 2.75 \qquad \text{(iii)}$$

7.11 Beam strength:

From Table17.3 Lewis form factor Y for 24 teeth is 0.337

$$S_b = m\ b\ \sigma_b\ Y = 6(60)\left(\frac{450}{3}\right)(0.337) = 18\,198 \text{ N} \qquad \text{(i)}$$

Wear strength:

$$Q = \frac{2\ z_g}{z_g + z_p} = \frac{2\ (48)}{(48 + 24)} = 1.333$$

$$K = 0.16\left(\frac{BHN}{100}\right)^2 = 0.16\left(\frac{250}{100}\right)^2 = 1$$

$$d_p' = m\ z_p = 6(24) = 144 \text{ mm}$$

$$S_w = b\ Q\ d_p'\ K = 60(1.333)(144)(1) = 11\,517.12 \text{ N} \qquad \text{(ii)}$$

$$v = \frac{\pi\ d_p'\ n_p}{60 \text{ x } 10^3} = \frac{\pi\ (144)\ (1000)}{60 \text{ x } 10^3} = 7.5398 \text{ m/s}$$

$$C_v = \frac{3}{3 + v} = \frac{3}{3 + 7.5398} = 0.2846$$

$$S_w < S_b$$

$$S_w = \frac{C_s}{C_v} P_t\ (fs) \qquad 11\,517.12 = \frac{1.5}{0.2846} P_t\ (2)$$

$$P_t = 1092.59 \text{ N}$$

$$M_t = P_t \left(\frac{d_p'}{2}\right) = 1092.59\left(\frac{144}{2}\right) = 78\ 666.48 \text{ N} - \text{mm}$$

$$kW = \frac{2\ \pi\ n\ M_t}{60x10^6} = \frac{2\ \pi\ (1000)(78\ 666.48)}{60x10^6} = 8.24 \qquad \text{(iii)}$$

17.12 $z_p = 18$

$$z_g = i\ z_p = \left(\frac{720}{144}\right)(18) = 90 \qquad \text{(i)}$$

$$C_v = \frac{3}{3+v} = \frac{3}{3+5} = \frac{3}{8}$$

From Table17.3 Lewis form factor Y for 18 teeth is 0.308

$$m = \left[\frac{60\ x\ 10^6}{\pi}\left\{\frac{(kW)\ C_s\ (fs)}{z_p\ n_p\ C_v\left(\frac{b}{m}\right)\left(\frac{S_{ut}}{3}\right)Y}\right\}\right]^{1/3}$$

$$= \left[\frac{60\ x\ 10^6}{\pi}\left\{\frac{(5)\ (1.25)\ (2)}{(18)\ (720)\left(\frac{3}{8}\right)(10)\left(\frac{410}{3}\right)(0.308)}\right\}\right]^{1/3} = 4.89 \text{ mm}$$

The first preference value of the module is 5 mm.

m = 5 mm (ii)

$$d_p' = m\ z_p = 5(18) = 90 \text{ mm}$$

$$d_g' = m\ z_g = 5(90) = 450 \text{ mm}$$

b = 10 m = 10 (5) = 50 mm (iii)

Static load:

$$M_t = \frac{60 \text{ x } 10^6 \text{ (kW)}}{2 \pi n_p} = \frac{60 \text{ x } 10^6 (5)}{2 \pi (720)} = 66\ 314.56 \text{ N} - \text{mm}$$

$$P_t = \frac{2 M_t}{d_p^{'}} = \frac{2 (66\ 314.56)}{90} = 1473.66 \text{ N}$$

Dynamic load:

For Grade 6,

$e = 8 + 0.63\ \phi$

For pinion,

$$\phi = m + 0.25 \sqrt{d_p^{'}} = 5 + 0.25 \sqrt{90}$$

$e_p = 8 + 0.63\ \phi = 12.644\ \mu m$

For gear,

$$\phi = m + 0.25 \sqrt{d_g^{'}} = 5 + 0.25 \sqrt{450}$$

$e_p = 8 + 0.63\ \phi = 14.491\ \mu m$

$\therefore e = e_p + e_g = 12.644 + 14.491 = 27.135\ \mu m$ or $(27.135 \text{ x } 10^{-3})$ mm

From Table 17.7, the value of deformation factor C is 11 400 N/mm^2.

$$v = \frac{\pi d_p^{'} n_p}{60 \text{ x } 10^3} = \frac{\pi (90)(720)}{60 \text{ x } 10^3} = 3.3929 \text{ m/s}$$

From Eq. (17.26),

$$P_d = \frac{21 v\ (C e b + P_t)}{21 v + \sqrt{(C e b + P_t)}}$$

$$= \frac{21\,(3.3929)\ \left[11\,400\,(27.135 \text{ x } 10^{-3})\,(50)\ +\ 1473.66\right]}{21\,(3.3929)\ +\ \sqrt{\left[11\,400\,(27.135 \text{ x } 10^{-3})\,(50)\ +\ 1473.66\right]}}$$

$= 5993\ \text{N}$

Effective load:

$P_{eff} = (C_s\,P_t + P_d) = 1.25(1473.66) + 5993 = 7835.08\ \text{N}$

Beam strength:

$$S_b = m\ b\ \sigma_b\ Y = 5(50)\left(\frac{410}{3}\right)(0.308) = 10\,523.33\ \text{N}$$

$$(fs) = \frac{S_b}{P_{eff}} = \frac{10\,523.33}{7835.08} = 1.34 \qquad \text{(iv)}$$

Surface hardness:

$S_w = (fs)\,P_{eff} = 2\,(7835.08) = 15670.16\ \text{N}$

$$Q = \frac{2\ z_g}{z_g + z_p} = \frac{2\ (90)}{(90 + 18)} = 1.667$$

$S_w = b\ Q\ d_p^{'}\ K$

$$15670.16 = 50(1.667)(90)\ (0.16)\left(\frac{BHN}{100}\right)^2$$

BHN = 361.33 or 370 (v)

CHAPTER 18

18.1 From Eq.(18.7),

$$a = \frac{m_n\ (z_1 + z_2)}{2 \cos \psi} \qquad \text{or} \qquad 165 = \frac{4\ (25 + 50)}{2 \cos \psi}$$

$$\psi = 24.62^0 \qquad \text{(Ans)}$$

18.2 $$d_p = \frac{z_p\ m_n}{\cos \psi} = \frac{20\ (5)}{\cos (15^0)} = 103.53 \text{ mm}$$

$$d_g = \frac{z_g\ m_n}{\cos \psi} = \frac{60\ (5)}{\cos (15^0)} = 310.58 \text{ mm} \qquad \text{(i)}$$

$$a = \frac{m_n\ (z_1 + z_2)}{2 \cos \psi} = \frac{5\ (20 + 60)}{2 \cos 15^0} = 207.06 \text{ mm} \qquad \text{(ii)}$$

18.3 $$m = \frac{m_n}{\cos \psi} = \frac{3}{\cos (23^0)} = 3.26 \text{ mm} \qquad \text{(i)}$$

$$\tan \alpha = \frac{\tan \alpha_n}{\cos \psi} = \frac{\tan (20^0)}{\cos (23^0)} \qquad \text{or} \qquad \alpha = 21.57^0 \qquad \text{(ii)}$$

$$p_a = \frac{p}{\tan \psi} = \frac{\pi\ m}{\tan \psi} = \frac{\pi\ (3.26)}{\tan (23^0)} = 24.13 \text{ mm} \qquad \text{(iii)}$$

18.4 $$(M_t) = \frac{60 \times 10^6\ (kW)}{2\ \pi\ n} = \frac{60 \times 10^6\ (7.5)}{2\ \pi\ (2000)} = 35\,809.86 \text{ N} - \text{mm}$$

$$d = \frac{z\ m_n}{\cos \psi} = \frac{18\ (6)}{\cos (23^0)} = 117.33 \text{ mm}$$

$$P_t = \frac{2\ (M_t)}{d} = \frac{2\ (35\ 809.86)}{117.33} = 610.41\ \text{N}$$

$$P_a = P_t \tan\psi = 610.41\ \tan(23^0) = 259.10\ \text{N}$$

$$P_r = P_t \left[\frac{\tan\alpha_n}{\cos\psi}\right] = 610.41 \left[\frac{\tan\ (20^0)}{\cos\ (23^0)}\right] = 241.36\ \text{N}$$

18.5 $a = \dfrac{m_n\ (z_1 + z_2)}{2\cos\psi}$ $\qquad 285 = \dfrac{5\ (35 + 70)}{2\cos\psi}$

$\psi = 22.92^0$ (i)

Beam strength:

Since both gears are made of the same material, the pinion is weaker than the gear.

