higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

# MARKING GUIDELINE

## NATIONAL CERTIFICATE

## MECHANICAL DRAWING AND DESIGN N6

## 10 APRIL 2018

**This marking guideline consists of 15 pages.**

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## QUESTION 1

### 1.1 Gear teeth

$$PCD = m \times T_A$$
$$240 = 5 \times T_A$$
$$T_A = 48$$
$$T_B = 2 \times 48$$
$$T_B = 96 \quad (1)$$

### 1.2 Torques on shaft

$$P = \frac{2 \times \pi \times N \times T}{60}$$

$$40 \times 10^3 = \frac{2 \times 3{,}142 \times 1\,100 \times T}{60}$$

$$T = \frac{40 \times 10^3 \times 60}{2 \times 3{,}142 \times 1\,100}$$

$$T = 347{,}2\ Nm \quad (1)$$

### 1.3 Face width

$$V_A = \frac{\pi \times PCD \times N_A}{60}$$
$$V_A = \frac{\pi \times 024 \times 2\,200}{60}$$
$$V_A = 27{,}65\ m/s \quad (1)$$

$$C_v = \frac{5{,}6}{5{,}6 + V_A}$$
$$C_v = \frac{5{,}6}{5{,}6 + 27{,}65}$$
$$C_v = 0{,}1684 \quad (1)$$

$$P = F_t \times v$$
$$40 \times 10^3 = F_t \times 27{,}65$$
$$F_t = \frac{40 \times 10^3}{27{,}65}$$
$$F_t = \frac{40 \times 10^3}{27{,}65}$$
$$F_t = 1\,446{,}67\ N \quad (1)$$

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**Form factor**

$$y_A = 0{,}154 - \frac{0{,}912}{T_A}$$
$$y_A = 0{,}154 - \frac{0{,}912}{48}$$
$$y_A = 0{,}154 - 0{,}019$$
$$y_A = 0{,}135 \quad (1)$$

$$y_B = 0{,}154 - \frac{0{,}912}{T_B}$$
$$y_B = 0{,}154 - \frac{0{,}912}{96}$$
$$y_B = 0{,}154 - 0{,}0095$$
$$y_B = 0{,}145 \quad (1)$$

**Working stress for gear A**

$$\sigma = \sigma_o \times C_v \times y_A$$
$$\sigma_A = 112 \times 10^6 \times 0{,}1684 \times 0{,}135$$
$$\sigma_A = 2{,}546 \text{ MPa} \quad (1)$$

**Working stress for gear B**

$$\sigma = \sigma_o \times C_v \times y_B$$
$$\sigma_B = 120 \times 10^6 \times 0{,}1684 \times 0{,}145$$
$$\sigma_B = 2{,}93 \text{ MPa} \quad (1)$$

$$F_t = \pi \times m \times b \times \sigma \times y$$
$$1\,446{,}67 = \pi \times 5 \times 10^{-3} \times b \times 2{,}546 \times 10^6$$
$$b = \frac{1\,446{,}67}{\pi \times 5 \times 2{,}546 \times 10^3}$$
$$b = 36{,}17 \text{ mm} \quad (1)$$

$$b_{min} = 2{,}5 \times \pi \times m$$
$$= 2{,}5 \times \pi \times 5$$
$$b_{min} = 39{,}3 \text{ mm} \quad (1)$$

$$b_{max} = 4 \times \pi \times m$$
$$= 4 \times \pi \times 5$$
$$b_{max} = 62{,}8 \text{ mm} \quad (1)$$