$$z_p' = \frac{z_p}{\cos^3\psi} = \frac{35}{\cos^3(22.92^0)} = 44.79$$

From Table17.3,

$$Y = 0.389 + \frac{(0.399-0.389)(44.79-40)}{(45-40)} = 0.3986$$

$$\sigma_b = \frac{S_u}{3} = \frac{600}{3} = 200\ \text{N/mm}^2$$

$S_b = m_n\ b\ \sigma_b\ Y = 5(50)(200)(0.3986) = 19\ 930$ N (ii)

Wear strength:

$$Q = \frac{2\ z_g}{z_g + z_p} = \frac{2(70)}{70+35} = 1.333$$

$$d_p = \frac{z_p\ m_n}{\cos\psi} = \frac{35(5)}{\cos(22.92^0)} = 190\ \text{mm}$$

$$K = 0.16 \left(\frac{BHN}{100}\right)^2 = 0.16 \left(\frac{300}{100}\right)^2 = 1.44 \ N/mm^2$$

$$S_w = \frac{b\ Q\ d_p\ K}{\cos^2 \psi} = \frac{50(1.333)(190)(1.44)}{\cos^2 (22.92^0)} = 21495.64 \text{ N} \qquad \text{(iii)}$$

Static load:

$$M_t = \frac{60 \times 10^6 \,(kW)}{2\ \pi\ n_p} = \frac{60 \times 10^6 \,(20)}{2\ \pi\ (720)} = 265\ 258.24\ \text{N} - \text{mm}$$

$$P_t = \frac{2\ M_t}{d_p} = \frac{2(265\ 258.24)}{190} = 2792.19 \quad \text{N} \qquad \text{(iv)}$$

Dynamic load:

From Table 17.8, the error for Grade 6 is given by,

$e = 8 + 0.63\ \phi$ where $\phi = m_n + 0.25\ \sqrt{d}$

For pinion,

$\phi = m_n + 0.25\ \sqrt{d}_p = 5 + 0.25\ \sqrt{190}$

$e_p = 8 + 0.63\ (5 + 0.25\ \sqrt{190}\ ) = 13.32\ \ \mu m$

For gear,

$$d_g = \frac{z_g\ m_n}{\cos \psi} = \frac{70(5)}{\cos (22.92^0)} = 380\ \text{mm}$$

$\phi = m_n + 0.25\ \sqrt{d}_g = 5 + 0.25\ \sqrt{380}$

$e_g = 8 + 0.63\ (5 + 0.25\ \sqrt{380}) = 14.22\ \mu m$

$e = e_p + e_g = 13.32 + 14.22 = 27.54\ \mu m$ or (27.54×10^{-3}) mm

Also, $C = 11400$ N/mm^2 $b = 50$ mm $P_t = 2792.19$ N

$$v = \frac{\pi\ d_p\ n_p}{60\ \times 10^3} = \frac{\pi\ (190)(720)}{60\ \times 10^3} = 7.163\ m/s$$

From Eq. (18.21),

$$P_d = \frac{21\ v\ (C\ e\ b\ \cos^2\ \psi + P_t)\ \cos\psi}{21\ v + \sqrt{(C\ e\ b\ \cos^2\ \psi\ + P_t)}}$$

$$= \frac{21\ (7.163)\ \left[11400\,(27.54\ x\ 10^{-3})\ (50)\ \cos^2(22.92) + 2792.19\right]\cos(22.92)}{21(7.163) + \sqrt{\left[11400\,(27.54\ x\ 10^{-3})\ (50)\ \cos^2(22.92) + 2792.19\right]}}$$

$= 8047.29$ N (v)

From Eq. (18.22),

$P_{eff} = (C_s\ P_t + P_d) = 1.25(2792.19) + 8047.29 = 11\ 537.53$ N (vi)

For bending,

$$(fs) = \frac{S_b}{P_{eff}} = \frac{19\ 930}{11\ 537.53} = 1.73 \qquad \text{(vii)}$$

For pitting,

$$(fs) = \frac{S_w}{P_{eff}} = \frac{21\ 495.64}{11\ 537.53} = 1.86 \qquad \text{(viii)}$$

CHAPTER 19

19.1 $D_p = m\ z_p = 4(30) = 120 \text{ mm}$

$D_g = m\ z_g = 4(48) = 192 \text{ mm}$ (i)

$\tan\gamma = \dfrac{z_p}{z_g} = \dfrac{30}{48}$ $\gamma = 32^0$

$\tan\Gamma = \dfrac{z_g}{z_p} = \dfrac{48}{30}$ $\Gamma = 58^0$ (ii)

$$A_0 = \sqrt{\left(\frac{D_p}{2}\right)^2 + \left(\frac{D_g}{2}\right)^2} = \sqrt{\left(\frac{120}{2}\right)^2 + \left(\frac{192}{2}\right)^2}$$

$A_0 = 113.21 \text{ mm}$ (iii)

19.2 $M_t = \dfrac{60 \text{ x } 10^6 \text{ (kW)}}{2\ \pi\ n_p} = \dfrac{60 \text{ x } 10^6 \text{ (5)}}{2\ \pi\ (800)} = 59\ 683.1 \text{ N} - \text{mm}$

$\tan\gamma = \dfrac{z_p}{z_g} = \dfrac{1}{2} = 0.5$ or $\gamma = 26.565^0$

$$r_m = \left[\frac{D_p}{2} - \frac{b\sin\gamma}{2}\right] = \left[\frac{80}{2} - \frac{40\sin(26.565)}{2}\right] = 31.056 \text{ mm}$$

$P_t = \dfrac{M_t}{r_m} = \dfrac{59\ 683.1}{31.056} = 1921.79 \text{ N}$ (i)

$P_r = P_t \tan\alpha\ \cos\gamma = 1921.79\ \tan(20)\ \cos(26.565) = 625.63 \text{ N}$ (ii)

$P_a = P_t \tan\alpha\ \sin\gamma = 1921.79\ \tan(20)\ \sin(26.565) = 312.81 \text{ N}$ (iii)

19.3 Since the same material is used for both pinion and gear, the pinion is weaker than the gear.

$$D_p = m\ z_p = 6(30) = 180\ \text{mm}$$

$$D_g = m\ z_g = 6(45) = 270\ \text{mm}$$

$$A_o = \sqrt{\left(\frac{D_p}{2}\right)^2 + \left(\frac{D_g}{2}\right)^2} = \sqrt{\left(\frac{180}{2}\right)^2 + \left(\frac{270}{2}\right)^2} = 162.25\ \text{mm}$$

$$\tan\gamma = \frac{z_p}{z_g} = \frac{30}{45} \qquad \text{or} \qquad \gamma = 33.69^0$$

$$z_p' = \frac{z_p}{\cos\gamma} = \frac{30}{\cos(33.69)} = 36.06$$

From Table 17.3,

$$Y = 0.373 + \frac{(0.380 - 0.373)(36.06 - 35)}{(37 - 35)} = 0.3767$$

$$\sigma_b = \frac{S_{ut}}{3} = \frac{600}{3} = 200\ \text{N/mm}^2$$

$$S_b = m\ b\ \sigma_b\ Y\left[1 - \frac{b}{A_o}\right] = 6\ (50)(200)\ (0.3767)\left[1 - \frac{50}{162.25}\right]$$

$S_b = 15\ 636.82$ N (Ans)

19.4 Since the same material is used for both pinion and gear, the pinion is weaker than the gear.

$$D_p = m\ z_p = 6(24) = 144\ \text{mm}$$

$$D_g = m\ z_g = 6(48) = 288\ \text{mm}$$

$$A_o = \sqrt{\left(\frac{D_p}{2}\right)^2 + \left(\frac{D_g}{2}\right)^2} = \sqrt{\left(\frac{144}{2}\right)^2 + \left(\frac{288}{2}\right)^2} = 161\ \text{mm}$$

$$\tan \gamma = \frac{z_p}{z_g} = \frac{24}{48} = 0.5 \qquad \text{or} \qquad \gamma = 26.57^0$$

$$z_p' = \frac{z_p}{\cos \gamma} = \frac{24}{\cos (26.57)} = 26.83$$

From Table 17.3,

$$Y = 0.344 + \frac{(0.348 - 0.344)(26.83 - 26)}{(27 - 26)} = 0.3473$$

$$S_b = m\ b\ \sigma_b\ Y \left[1 - \frac{b}{A_o}\right] = 6\ (50)\left(\frac{220}{3}\right)(0.3473) \left[1 - \frac{50}{161}\right]$$

$$S_b = 5267.74\ \text{N} \qquad \text{(i)}$$

$$v = \frac{\pi\ D_p\ n_p}{60\ x\ 10^3} = \frac{\pi\ (144)\ (300)}{60\ x\ 10^3} = 2.262\ m/s$$