1.4 **Force on flywheel**

$$W_{flywheel} = m \times g$$
$$= 200 \times 9{,}81$$
$$= 1\,962 \text{ N} \quad (1)$$

$$\frac{N_A}{N_B} = \frac{2}{1}$$

$$N_B = \frac{N_A}{2} = \frac{2\,200}{2}$$

$$N_B = 1\,100 \text{ r/min} \quad (1)$$

**Forces on belt pulley**

$$V_c = \frac{\pi \times PCD \times N_B}{60}$$

$$V_c = \frac{\pi \times 0{,}5 \times 1\,100}{60}$$
$$V_c = 28{,}80 \text{ r/min} \quad (1)$$

$$P = (T_1 - T_2)V_c$$

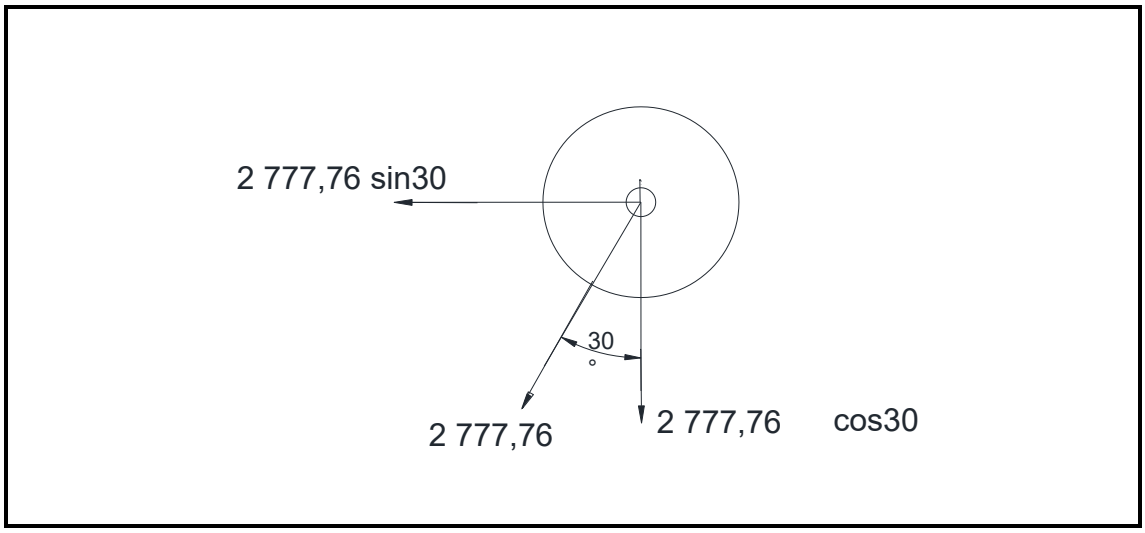
$$\frac{T_1}{T_2} = e^{\mu \times \theta}$$

$$\frac{T_1}{T_2} = e^{0{,}3 \times \frac{210 \times 3{,}142}{180}}$$
$$T_1 = 3T_2 \quad (1)$$

$$40 \times 10^3 = (T_1 - T_2)28{,}80$$
$$40 \times 10^3 = (3T_2 - T_2)28{,}80$$
$$40 \times 10^3 = (2T_2)28{,}80$$
$$T_2 = \frac{40 \times 10^3}{28{,}80 \times 2} \quad (1)$$

$$T_2 = 694{,}44 \text{ N}$$
$$T_1 = 3 \times 694{,}44$$
$$T_1 = 2\,083{,}32 \text{ N} \quad (1)$$

$$T_1 + T_2 = 2\,083{,}32 + 694{,}44$$
$$T_1 + T_2 = 2\,777{,}76 \text{ N} \quad (1)$$




(1)

**Vertical and horizontal forces on pulley**

$F_V = (T_1 + T_2)\cos 30$

$= 2\,777{,}76 \times 0{,}866$

$= 2\,405{,}61\ N$ (1)

$F_H = (T_1 + T_2)\sin 30$

$= 2\,777{,}76 \times 0{,}5$

$= 1\,388{,}88\ N$ (1)

**Determination of forces on the gear**

$$P = \frac{2 \times \pi \times N \times T}{60}$$

$$T = \frac{60 \times P}{2 \times \pi \times N}$$ (1)

**Torque on pinion**

$$T = \frac{60 \times 40\,000}{2 \times \pi \times 2\,200}$$

$T = 173{,}60\ Nm$ (1)

$$F_t = \frac{\text{torque} \times 2}{PCD}$$

$$F_t = \frac{173{,}60 \times 2}{0{,}24}$$

$F_t = 1\,446{,}67\ N$ (1)