For generated teeth,

$$C_v = \frac{5.6}{5.6 + \sqrt{v}} = \frac{5.6}{5.6 + \sqrt{2.262}} = 0.7883$$

$$S_b = P_{eff}\ (fs)$$

$$S_b = \frac{C_s}{C_v} P_t\ (fs) \qquad 5267.74 = \frac{(1.5)}{(0.7883)} P_t\ (2)$$

$$P_t = 1384.19\ \text{N} \qquad \text{(ii)}$$

$$M_t = P_t \left(\frac{D_p}{2}\right) = 1384.19\left(\frac{144}{2}\right) = 99\ 661.68\ \text{N} - \text{mm}$$

$$kW = \frac{2\ \pi\ n\ M_t}{60x10^6} = \frac{2\ \pi\ (300)(99\ 661.68)}{60x10^6} = 3.13 \qquad \text{(iii)}$$

19.5 $E_p = E_g = 114\ 000\ \text{N/mm}^2$

$$K = \frac{\sigma_c^2\ \sin\alpha\ \cos\alpha\ \left[\frac{1}{E_p} + \frac{1}{E_g}\right]}{1.4}$$

$$= \frac{(90)^2\ \sin(20)\ \cos(20)\ \left[\frac{1}{114\ 000} + \frac{1}{114\ 000}\right]}{1.4}$$

$$= 0.0326\ \ \text{N/mm}^2$$

$$D_p = m\ z_p = 6(30) = 180\ \text{mm}$$

$$D_g = m\ z_g = 6(40) = 240\ \text{mm}$$

$$\tan\gamma = \frac{z_p}{z_g} = \frac{30}{40} = 0.75 \qquad \text{or} \qquad \gamma = 36.87^0$$

$$Q = \frac{2\ z_g}{z_g + z_p\ \tan\gamma} = \frac{2(40)}{40 + 30\ \tan(36.87)} = 1.28$$

$$S_w = \frac{0.75\ b\ Q\ D_p\ K}{\cos\gamma} = \frac{0.75\ (50)\ (1.28)\ (180)\ (0.0326)}{\cos(36.87)}$$

$S_w = 352.08$ N (Ans)

19.6 $D_p = m\ z_p = 3(40) = 120\ \text{mm}$

$$\tan\gamma = \frac{z_p}{z_g} = \frac{40}{65} \qquad \text{or} \qquad \gamma = 31.61^0$$

$$Q = \frac{2\ z_g}{z_g\ + z_p\ \tan\gamma} = \frac{2\ (65)}{65 + 40\ \tan(31.61)} = 1.45$$

$$K = 0.16 \left(\frac{BHN}{100}\right)^2 = 0.16 \left(\frac{300}{100}\right)^2 = 1.44\ N/mm^2$$

$$S_w = \frac{0.75\ b\ Q\ D_p\ K}{\cos\gamma} = \frac{0.75\ (35)\ (1.45)\ (120)\ (1.44)}{\cos(31.61)}$$

S_w = 7723.02 N (Ans)

19.7 Beam strength:

Since the same material is used for both pinion and gear, the pinion is weaker than the gear.

$$D_p = m\ z_p = 6(30) = 180\ mm$$

$$D_g = m\ z_g = 6(45) = 270\ mm$$

$$A_o = \sqrt{\left(\frac{D_p}{2}\right)^2 + \left(\frac{D_g}{2}\right)^2} = \sqrt{\left(\frac{180}{2}\right)^2 + \left(\frac{270}{2}\right)^2} = 162.25\ mm$$

$$\tan\gamma = \frac{z_p}{z_g} = \frac{30}{45} \quad \text{or} \quad \gamma = 33.69^0$$

$$z_p' = \frac{z_p}{\cos\gamma} = \frac{30}{\cos(33.69)} = 36.06$$

From Table 17.3,

$$Y = 0.373 + \frac{(0.38 - 0.373)(36.06 - 35)}{(37 - 35)} = 0.3767$$

$$S_b = m\ b\ \sigma_b\ Y\ \left[1 - \frac{b}{A_o}\right] = 6\ (50)\left(\frac{570}{3}\right)(0.3767)\ \left[1 - \frac{50}{162.25}\right]$$

S_b = 14 854.98 N

Wear strength:

$$Q = \frac{2\ z_g}{z_g\ +\ z_p\ \tan\gamma} = \frac{2\ (45)}{45 + 30\ \tan(33.69)} = 1.3846$$

$$K = 0.16\left(\frac{BHN}{100}\right)^2 = 0.16\left(\frac{350}{100}\right)^2 = 1.96\ N/mm^2$$

$$S_w = \frac{0.75\ b\ Q\ D_p\ K}{\cos\gamma} = \frac{0.75\ (50)\ (1.3846)\ (180)\ (1.96)}{\cos(33.69)}$$

S_w = 22 015.79 N

Static load:

$$M_t = \frac{60\ x\ 10^6\ (kW)}{2\ \pi\ n_p} = \frac{60\ x\ 10^6\ (16.5)}{2\ \pi\ (500)} = 315\,126.79\ N - mm$$

$$P_t = \frac{2\ M_t}{D_p} = \frac{2\,(315\,126.79)}{180} = 3501.41\ N$$

Dynamic load:

$$e = 20\ \mu m = 20x10^{-3}\ mm$$

$$v = \frac{\pi\ D_p\ n_p}{60\ x\ 10^3} = \frac{\pi\ (180)\ (500)}{60\ x\ 10^3} = 4.7124\ \ m/s$$

Also, C = 11400 N/mm^2 b = 50 mm P_t = 3501.41 N

From Eq. (19.21),

$$P_d = \frac{21\,v\;(C\;e\;b + P_t)}{21v + \sqrt{(C\;e\;b + P_t)}}$$

$$= \frac{21\,(4.7124)\left[11400\,(20x10^{-3})(50) + 3501.41)\right]}{21(4.7124) + \sqrt{\left[11400\,(20x10^{-3})(50) + 3501.41)\right]}}$$

P_d = 6671.66 N

Effective load:

From Eq. (19.22),

$P_{eff} = C_s\,P_t + P_d$ = 1.5(3501.41) + 6671.66

P_{eff} = 11 923.78 N

Factor of safety:

For bending consideration,

$$\left(fs\right) = \frac{S_b}{P_{eff}} = \frac{14\ 854.98}{11\ 923.78} = 1.25 \qquad \text{(i)}$$

For wear consideration,

$$\left(fs\right) = \frac{S_w}{P_{eff}} = \frac{22\ 015.79}{11923.78} = 1.85 \qquad \text{(ii)}$$

CHAPTER 20

20.1 For the given pair,

$z_1 = 2$ $z_2 = 54$ teeth $q = 10$ $m = 5$ mm

From Eq. (20.9) and (20.10),

$$a = \frac{1}{2} m\,(q + z_2) = \frac{1}{2}(5)\,(10 + 54) = 160 \text{ mm} \qquad \text{(i)}$$

$$i = \frac{z_2}{z_1} = \frac{54}{2} = 27 \qquad \text{(ii)}$$

Dimensions of worm:

$d_1 = q\,m = 10(5) = 50$ mm

$$d_{a1} = m(q + 2) = 5(10 + 2) = 60 \text{ mm}$$

$$\tan\gamma = \frac{z_1}{q} = \frac{2}{10} = 0.2 \qquad \text{or} \qquad \gamma = 11.31^0$$

$$d_{f1} = m(q + 2 - 4.4\cos\gamma) = 5\left[10 + 2 - 4.4\cos(11.31^0)\right] = 38.427 \text{ mm}$$

$$p_x = \pi\,m = \pi(5) = 15.708 \text{ mm}$$

Dimensions of worm wheel:

$d_2 = m\,z_2 = 5\,(54) = 270$ mm

$$d_{a2} = m(z_2 + 4\cos\gamma - 2) = 5\left[54 + 4\cos(11.31^0) - 2\right] = 279.612 \text{ mm}$$

$$d_{f2} = m(z_2 - 2 - 0.4\cos\gamma) = 5\left[54 - 2 - 0.4\cos(11.31^0)\right] = 258.039 \text{ mm}$$

20.2 $z_1 = 2$ $z_2 = 52$ teeth $q = 10$ $m = 4$ mm

$d_1 = q\,m = 10(4) = 40$ mm

$$\tan\gamma = \frac{z_1}{q} = \frac{2}{10} = 0.2 \qquad \text{or} \qquad \gamma = 11.31^0$$

$$M_t = \frac{60 \text{ x } 10^6 \text{ (kW)}}{2 \pi n_1} = \frac{60 \text{ x } 10^6 \text{ (10)}}{2 \pi (720)} = 132\ 629.12 \text{ N} - \text{mm}$$

From Eq. (20.29),

$$(P_1)_t = \frac{2 M_t}{d_1} = \frac{2 (132\ 629.12)}{40} = 6631.46 \text{ N}$$

From Eqs. (20.30),

$$(P_1)_a = (P_1)_t \text{ x } \frac{(\cos\alpha \ \cos\gamma - \mu \sin\gamma)}{(\cos \alpha \sin\gamma + \mu \cos\gamma)}$$

$$= 6631.46 \text{ x } \frac{[\cos(20) \cos(11.31) - 0.04 \sin(11.31)]}{[(\cos(20) \sin(11.31) + 0.04 \cos(11.31)]} = 27\ 105.78 \text{ N}$$