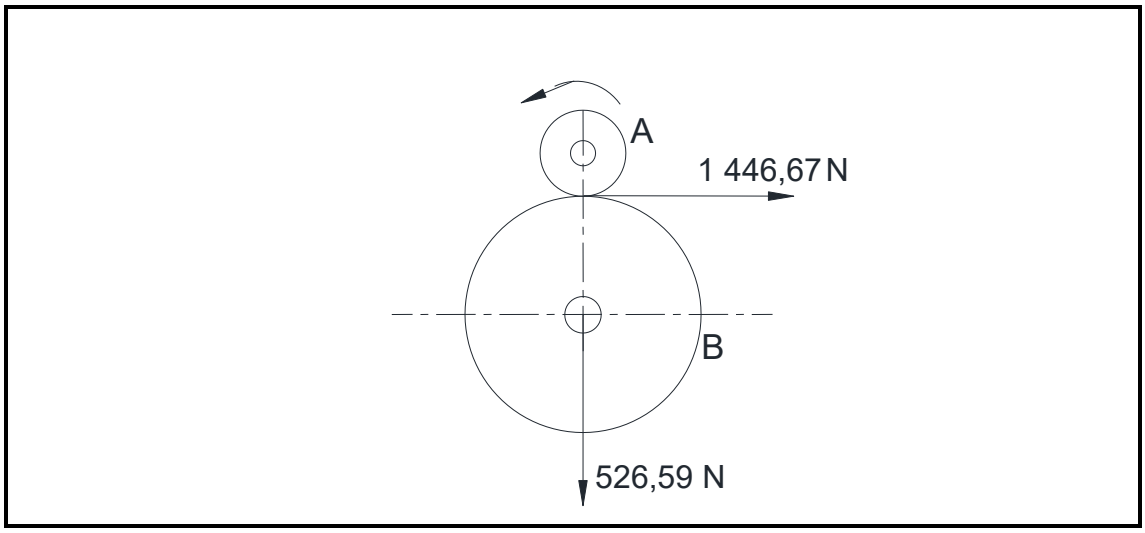
$F_r = \tan 20 \times 1\,446{,}67$

$= 0{,}364 \times 1\,446{,}67$

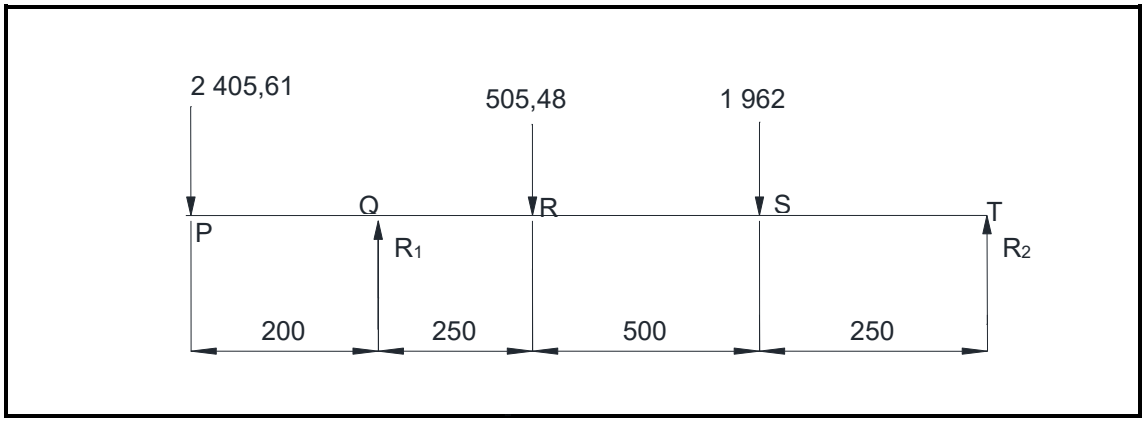
$F_r = 526{,}59\ N$ (1)