From Eq. (20.31),

$$(P_1)_r = (P_1)_t \text{ x } \frac{\sin\alpha}{(\cos \alpha \sin\gamma + \mu \cos\gamma)}$$

$$= 6631.46 \text{ x } \frac{\sin(20)}{[\cos(20) \sin(11.31) + 0.04 \cos(11.31)]} = 10\ 147.47 \text{ N}$$

The force components acting on the worm wheel:

$(P_2)_t = (P_1)_a = 27105.78$ N (i)

$(P_2)_a = (P_1)_t = 6631.46$ N (ii)

$(P_2)_r = (P_1)_r = 10\ 147.47$ N (iii)

20.3 $z_1 = 1$ $z_2 = 52$ teeth $q = 10$ $m = 8$ mm

$d_1 = q\ m = 10(8) = 80$ mm

$$\tan \gamma = \frac{z_1}{q} = \frac{1}{10} = 0.1 \qquad \text{or} \qquad \gamma = 5.71^0$$

From Eq. (20.33),

$$v_s = \frac{\pi\, d_1\, n_1}{60\,000 \cos\gamma} = \frac{\pi(80)(1000)}{60\,000 \cos(5.71)} = 4.21 \text{ m/s}$$

From Fig. 20.9, the coefficient of friction is 0.027. (i)

From Eq. (20.34),

$$\eta = \frac{(\cos\alpha - \mu\tan\gamma)}{(\cos\alpha + \mu\cot\gamma)} = \frac{[\cos(20) - 0.027\tan(5.71)]}{[\cos(20) + 0.027\cot(5.71)]} = 0.7745$$

$\eta = 77.45\%$ (ii)

20.4 $z_1 = 1$ $z_2 = 40$ teeth $q = 10$ $m = 4$ mm

$$i = \frac{z_2}{z_1} = \frac{40}{1} = 40$$

$n_1 = 1000$ r.p.m. $n_2 = \frac{1000}{i} = \frac{1000}{40} = 25$ r.p.m.

$d_2 = m\, z_2 = 4(40) = 160$ mm

$$\tan\gamma = \frac{z_1}{q} = \frac{1}{10} = 0.1 \qquad \text{or} \qquad \gamma = 5.71^0$$

From Eq. (20.20),

$$F = 2m\sqrt{(q+1)} = 2(4)\sqrt{(10+1)} = 26.533 \text{ mm}$$

From Eq. (20.13) and (20.14),

$$c = 0.2m\cos\gamma = 0.2(4)\cos(5.71) = 0.796 \text{ mm}$$

$$d_{a1} = m(q+2) = 4(10+2) = 48 \text{ mm}$$

From Eq. (20.21),

$$l_r = (d_{a1} + 2c)\ \sin^{-1}\left[\frac{F}{(d_{a1} + 2c)}\right]$$

$$= (48 + 2\ \text{x}\ 0.796)\ \sin^{-1}\left[\frac{26.533}{(48 + 2\ \text{x}\ 0.796)}\right] = 27.997 \quad \text{mm}$$

For case-hardened carbon steel 14C4, (Table 20.2),

S_{b1} = 28.2

For sand cast phosphor-bronze,

S_{b2} = 5.0

From Fig. 20.14,

X_{b1} = 0.27 for n_1 = 1000 r.p.m.

X_{b2} = 0.51 for n_2 = 25 r.p.m.

From Eqs. (20.35) and (20.36),

$$(M_t)_1 = 17.65\ X_{b1}\ S_{b1}\ m\ l_r\ d_2\ \cos\gamma$$

$$= 17.65\ (0.27)(28.2)(4)(27.997)(160)\ \cos(5.71)$$

= 2 396 011.05 N-mm

$$(M_t)_2 = 17.65\ X_{b2}\ S_{b2}\ m\ l_r\ d_2\ \cos\gamma$$

$$= 17.65\ (0.51)\ (5)(4)\ (27.997)(160)\ \cos(5.71)$$

= 802 446.57 N-mm

The lower value of the torque on the worm wheel is 802 446.57 N-mm.

$$\text{kW} = \frac{2\ \pi\ n_2\ (M_t)}{60 \times 10^6} = \frac{2\ \pi\ (25)\ (802\,446.57)}{60 \times 10^6} = 2.1 \qquad \text{(Ans)}$$

20.5 For the given pair of worm gears,

m = 4 mm d_2 = 160 mm   q = 10 z_1 = 1

For (q = 10) and (z_1 = 1), the zone factor Y_z from Table 20.4 is given by

Y_z =1.143

For case-hardened carbon steel 14C4 (Table 20.3),

S_{c1} = 4.93

For sand cast phosphor-bronze,

S_{c2} = 1.06

d_1 = q m = 10 (4) = 40 mm

From Eq. (20.33),

$$v_s = \frac{\pi\, d_1\, n_1}{60\ 000 \cos\gamma} = \frac{\pi(40)(1000)}{60\ 000 \cos(5.71)} = 2.1 \text{ m/s}$$

For v_s = 2.1 m/s   and n_1 = 1000 r.p.m. (Fig.20.15),

X_{c1} = 0.145

For v_s = 2.1 m/s   and n_1 = 25 r.p.m.

X_{c2} = 0.35

From Eqs. (20.38) and (20.39),

$$(M_t)_3 = 18.64\ X_{c1}\ S_{c1}\ Y_z\ (d_2)^{1.8}\ m$$

$$= 18.64\ (0.145)\ (4.93)(1.143)\ (160)^{1.8}\ (4)$$

$$= 565\ 175.1 \text{ N-mm}$$

$$(M_t)_4 = 18.64\ X_{c2}\ S_{c2}\ Y_z\ (d_2)^{1.8}\ m$$

$$= 18.64\ (0.35)\ (1.06)(1.143)\ (160)^{1.8}\ (4)$$

$$= 293\ 320.22 \text{ N-mm} \quad \text{(lower value)}$$

$$kW = \frac{2\ \pi\ n_2\ (M_t)}{60 \times 10^6} = \frac{2\ \pi\ (25)\ (293320.22)}{60 \times 10^6} = 0.77 \qquad \text{(Ans)}$$

20.6 From Fig. 20.9, the coefficient of friction is 0.035 for (v_s = 2.1 m/s)

From Eq. (20.34),

$$\eta = \frac{(\cos\alpha\ - \mu\ \tan\gamma)}{(\cos\ \alpha\ + \mu\ \cot\gamma)} = \frac{[\cos(20)\ - 0.035\ \tan(5.71)]}{[\cos\ (20)\ + 0.035 \cot(5.71)]} = 0.7259$$

From Eq. (20.40),

$$kW = \frac{k\ (t - t_o) A}{1000 (1 - \eta)} = \frac{25\ (45)(0.25)}{1000 (1 - 0.7259)} = 1.03 \qquad \text{(Ans)}$$

CHAPTER 21

21.1 $U_o = 3000 \quad N-m \quad K = 0.9 \qquad C_s = 0.2$

$$\omega = \frac{2\,\pi\, n}{60} = \frac{2\,\pi\,(200)}{60} = 20.944 \;\; rad/s$$

From Eq. (21.14),

$$I_r = \frac{U_o\;K}{\omega^2\;C_s} = \frac{(3000)(0.9)}{(20.944)^2\,(0.2)} = 30.776 \quad kg-m^2$$

From Eq. (21.15),

$$m_r = \frac{I_r}{R^2} = \frac{30.776}{(0.5)^2} = 123.1 \text{ kg}$$

$$m_r = 2\pi R\left(\frac{b}{1000}\right)\left(\frac{t}{1000}\right)\rho$$

$$123.1 = 2\pi(0.5)\left(\frac{t}{1000}\right)\left(\frac{t}{1000}\right)(7100)$$

t = 74.29 or 75 mm $\qquad$ b = t = 75 mm $\qquad$ (Ans)

21.2 The turning moment diagram is shown in Fig. 21.1-solu. It is assumed that the energy stored in the flywheel is U at point A. Therefore,

Energy at B = U - 30

Energy at C = U - 30 + 400 = U + 370

Energy at D = U + 370 - 270 = U + 100

Energy at E = U + 100 + 330 = U + 430 (maximum)

Energy at F = U + 430 – 310 = U + 120

Energy at G = U + 120 + 230 = U + 350

Energy at H = U + 350 - 380 = U – 30   (minimum)

Energy at I = U – 30 + 270 = U + 240

Energy at J = U + 240 – 240 = U

The maximum and minimum energy occurs at points E and H. The angular velocity of the flywheel will be maximum at point E and minimum at point H.