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1.5




(2)




(1)

Sum of forces in one direction = the sum of forces in the opposite direction

$R_1 + R_2 = 2\,405{,}61 + 526{,}59 + 1\,962$

$R_1 + R_2 = 4\,894{,}2\ N$ (1)

**Taking moment about Q**

$1{,}2 \times R_2 = 2\,405{,}61 \times 0{,}2 + 526{,}59 \times 0{,}4 + 1\,962 \times 0{,}9$ (1)

$1{,}2 \times R_2 = 481{,}12 + 210{,}64 + 1\,765{,}8$

$1{,}2 \times R_2 = 2\,457{,}56$

$R_2 = 2\,047{,}97\ N$ (1)

$R_1 = 4\,894{,}2 - 2\,047{,}97$

$R_1 = 2\,846{,}23\ N$ (1)

**Vertical bending moments**

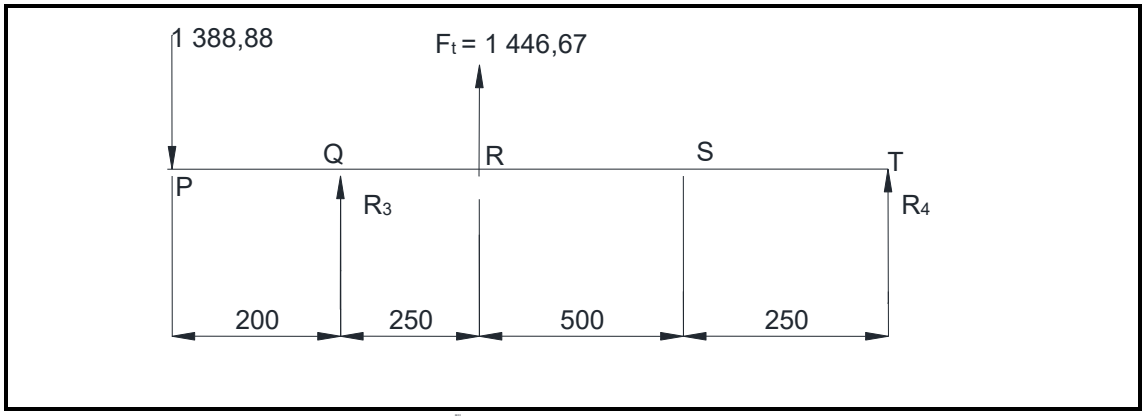
$\mathrm{BM_Q} = -2\,405{,}61 \times 0{,}2$

$= -481{,}12\ \mathrm{Nm}$ (1)

$$BM_R = -2405{,}61 \times 0{,}6 + 2846{,}23 \times 0{,}4$$
$$= -1443{,}37 + 1138{,}49$$
$$= -304{,}88\ Nm$$

$$BM_S = 2047{,}97\ \times 0{,}3$$
$$= 614{,}39\ Nm$$ (1)

**Horizontal reactions on shaft**




(1)

$\mathrm{R_3} + \mathrm{R_4} + \mathrm{F_t} = 1\,388{,}88$

$\mathrm{R_3} + \mathrm{R_4} = 1\,388{,}88 - \mathrm{F_t}$

$\mathrm{R_3} + \mathrm{R_4} = 1\,388{,}88 - 1\,446{,}67$

$\mathrm{R_3} + \mathrm{R_4} = -57{,}79$ (1)

**Taking moment about Q**

$1{,}2 \times R_4 + F_t \times 0{,}4 = 1\,388{,}88 \times 0{,}2$

$1{,}2 \times R_4 = 1\,388{,}88 \times 0{,}2 - 1\,446{,}67 \times 0{,}2$

$1{,}2 \times R_4 = 277{,}78 - 289{,}33$ (1)

$1{,}2 \times R_4 = -11{,}55$

$R_4 = \dfrac{-11{,}55}{1{,}2}$

$R_4 = -9{,}63\ \text{N}$ (1)