$$U_o = U_E - U_H = (U + 430) - (U - 30) = 460 \text{ mm}^2$$

$$U_o = 460(1250)\left(\frac{2\pi}{180}\right) \text{ N} - \text{m} \quad \text{or} \quad \text{J}$$

$$= 20\,071.29 \text{ N-m}$$

$$\omega = \frac{2\pi n}{60} = \frac{2\pi(240)}{60} = (8\pi) \text{ rad/s}$$

From Eq. 21.14,

$$I_r = \frac{U_o K}{\omega^2 C_s} = \frac{(20\,071.29)(0.9)}{(8\pi)^2(0.02)} = 1429.91 \text{ kg} - \text{m}^2$$

From Eq. 21.16, the mean radius R of the rim is given by,

$$R < \frac{30}{\omega} \quad \text{or} \quad R < \frac{30}{(8\pi)} \quad \text{or} \quad R < 1.19 \text{ m}$$

Therefore,   R = 1.15 m   (i)

From Eq. (21.15),

$$m_r = \frac{I_r}{R^2} = \frac{1429.91}{(1.15)^2} = 1081.22 \text{ kg}$$

$$m_r = 2\pi R\left(\frac{b}{1000}\right)\left(\frac{t}{1000}\right)\rho$$

$$1081.22 = 2\pi(1.15)\left(\frac{1.5\,t}{1000}\right)\left(\frac{t}{1000}\right)(7100)$$

t = 118.53 or 120 mm b = 1.5(118.53) = 177.8 or 180 mm

Dimensions of cross-section = 120x180 mm (ii)

21.3 From Eq. (21.21),

$$m = b\,t\,\rho = (200)(100)(7200\,x\,10^{-9}) = 0.144\ kg/mm$$

A = b t = (200)(100) = 20 000 mm^2

For four spokes, $2\ \alpha = \dfrac{\pi}{2}$

From Eq. (21.19) (four spokes),

$$C = \left[\frac{72\ 960\ R^2}{t^2} + 0.643 + \frac{A}{A_1}\right] = \left[\frac{72\ 960\ (1)^2}{(100)^2} + 0.643 + \frac{20\ 000}{6500}\right]$$

$$= 11.016$$

$$v = \omega R = \left(\frac{2\ \pi\ n}{60}\right)R = \left(\frac{2\ \pi\ (720)}{60}\right)(1) = 75.398\ m/s$$

$$\left(\frac{1000\ m\,v^2}{b\,t}\right) = \frac{(1000)(0.144)(75.398)^2}{(20\ 000)} = 40.931$$

From Eq. (21.18), the stresses in the rim are given by:

At $\phi = 45^0$,

$$\sigma_t = \frac{(1000)\,m\ v^2}{b\,t}\left[1 - \frac{\cos\phi}{3C\sin\alpha} \pm \frac{2(1000)R}{C\ t}\left(\frac{1}{\alpha} - \frac{\cos\phi}{\sin\alpha}\right)\right]$$

$$= (40.931)\left[1 - \frac{\cos(45)}{3(11.016)\sin(45)} \pm \frac{2(1000)(1)}{(11.016)(100)}\left(\frac{4}{\pi} - \frac{\cos(45)}{\sin(45)}\right)\right]$$

$$= 59.997 \text{ or } 60 \;\; \text{N/mm}^2 \qquad \text{(using positive sign)} \qquad \text{(i)}$$

At $\phi = 0^0$,

$$\sigma_t = (40.931)\left[1 - \frac{1}{3(11.016)\sin(45)} \pm \frac{2(1000)(1)}{(11.016)(100)}\left(\frac{4}{\pi} - \frac{1}{\sin(45)}\right)\right]$$

$$= 49.66 \;\; \text{N/mm}^2 \qquad \text{(using negative sign)}$$

From Eq. 21.17, the stress in the spoke is given by,

$$\sigma_t = \frac{2}{3}\left[\frac{(1000)\,m\;v^2}{C\;A_1}\right] = \frac{2}{3}\left[\frac{(1000)(0.144)\;(75.398)^2}{(11.016)\;(6500)}\right]$$

$$= 7.62 \;\; \text{N/mm}^2 \qquad \text{(ii)}$$

CHAPTER 22

22.1 $\sigma_t = \dfrac{S_{yt}}{(fs)} = \dfrac{230}{2.5} = 92 \text{ N/mm}^2$

$$t = \frac{P_i\ D_i}{2\ \sigma_t} = \frac{(10)\ (200)}{2\ (92)} = 10.87 \text{ mm} \qquad \text{(Ans)}$$

22.2 $\sigma_t = \dfrac{S_{yt}}{(fs)} = \dfrac{200}{2.5} = 80 \text{ N/mm}^2$

Thickness of cylindrical wall:

$$t = \frac{P_i\ D_i}{2\ \sigma_t} = \frac{(3)\ (500)}{2\ (80)} = 9.38 \text{ mm} \qquad \text{(i)}$$

Thickness of hemispherical ends:

$$t = \frac{P_i\ D_i}{4\ \sigma_t} = \frac{(3)\ (500)}{4\ (80)} = 4.69 \text{ mm} \qquad \text{(ii)}$$

22.3 Assumptions: (i) The cylinder is made of ductile material.

(ii) The cylinder is closed at two ends.

When the cylinder is subjected to internal pressure, the three principal stresses are as follows, [Eqs. (22.9), (22.8) and (22.12)]

$$\sigma_t = + \frac{P_i\ (D_o^2 + D_i^2)}{(D_o^2 - D_i^2)} \qquad \text{(a)}$$

$$\sigma_r = - P_i \qquad \text{(b)}$$

$$\sigma_l = + \frac{P_i\ D_i^2}{(D_o^2 - D_i^2)} \qquad \text{(c)}$$

Rearranging the given equation,

$$\sigma = \frac{S_{yt}}{(fs)} = \sqrt{\frac{1}{2}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]} \qquad \text{we get,}$$

$$\sigma^2 = (\sigma_t^2 + \sigma_r^2 + \sigma_i^2) - (\sigma_t\sigma_r + \sigma_r\sigma_l + \sigma_l\sigma_t) \qquad \text{(d)}$$

Substituting (a), (b) and (c) in above expression,

$$\sigma = \frac{\sqrt{3}\, P_i\, D_o^2}{(D_o^2 - D_i^2)}$$

Rearranging the terms,

$$\frac{D_o^2}{D_i^2} = \frac{\sigma}{\sigma - \sqrt{3}\,P_i} \qquad \text{or} \qquad \frac{D_o}{D_i} = \sqrt{\frac{\sigma}{\sigma - \sqrt{3}\,P_i}}$$

Substituting $D_o = (D_i + 2t)$ in above expression,

$$t = \frac{D_i}{2}\left[\sqrt{\frac{\sigma}{(\sigma - \sqrt{3}\,P_i)}} - 1\right] \qquad \text{where } \sigma = \frac{S_{yt}}{(fs)} \qquad \text{(Ans)}$$

22.4 Assumptions: (i) The cylinder is made of ductile material.

(ii) The cylinder is open at two ends.

When the cylinder is subjected to internal pressure, the maximum stresses at the inner surface of the cylinder are given by, [Eqs. (22.9) and (22.8)]

$$\sigma_t = + \frac{P_i\,(D_o^2 + D_i^2)}{(D_o^2 - D_i^2)} \qquad \text{(a)}$$

$$\sigma_r = -P_i \qquad \text{(b)}$$

The maximum shear stress is given by,

$$\tau = \frac{1}{2}(\sigma_t - \sigma_r) = \frac{1}{2}\left[\frac{P_i\,(D_o^2 + D_i^2)}{(D_o^2 - D_i^2)} + P_i\right]$$

$$\tau = \frac{P_i \; D_o^2}{(D_o^2 - D_i^2)} \qquad \text{or} \qquad \frac{D_o^2 - D_i^2}{D_o^2} = \frac{P_i}{\tau}$$

Rearranging the terms,

$$\frac{D_o}{D_i} = \sqrt{\frac{\tau}{\tau - P_i}}$$

Substituting $D_o = (D_i + 2t)$ in above expression,

$$t = \frac{D_i}{2}\left[\sqrt{\frac{\tau}{(\tau - P_i)}} - 1\right] \qquad \text{where } \tau = \frac{S_{sy}}{(fs)} = \frac{0.5\,S_{yt}}{(fs)} \qquad \text{(Ans)}$$

22.5 Since the cylinder material is brittle, maximum principal stress theory is applicable.

$$\sigma_t = \frac{P_i\,(D_o^2 + D_i^2)}{(D_o^2 - D_i^2)} = \frac{15\,(240^2 + 200^2)}{(240^2 - 200^2)} = 83.18 \text{ N/mm}^2$$

$$(fs) = \frac{S_{ut}}{\sigma_t} = \frac{300}{83.18} = 3.61 \qquad \text{(i)}$$

It is seen from expression of (σ_t) that when pressure is raised by 50%, (σ_t) also increases by 50%.