$+R_4 = -57{,}79$

$R_3 = -57{,}79 - R_4$ (1)

$R_3 = -57{,}79 + 9{,}63$

$= -48{,}16\ \text{N}$ (1)

**Horizontal bending moments**

$BM_Q = -1\,388{,}88 \times 0{,}2$

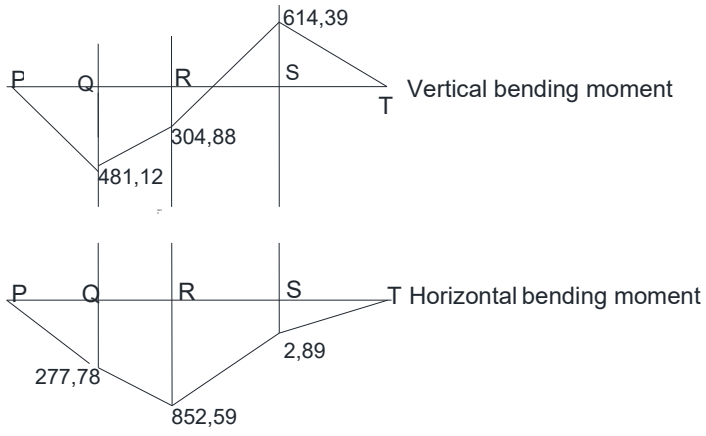
$= -277{,}78\ \text{Nm}$

$BM_R = -1\,388{,}88 \times 0{,}6 + (-48{,}16 \times 0{,}4)$

$= -852{,}59\ \text{Nm}$

$BM_S = -9{,}63 \times 0{,}3$

$= -2{,}89\ \text{Nm}$ (1)




(4)

1.6 **Maximum resultant bending moments**

$$\begin{aligned} BM_Q &= \sqrt{(-481{,}12)^2 + (-277{,}78)^2} \\ &= \sqrt{231\,476{,}45 + 77\,161{,}73} \\ &= 555{,}55 \text{ Nm} \end{aligned}$$ (1)

$$BM_R = \sqrt{(-304{,}88\ )^2 + (-852{,}59\ )^2}$$
$$BM_R = \sqrt{92\,951{,}81 + 726\,909{,}71}$$
$$BM_R = 905{,}46 \text{ Nm}$$ (1)

$$BM_S = \sqrt{(614{,}39\ )^2 + (-2{,}89\ )^2}$$
$$BM_S = 614{,}4 \text{ Nm}$$
Use $905{,}46$ Nm (1)

1.7 **Shaft diameter**

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

$$T_E = \sqrt{905{,}46^{\,2} + 347{,}2^2}$$
$$T_E = \sqrt{819\,857{,}81 + 120\,547{,}84}$$
$$T_E = 969{,}75 \text{ Nm}$$ (1)

$$T_E = \frac{\pi}{16} \times \frac{(D^4 - d^4)}{D} \times \tau$$
$$T_E = \frac{\pi}{16} \times \frac{([2d]^4 - d^4)}{2d} \times \tau$$
$$T_E = \frac{\pi}{32} \times 15d^3 \times \tau$$
$$969{,}75 = \frac{\pi}{32} \times 15d^3 \times 40 \times 10^6$$
$$d^3 = \frac{969{,}75}{40 \times 10^6} \times \frac{32}{\pi \times 15}$$
$$d = \sqrt[3]{16{,}46 \times 10^{-6}}$$
$$d = 0{,}0406 \text{ m}$$
$$d = 41 \text{ mm}$$
$$D = 82 \text{ mm}$$ (1)