$$(fs) = \frac{S_{ut}}{1.5\sigma_t} = \frac{300}{1.5(83.18)} = 2.4 \qquad \text{(ii)}$$

22.6 From Eq. (22.7),

$$\sigma_t = \frac{P_i\;D_i^2}{(D_o^2 - D_i^2)}\left[\frac{D_o^2}{4\,r^2} + 1\right] = \frac{50\,(20)^2}{(40^2 - 20^2)}\left[\frac{40^2}{4\,r^2} + 1\right]$$

$$\sigma_t = 16.667\left[\frac{400}{r^2} + 1\right] \qquad \text{(a)}$$

From Eq. (22.6),

$$\sigma_r = \frac{P_i\ D_i^2}{(D_o^2 - D_i^2)}\left[\frac{D_o^2}{4\ r^2} - 1\right] = \frac{50\ (20)^2}{(40^2 - 20^2)}\left[\frac{40^2}{4\ r^2} - 1\right] \qquad \text{or}$$

$$\sigma_r = 16.667\left[\frac{400}{r^2} - 1\right] \qquad \text{(b)}$$

Substituting value of r from 0 to 20 mm,

R (mm)	10	12	14	16	18	20
(σ_t) (N/mm^2)	83.34	62.96	50.68	42.71	37.24	33.33
(σ_r) (N/mm^2)	50	29.63	17.35	9.38	3.91	0

22.7 D_1 = 200 mm D_2 = 300 mm D_3 = 400 mm

δ = 0.25 mm E = 207x10^3 N/mm^2

From Eq. (22.22),

$$\delta = \frac{P\ D_2}{E}\left[\frac{2\ D_2^2\ (D_3^2 - D_1^2)}{(D_3^2 - D_2^2)\ (D_2^2 - D_1^2)}\right]$$

$$0.25 = \frac{P\ (300)}{(207\ \text{x}\ 10^3)}\left[\frac{2\ (300)^2\ (400^2 - 200^2)}{(400^2 - 300^2)\ (300^2 - 200^2)}\right]$$

P = 27.95 MPa (i)

The maximum principal stress is tangential stress at the inner surface of jacket.

From Eq. (22.9),

$$\sigma_t = \frac{P(D_3^2 + D_2^2)}{(D_3^2 - D_2^2)} = \frac{27.95\ (400^2 + 300^2)}{(400^2 - 300^2)}$$

$$= 99.82\ \text{N/mm}^2 \qquad \text{(ii)}$$

22.8 $\dfrac{k_b}{k_c} = 1.5 \qquad k_b = 1.5\ k_c \qquad P_l = 10\ 000$ N

$$\left[\frac{k_b}{k_b + k_c}\right] = \frac{1.5\ k_c}{1.5\ k_c + k_c} = \frac{1.5}{2.5} = 0.6$$

$$(P_i)\ \text{per bolt} = \frac{\pi}{4}(300)^2(1)\left(\frac{1}{12}\right) = 5890.49\ \text{N}$$

The resultant load on the bolt is given by Eqs. (22.26) and (22.27).

$$P = P_l + P_i\left[\frac{k_b}{k_b + k_c}\right] = 10\ 000 + 5890.49(0.6) = 13\ 534.29\ \text{N}$$

22.9 $P_i = 1.05(1.5) = 1.575$ MPa or N/mm^2

$$\sigma_t = \frac{S_{yt}}{1.5} = \frac{255}{1.5} = 170\ \ \text{N/mm}^2$$

Thickness of cylindrical shell:

From Eq. (22.29),

$$t = \frac{P_i\ D_i}{2\ \sigma_t\ \eta - P_i} + CA = \frac{(1.575)(1650)}{2(170)(0.8) - 1.575} + 2$$

$t = 11.61$ mm (i)

Thickness of torispherical end: [Eq. (22.33)]

$$t = \frac{0.885\ P_i\ L}{\sigma_t\ \eta - 0.1\ P_i} + CA = \frac{0.885\ (1.575)\ (1300)}{(170)\ (0.8) - 0.1\ (1.575)} + 2$$

$t = 15.34$ mm (ii)

22.10 $\sigma_t = \dfrac{S_{yt}}{1.5} = \dfrac{210}{1.5} = 140\ \ N/mm^2$

$$t_r = \frac{P_i\ D_i}{2\ \sigma_t\ \eta\ -\ P_i} = \frac{(0.75)\ (2000)}{2\ (140)\ (0.85) - 0.75} = 6.32\ \text{mm}$$

$$d = d_i + 2\ (CA) = 300 + 2(2) = 304\ \ \text{mm}$$

$$A = d\ t_r = 304(6.32) = 1921.28\ \text{mm}^2 \qquad \text{(a)}$$

$$t_{rn} = \frac{P_i\ d_i}{2\ \sigma_t\ \eta\ -\ P_i} = \frac{(0.75)\ (300)}{2\ (140)\ (0.85)\ -\ 0.75} = 0.95\ \text{mm}$$

The limiting dimension X is the higher of the following two values:

X = d = 304 mm

$$X = \left[\frac{d_i}{2} + t + t_n - 3CA\right] = (150+10+10–6) = 164\ \text{mm}$$

Therefore, X = 304 mm

$$h_1 = 2.5(t - CA) = 2.5(10-2) = 20\ \text{mm}$$

$$h_2 = 15\ \text{mm}$$

The areas available for reinforcement within the above limits are as follows:

$$A_1 = (2X - d)(t - t_r - CA) = [2(304) - 304](10 - 6.32 - 2) = 510.72\ \text{mm}^2$$

$$A_2 = 2\ h_1\ (t_n - t_{rn} - CA) = 2(20)(10 – 0.95 - 2) = 282\ \ \text{mm}^2$$

$$A_3 = 2\ h_2\ (t_n - 2CA) = 2\ (15)\ (10 – 2x2) = 180\ \text{mm}^2$$

$\therefore$ $(A_l + A_2 + A_3) = 972.72\ \text{mm}^2$ (b)

From (a) and (b),

$A > (A_1 + A_2 + A_3)$

Therefore a reinforcing pad is necessary. The area of the reinforcing pad A_4 is given by

$$A_4 = A - (A_1 + A_2 + A_3) = 1921.28 - 972.72 = 948.56 \text{ mm}^2$$

The thickness of the reinforcing pad is 10 mm. Therefore the width of the pad is given by,

$$w = \frac{948.56}{10} = 94.86 \text{ or } 95 \text{ mm}$$

Dimensions of pad:

inner diameter of the pad = 300 + 20 = 320 mm. (i)

outer diameter of pad = 320 + 95 = 415 mm (ii)

CHAPTER 23

23.1 Let us assume that the number of wire ropes is z. The force acting on each wire rope comprises the following factors;

(i) the weight of the hoist with material to be raised;

(ii) the weight of the wire rope, and

(iii) the force due to acceleration of the material and the wire rope.

The weight of the hoist with material raised by each wire rope is given by,

$$\left(\frac{10x10^3}{z}\right) \quad N \qquad\qquad (i)$$

The mass of 100 m long wire rope is 34.6 kg. Since the height is 3 m, the weight of the wire is given by,

$$34.6\left(\frac{3}{100}\right)(9.81) \qquad or \qquad 10.18\ N \qquad\qquad (ii)$$

The mass of the material raised by each wire rope is $\left[\left(\frac{10x10^3}{9.81}\right)\left(\frac{1}{z}\right)\right]$ and that of each wire rope is $\left[34.6\left(\frac{3}{100}\right)\right]$. The force due to acceleration (i.e. mass x acceleration) is given by,

$$\left[\left(\frac{10x10^3}{9.81}\right)\left(\frac{1}{z}\right) + 34.6\left(\frac{3}{100}\right)\right] \ (1)$$

From Table 23.4, the breaking strength of the wire rope is 54 kN. The factor of safety is 10.

$$\frac{54\ 000}{10} = \frac{10x10^3}{z} + 10.18 + \left[\frac{10x10^3}{9.81z} + 34.6\left(\frac{3}{100}\right)\right]$$

z = 2.045 or 3 wire ropes (Ans)

23.2 From Eq. 23.3 and Table 23.7,

$$P_b = \frac{A\,E_r\,d_w}{D} = \frac{(0.40\,d_r^2)(83\ 000)(0.063\,d_r)}{(45\,d_r)} = 46.48\,d_r^2 = 46.48(10)^2 = 4648\ \text{N}$$