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

$$M_E = \frac{1}{2}( 905{,}46 + 969{,}75 )$$

$$M_E = 937{,}61 \text{ Nm} \quad (1)$$

$$M_E = \frac{\pi}{16} \times \frac{(D^4 - d^4)}{D} \times \sigma \quad (1)$$

$$M_E = \frac{\pi}{16} \times \frac{([2d]^4 - d^4)}{2d} \times \sigma$$

$$937{,}61 = \frac{\pi}{32} \times 15d^3 \times 50 \times 10^6$$

$$d^3 = \frac{937{,}61}{50 \times 10^6} \times \frac{32}{\pi \times 15}$$

$$d = \sqrt[3]{12{,}73 \times 10^{-6}}$$

$$d = 0{,}0357 \text{ m}$$

$$d = 35{,}7 \text{ mm}$$

Say $d = 36$ mm

$$D = 72 \text{ mm} \quad (1)$$

1.8 **The gear arms**

$$PCD_B = 2 \times 240$$

$$= 480 \text{ mm} \quad (1)$$

No arms = 4 (from tables)

$$d = 41 \text{ mm}$$

$$D = 82 \text{ mm}$$

$$d_{BOSS} = 2 \times d_{SHAFT}$$

$$d_{BOSS} = 2 \times 82$$

$$= 164 \text{ mm} \quad (1)$$

$$L_{BENDING} = \frac{PCD}{2} - \frac{d_{BOSS}}{2}$$

$$= \frac{480}{2} - \frac{164}{2}$$

$$L_{BENDING} = 158 \text{ mm} \quad (1)$$

$$= \frac{F_T \times L}{arm}$$

$$M = \frac{1\,446{,}67 \times 0{,}158}{4}$$

$$= 57{,}1 \text{ Nm} \quad (1)$$

$$M = \sigma \times Z$$

$$57{,}1 = 40 \times 10^6 \times Z$$

$$Z = \frac{57{,}1}{40 \times 10^6}$$

$$Z = 1{,}428 \times 10^{-6} \text{ m}^3$$

$$Z = \frac{d^3}{12} \quad (1)$$

$$d^3 = 1{,}428 \times 10^{-6} \times 12$$

$$d = \sqrt[3]{1{,}428 \times 10^{-6} \times 12}$$

$$d = 4{,}14 \times 10^{-2} \text{ m}$$

$$d = 41{,}4 \text{ mm} \quad (1)$$

$$b = \frac{41{,}4}{2} \text{ mm}$$

$$b = 20{,}7 \text{ mm} \quad (1)$$

**[61]**

## QUESTION 2

### Surface area of bearing

$$A = d \times L$$

$$A = 0{,}05 \times 0{,}04$$

$$A = 0{,}002\ m^2$$ (1)

$$P = \frac{F}{A}$$

$$95 \times 10^6 = \frac{F}{0{,}002}$$

$$F = 190\ kN$$ (1)

### Surface area of a section through the column

$$A = \frac{\pi}{4} \times a \times b$$

$$= \frac{\pi}{4} \times 0{,}06 \times 0{,}03$$ (1)

$$= 0{,}0014\ m^2$$ (1)

$$I_{xx} = \frac{\pi \times b \times a^3}{64}$$

$$I_{xx} = \frac{\pi \times 0{,}03 \times 0{,}06^3}{64}$$ (1)

$$= 3{,}18 \times 10^{-7}\ m^4$$ (1)

$$k_{xx}^2 = \frac{I_{xx}}{A}$$

$$k_{xx}^2 = \frac{3{,}18 \times 10^{-7}}{0{,}0014}$$

$$= 2{,}27 \times 10^{-4}\ m^2$$ (1)

$$I_{yy} = \frac{\pi \times b^3 \times a}{64}$$

$$I_{yy} = \frac{\pi \times 0{,}03^3 \times 0{,}06}{64}$$ (1)

$$= 7{,}9 \times 10^{-8}\ m^4$$ (1)

$$k_{yy}^2 = \frac{I_{yy}}{A}$$

$$k_{yy}^2 = \frac{7{,}9 \times 10^{-8}}{0{,}0014}$$

$$= 5{,}64 \times 10^{-5}\ m^2$$ (1)

$$F = \frac{\sigma \times A}{1 + \frac{a}{n}\left(\frac{L^2}{k^2}\right)}$$

$$190\,000 = \frac{\sigma \times 0{,}0014}{1 + \frac{1}{1 \times 1\,600}\left(\frac{0{,}6^2}{2{,}27 \times 10^{-4}}\right)}$$ (3)