The total force acting on the wire rope consists of three factors discussed in the previous example, plus the bending load. The total force is given by,

$$\left[\frac{10x10^3}{3} + 10.18 + \frac{10x10^3}{9.81\ (3)} + 1.038\right] + 4648 \quad \text{or} \qquad 8332.34\ \text{N}$$

$$(fs) = \frac{54\ 000}{8332.34} = 6.48 \qquad \text{(Ans)}$$

23.3 $p = 0.0015\ S_{ut} = 0.0015(1770) = 2.655\ \text{N/mm}^2$

From Eq. (23.4), $p = \dfrac{2\ P}{d_r\ D}$

$$P = \frac{p\ d_r\ D}{2} = \frac{2.655(10)(450)}{2} = 5973.75\ \text{N} \qquad \text{(Ans)}$$

23.4 The maximum force on the piston rod is given by,

$$P = \frac{\pi}{4} D^2\ p = \frac{\pi}{4}(200)^2\ (1)\ \text{N}$$

The factor of safety is 5. Therefore,

$$P_{cr} = 5P = 5\left[\frac{\pi}{4}(200)^2\ (1)\right] = 157\ 079.63\ \text{N}$$

For circular cross-section,

$$k = \left(\frac{d}{4}\right) \qquad \left(\frac{l}{k}\right) = \left(\frac{1000}{d/4}\right) = \left(\frac{4000}{d}\right)$$

At this stage, it is not clear whether, one should use Euler's or Johnson's equation. Using Johnson's equation as a first trial,

$$P_{cr} = S_{yt} A \left[1 - \frac{S_{yt}}{4 n \pi^2 E} \left(\frac{l}{k}\right)^2 \right]$$

$$157\,079.63 = (380)\left(\frac{\pi d^2}{4}\right)\left[1 - \frac{380 \left(\frac{4000}{d}\right)^2}{4(2)\,\pi^2\,(207\,000)} \right]$$

d = 29.97 mm (Ans)

Check for design:

$$\left(\frac{l}{k}\right) = \frac{4000}{d} = \frac{4000}{29.97} = 133.47 \qquad \text{(i)}$$

The boundary line between Euler's and Johnson's equations is given by

$$\frac{S_{yt}}{2} = \frac{n \pi^2 E}{(l/k)^2} \qquad \text{or} \qquad \frac{380}{2} = \frac{(2)\,\pi^2\,(207\,000)}{(l/k)^2}$$

$$\left(\frac{l}{k}\right) = 146.65 \qquad \text{(ii)}$$

In this example, the slenderness ratio (133.47) is less than the boundary value of (146.65). Therefore the rod is treated as a short column and Johnson's equation used in the first trial is justified.

23.5 $d_c = d - p = 30 - 6 = 24$ mm

$$k = \left(\frac{d_c}{4}\right) = \frac{24}{4} = 6 \text{ mm} \qquad \left(\frac{l}{k}\right) = \left(\frac{500}{6}\right) = 83.33 \qquad \text{(i)}$$

$$\frac{S_{yt}}{2} = \frac{n\,\pi^2\,E}{(l/k)^2} \qquad \text{or} \qquad \frac{380}{2} = \frac{(0.25)\,\pi^2\,(207\,000)}{(l/k)^2}$$

$$\left(\frac{l}{k}\right) = 51.85 \qquad \text{(ii)}$$

In this example, the slenderness ratio (83.33) is more than the boundary value of (51.85). Therefore the screw is treated as a long column and Euler's equation is applicable.

$$P_{cr} = \frac{n\,\pi^2\,E\,A}{(l/k)^2} = \frac{(0.25)\,\pi^2\,(207\ 000)\left(\dfrac{\pi\,(24)^2}{4}\right)}{(83.33)^2} = 33\ 275.13 \text{ N}$$

$$(fs) = \frac{P_{cr}}{P} = \frac{33\ 275.13}{10\ 000} = 3.33 \qquad \text{(Ans)}$$

23.6 $k = \left(\frac{d}{4}\right) = \frac{6}{4} = 1.5$ mm $\qquad \left(\frac{l}{k}\right) = \left(\frac{300}{1.5}\right) = 200$ (i)

$$\frac{S_{yt}}{2} = \frac{n\,\pi^2\,E}{(l/k)^2} \qquad \text{or} \qquad \frac{400}{2} = \frac{(1)\,\pi^2\,(207\,000)}{(l/k)^2}$$

$$\left(\frac{l}{k}\right) = 101.07 \qquad \text{(ii)}$$

In this example, the slenderness ratio (200) is more than the boundary value of (101.7). Therefore the screw is treated as a long column and Euler's equation is applicable.

$$P_{cr} = \frac{n\,\pi^2\,E\,A}{(l/k)^2} = \frac{(1)\,\pi^2\,(207\,000)\left(\frac{\pi\,(6)^2}{4}\right)}{(200)^2} = 1444.12 \text{ N}$$

$$P = \frac{P_{cr}}{(fs)} = \frac{1444.12}{3.5} = 412.6 \text{ N} \qquad \text{(Ans)}$$

CHAPTER 24

24.1 $x_1 = 10 – 0.025 = 9.975$ mm

$x_2 = 10 + 0.025 = 10 .025$ mm

$$Z_1 = \frac{9.975 - 10.02}{0.01} = -4.5$$

$$Z_2 = \frac{10.025 - 10.02}{0.01} = 0.5$$

From Table 24.6, the area below normal curve from Z = 0 to Z = 0.5 is 0.1915. Since Z_1 is more than (-3.9), the area below normal curve in negative half is 0.5. Refer to Fig.24.1-solu.

Shaded area = 0.5 – 0.1915 = 0.3085

% of rejection = 30.85 % (Ans)

24.2 $x_1 = 25 + 0.15 = 25.15$ mm

$x_2 = 25 - 0.15 = 24.85$ mm

$$Z_1 = \frac{25.15 - 25}{0.1} = +1.5$$

$$Z_2 = \frac{24.85 - 25}{0.1} = -1.5$$

From Table 24.6, the area below normal curve from Z = 0 to Z = 1.5 is 0.4332. Refer to Fig.24.2-solu.

% of rejected forgings = (1 – 2x0.4332)x100 = 13.36 % (Ans)

24.3 Five bolts are rejected out of a sample of 100 bolts. For 5% rejection, the area below normal curve in positive half is given by,

$$A = \frac{1}{2}(1-0.05) = 0.475$$

From Table 24.6, the corresponding values of Z_1 and Z_2 are +1.96 and –1.96.

$$x_1 = \mu + \hat{\sigma} Z_1 = 10.5 + 0.02x1.96 = 10.5 + 0.0392 \text{ mm}$$

$$x_2 = \mu - \hat{\sigma} Z_2 = 10.5 - 0.02x1.96 = 10.5 - 0.0392 \text{ mm}$$

Tolerances = 10.5 $\pm$ 0.0392 mm (Ans)

24.4 There are two populations – population of bearing dimension denoted by letter B and that of journal dimension denoted by letter J.

The limiting dimensions for bearing 20H7 are (Table 3.2)

$$\frac{20.021}{20.000} \text{ mm} \quad \text{or} \quad 20.0105 \pm 0.0105 \text{ mm}$$

The design tolerance and natural tolerance are equal. Therefore,

$$\mu_B = 20.0105 \text{ mm} \qquad \text{and} \qquad \hat{\sigma}_B = \frac{0.0105}{3} = 0.0035 \text{ mm}$$

The limiting dimensions for journal 20e8 are [Table 3.3(a)]

$$\frac{19.960}{19.927} \text{ mm} \quad \text{or} \quad 19.9435 \pm 0.0165 \text{ mm}$$

Therefore,

$\mu_J = 19.9435$ mm and $\hat{\sigma}_J = \frac{0.0165}{3} = 0.0055$ mm

The population for clearance is denoted by the letter C. It is obtained by subtracting the population of journal from the population of bearing. From Eq. (24.12),

$\mu_C = \mu_B - \mu_J =$ 20.0105 – 19.9435 = 0.067 mm

From Eq. (24.14),

$$\hat{\sigma}_c = \sqrt{(\hat{\sigma}_B)^2 + (\hat{\sigma}_J)^2} = \sqrt{(0.0035)^2 + (0.0055)^2} = 0.00652 \text{ mm}$$

For higher limit of clearance,

$$Z_1 = \frac{0.08 - 0.067}{0.00652} = +1.99$$

For lower limit of clearance,

$$Z_1 = \frac{0.05 - 0.067}{0.00652} = -2.61$$

From Table 24.6, the areas below the normal curve from Z = 0 to Z = 1.99 and Z = 0 to Z = 2.61 are 0.4767 and 0.4955 respectively.

% of rejected assemblies = [1 – (0.4767 + 0.4955)]x100

= 2.78% (Ans)

24.5 For the population of component A,

$\mu_A = 10.00$ mm $\hat{\sigma}_A = \frac{0.6}{3} = 0.2$ mm

The standard deviation and the mean of the assembly dimension (a) are denoted by ($\hat{\sigma}_a$) and (μ_a) respectively.