(1)

$$\sigma = 270{,}23\ MPa$$

$$F = \frac{\sigma \times A}{1 + \frac{a}{n}\left(\frac{L_E{}^2}{k^2}\right)}$$

$$L_E = \frac{0{,}6}{2}$$

$$= 0{,}3$$ (1)

$$190\,000 = \frac{\sigma \times 0{,}0014}{1 + \frac{1}{4 \times 1\,600}\left(\frac{0{,}3^2}{5{,}64 \times 10^{-5}}\right)}$$ (3)

$$\sigma = 169{,}55\ MPa$$ (1)

**[19]**

## QUESTION 3

3.1 $\theta = 120^o$ (1)

$$\alpha = \frac{\theta}{2} = \frac{120^o}{2}$$

$$\theta = 60^o$$

$$F_N = \frac{35 \times 10^3}{\sin 60}$$ (1)

$$F_N = \frac{35 \times 10^3}{0{,}866}$$

$$F_N = 40{,}41\ kN$$ (1)

3.2 **Inner diameter of bearing**

$$\sin 60 = \frac{R - r}{w}$$

$$w = \frac{R - r}{\sin 60} \quad (1)$$

$$R_f = \frac{R + r}{2}$$

$$F_N = P \times A$$

$$F_N = P \times 2 \times \pi \times w$$

$$40\,410 = 450 \times 10^3 \times 2 \times \pi \times \frac{R + r}{2} \times \frac{R - r}{\sin 60} \quad (1)$$

$$\frac{D}{d} = \frac{3}{1}$$

$$D = 3d \quad (1)$$

$$R = 3r$$

$$0{,}02475 = (3r + r) \times (3r - r) \quad (1)$$

$$0{,}02475 = 9r^2 - r^2$$

$$0{,}02475 = 8r^2$$

$$r = \sqrt{\frac{0{,}02475}{8}} \quad (1)$$

$$r = 0{,}05562$$

$$r = 56 \text{ mm}$$

$$d = 112 \text{ mm} \quad (1)$$

3.3 **Outer diameter of the bearing**

$$D = 3 \times 112 \quad (1)$$

$$D = 336 \text{ mm} \quad (1)$$

3.4 **Power lost by friction**

$$T = \mu \times F_N \times R_m$$

$$R_m = \frac{2}{3}\left[\frac{R^3 - r^3}{R^2 - r^2}\right]$$

$$R_m = \frac{2}{3}\left[\frac{0{,}168^3 - 0{,}056^3}{0{,}168^2 - 0{,}056^2}\right] \quad (1)$$

$$R_m = 0{,}121 \text{ m} \quad (1)$$

$$T = 0{,}09 \times 40\,410 \times 0{,}121$$
$$T = 440{,}06 \text{ Nm} \quad (1)$$

$$P = \frac{2 \times \pi \times N \times T}{60}$$

$$P = \frac{2 \times \pi \times 350 \times 440{,}06}{60}$$

$$P = 16{,}13 \text{ kW} \quad (1)$$

3.5 **Quantity of cooling water**

Heat lost = Heat gained

$$H_{lost} = H_{gained}$$

$$16{,}13 \times 10^3 = (m \times S.H.C \times \Delta T)_{\text{heat gained by oil}}$$

$$16{,}13 \times 10^3 = m \times 3{,}14 \times 10^3 \times (85 - 20) \quad (1)$$

$$m = \frac{16{,}13 \times 10^3}{65 \times 3{,}14 \times 10^3} \quad (1)$$

$$m = 0{,}079 \text{ kg/s}$$

$$Q = \frac{0{,}079}{0{,}85} \quad (1)$$

$$Q = 0{,}0929 \text{ lit/s}$$

$$Q = 0{,}0929 \times 60 \text{ lit/s} \quad (1)$$

$$Q = 5{,}574 \text{ lit/min} \quad (1)$$

**[20]**

**TOTAL: 100**

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