$\mu_a = \mu_A + \mu_B \qquad 40 = 10 + \mu_B \qquad \text{or} \qquad \mu_B = 30$ mm

$$\hat{\sigma}_a = \frac{0.9}{3} = 0.3 \text{ mm}$$

$$\hat{\sigma}_a = \sqrt{(\hat{\sigma}_A)^2 + (\hat{\sigma}_B)^2}$$

$$\hat{\sigma}_B = \sqrt{(\hat{\sigma}_a)^2 - (\hat{\sigma}_A)^2} = \sqrt{(0.3)^2 - (0.2)^2} = 0.2236 \text{ mm}$$

$3\ \hat{\sigma}_B = 3\ (0.2236) = 0.67$ mm

Dimensions of component B = 30 ± 0.67 mm (Ans)

24.6 The standard deviation and the mean of the assembly dimension (a) are denoted by ($\hat{\sigma}_a$) and (μ_a) respectively.

$\mu_a = \mu_A + \mu_B + \mu_C = 20 + 10 + 15 = 45$ mm

$$\hat{\sigma}_a = \frac{0.9}{3} = 0.3 \text{ mm}$$

$$\hat{\sigma}_a = \sqrt{(\hat{\sigma}_A)^2 + (\hat{\sigma}_B)^2 + (\hat{\sigma}_C)^2} = \sqrt{3(\hat{\sigma})^2}$$

$0.3 = \sqrt{3}\ \hat{\sigma} \qquad \text{or} \qquad \hat{\sigma} = 0.173$ mm

Tolerance for individual components = $\pm 3\ \hat{\sigma}$

$= \pm 0.519$ or ± 0.52 mm (Ans)

24.7 The interference population is denoted by letter I.

$$\mu_I = \mu_A - \mu_B = 75 - 75.125 = -0.125 \text{ mm}$$

$$\hat{\sigma}_I = \sqrt{(\hat{\sigma}_A)^2 + (\hat{\sigma}_B)^2} = \sqrt{(0.025)^2 + (0.0375)^2} = 0.045 \text{ mm}$$

When interference is zero (I = 0),

$$Z = \frac{0 - (-0.125)}{0.045} = +2.78$$

Therefore, interference occurs when (Z > 2.78). From Table 24.6, the area below normal curve from Z = 0 to Z = 2.78 is 0.4973.

Probability of interference fit = (0.5 – 0.4973) x 100 = 0.27% (Ans)

24.8 w denotes the population of width. For this population,

$\mu_w = 50 \text{ mm}$ and $\hat{\sigma}_w = 0.5 \text{ mm}$

t denotes the population of thickness of the cross-section. For this population,

$\mu_t = 25 \text{ mm}$ and $\hat{\sigma}_t = 0.3 \text{ mm}$

A denotes the third population of the area of cross-section. It is obtained by multiplication of the width population by the population of thickness. From Table 24.7,

$$\mu_A = \mu_w \mu_t = 50(25) = 1250 \text{ mm}^2 \qquad \text{(i)}$$

$$\hat{\sigma}_A = \sqrt{\mu_w^2 (\hat{\sigma}_t)^2 + \mu_t^2 (\hat{\sigma}_w)^2 + (\hat{\sigma}_w)^2 (\hat{\sigma}_t)^2}$$

$$= \sqrt{(50)^2\,(0.3)^2 + (25)^2\,(0.5)^2 + (0.5)^2\,(0.3)^2}$$

$$= 19.53 \text{ mm}^2 \qquad \text{(ii)}$$

The population of cross-sectional area has a mean of 1250 mm^2 and a standard deviation of 19.53 mm^2. We can predict the mean and the standard deviation of the population of cross-sectional area. However, this population is not exactly normally distributed random variable.

24.9 S denotes the population of strength. For this population,

$\mu_S = 300 \text{ N/mm}^2$ and $\hat{\sigma}_S = 10 \text{ N/mm}^2$

The population of stress is denoted by σ. For this population,

$\mu_\sigma = 150 \text{ N/mm}^2$ and $\hat{\sigma}_\sigma = 20 \text{ N/mm}^2$

A third population of factor of safety is denoted by fs. It is obtained by dividing the strength population by the population of stress. From Table 24.7,

$$\mu_{fs} = \frac{\mu_S}{\mu_\sigma} = \frac{300}{150} = 2 \qquad \text{(i)}$$

$$\hat{\sigma}_{fs} = \frac{1}{\mu_\sigma}\left[\frac{\mu_S^2\,\hat{\sigma}_\sigma^2 + \mu_\sigma^2\,\hat{\sigma}_S^2}{\mu_\sigma^2 + \hat{\sigma}_\sigma^2}\right]^{1/2}$$

$$= \frac{1}{150}\left[\frac{300^2 \text{ x } 20^2 + 150^2 \text{ x} 10^2}{150^2 + 20^2}\right]^{1/2} = 0.27 \qquad \text{(ii)}$$

The population of factor of safety has a mean of 2 and a standard deviation of 0.27. We can predict the mean and the standard deviation of factor of safety population. However, the population is not normally distributed random variable.

24.10 $\mu = 15000$ hr and $\hat{\sigma} = 1000$ hr

From Eq.24.7,

$$Z = \frac{X - \mu}{\hat{\sigma}} = \frac{16500 - 15000}{1000} = 1.5$$

From Table 24.6, area below normal curve from Z = 0 to Z = 1.5 is 0.4332.

The area below the normal curve from Z = - ∞ to Z = 1.5 represents the probability of bearings that may fail within first 16 500 hr. This area is equal to (0.5 + 0.4332) or 0.9332.

Therefore, 93.32% bearings may fail within first 16 500 hr. (Ans)

24.11 Half the area of the curve is located on either side of the mean load of 5 kN.

The area below normal curve from Z = 0 to Z = $+\infty$ indicates the probability that the load will be more than 5 kN. This area is 0.5. Therefore, we can conclude that the probability of randomly selected load being more than 5 kN is 0.5 or 50 %. (i)

When randomly selected load is 6 kN, X = 6 kN

$$Z = \frac{X - \mu}{\hat{\sigma}} = \frac{6 - 5}{0.5} = +2$$

The area below normal curve from Z = 0 to Z = + 2 indicates the probability that the load selected at random will be between 5 to 6 kN. From Table 24.6, the area below normal curve from Z = 0 to Z = 2 is 0.4772. Therefore, the probability that a randomly selected load will be between 5 to 6 kN is 47.72 %. (ii)

24.12 S denotes the population of yield strength. For this population,

$\mu_S = 380 \text{ N/mm}^2$ and $\hat{\sigma}_S = 50 \text{ N/mm}^2$

The population of bending stress is denoted by σ.

$\mu_\sigma = 250 \text{ N/mm}^2$ and $\hat{\sigma}_\sigma = 25 \text{ N/mm}^2$

A third population of margin of safety is denoted by m. It is obtained by subtracting bending stress population from the population of yield strength. Therefore,

$$\mu_m = \mu_S - \mu_\sigma = 380 - 250 = 130 \text{ N/mm}^2$$

$$\hat{\sigma}_m = \sqrt{(\hat{\sigma}_S)^2 + (\hat{\sigma}_\sigma)^2} = \sqrt{(50)^2 + (25)^2} = 55.90 \text{ N/mm}^2$$

When (m = 0), the standard variable Z_0 is given by

$$Z_0 = \frac{m - \mu_m}{\hat{\sigma}_m} = \frac{0 - 130}{55.90} = -2.33$$

Conclusions:

(i) When Z = - 2.33, the value of 'm' is zero or there is no margin of safety.

(ii) The area below the normal curve from $Z = -\infty$ to Z = - 2.33 indicates the region of unreliability. In this region, ‘m’ is negative or the bending stress is more than the yield strength.

(iii) The area below the normal curve from $Z = -2.33$ to Z = $+\infty$ indicates the region of reliability. In this region, ‘m’ is positive or the bending stress is less than the yield strength.

From Table 24.6, the area below normal curve from Z = 0 to Z = +2.33 is 0.4901.

The total area below normal curve from Z = - 2.33 to Z = + ∞ consists of two parts namely, the area from Z = - 2.33 to Z = 0 and area from Z = 0 to Z = + ∞. Therefore, total area is equal to (0.4901+0.5) or 0.9901.

Reliability of beam = 0.9901 or 99.01% (i)

Average factor of safety = $\dfrac{\mu_S}{\mu_\sigma} = \dfrac{380}{250} = 1.52$ (ii)

Minimum yield strength = $\mu_S - 3\hat{\sigma}_S = 380 - 3(50) = 230\,\mathrm{N/mm^2}$

Maximum bending stress = $\mu_\sigma + 3\hat{\sigma}_\sigma = 250 + 3(25) = 325\,\mathrm{N/mm^2}$

Minimum factor of safety = $\dfrac{230}{325} = 0.71$ (iii)
