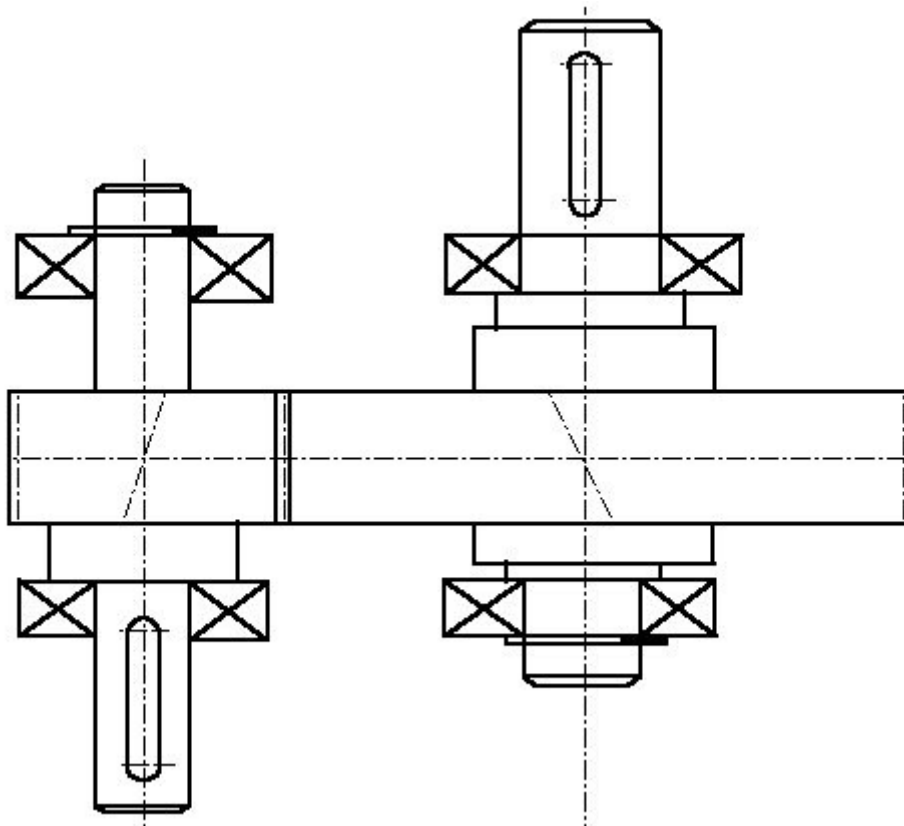


ENOSTOPENJSKI ZOBNIŠKI REDUKTOR Z VALJASTIMI ZOBNIKI S POŠEVNIMI ZOBMI

Definicija:

Konstruirajte enostopenjski zobniški reduktor z ohišjem ulite izvedbe in valjastimi zobniki s poševnimi zobmi, ki ga poganja elektromotor moči $P=25\text{ kW}$ pri vrtilni frekvenci $n_1=1500\text{ min}^{-1}$. Reduktor naj bo primeren za pogon mostnega žerjava. Prestavno razmerje reduktorja je $i=5$. Kot poševnosti $\beta=15^\circ$, standardni modul $m=5\text{ mm}$ in število zob manjšega zobnika $z_1=23\text{ zob}$. Življenjska doba ležajev naj bo $L_h=20 \times 10^3\text{ ur}$. Zobniki naj bodo izdelani s kakovostnim razredom 6.

Skica:



1. Izračun dimenzij zobnikov:

1.1. Manjši zobnik:

$$m_t = \frac{m}{\cos \beta}$$

$$m_t = \frac{5}{\cos 15^\circ}$$

$$m_t = 5,18 \text{ mm}$$

$$\tan \alpha_t = \frac{\tan \alpha}{\cos \beta}$$

$$\tan \alpha_t = \frac{\tan 20^\circ}{\cos 15^\circ}$$

$$\alpha_t = 20^\circ 39'$$

$$d_1 = z_1 \cdot m_t$$

$$d_1 = 23 \cdot 5,18$$

$$d_1 = 119,14 \text{ mm}$$

$$d_{a1} = d_1 + 2m$$

$$d_{a1} = 119,14 + 2 \cdot 5$$

$$d_{a1} = 129,14 \text{ mm}$$

$$d_{f1} = d_1 - 2,4 \cdot m$$

$$d_{f1} = 119,14 - 2,4 \cdot 5$$

$$d_{f1} = 107,14 \text{ mm}$$

$$d_{b1} = d_1 \cdot \cos \alpha_t$$

$$d_{b1} = 119,14 \cdot \cos 20^\circ 39'$$

$$d_{b1} = 111,49 \text{ mm}$$

1.2. Večji zobnik:

$$i = \frac{z_2}{z_1} \Rightarrow z_2 = i \cdot z_1 = 5 \cdot 23 = 115 \text{ zob}$$

$$d_2 = z_2 \cdot m$$

$$d_2 = 115 \cdot 5,18$$

$$d_2 = 595,7 \text{ mm}$$

$$d_{a2} = d_2 + 2m$$

$$d_{a2} = 595,7 + 2 \cdot 5$$

$$d_{a2} = 605,7 \text{ mm}$$

$$d_{f2} = d_2 - 2,4 \cdot m$$

$$d_{f2} = 595,7 - 2,4 \cdot 5$$

$$d_{f2} = 583,7 \text{ mm}$$

$$d_{b2} = d_2 \cdot \cos \alpha_t$$

$$d_{b2} = 595,7 \cdot \cos 20^\circ 39'$$

$$d_{b2} = 575,43 \text{ mm}$$

1.3. Izračun medosnega razmika:

$$a = \frac{d_1 + d_2}{2}$$

$$a = \frac{119,14 + 595,7}{2}$$

$$a = 357,42 \text{ mm}$$

$$b = 10 \cdot m$$

$$b = 10 \cdot 5$$

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

2. Izračun obremenitev zobnikov in gredi:

2.1. Izračun vrtilnega momenta motorja:

$$\omega = 2\pi \cdot n$$

$$\omega = 2\pi \cdot 25$$

$$\omega = 157,08 \text{ s}^{-1}$$

$$T_1 = \frac{P}{\omega}$$

$$T_1 = \frac{25000}{157,08}$$

$$T_1 = 159,15 \text{ Nm}$$

2.2. Izračun tangencialne sile:

$$F_t = \frac{2T_1}{d_{w1}}$$

$$F_t = \frac{2 \cdot 159,15}{0,11914}$$

$$F_t = 2671,65 \text{ N}$$

2.3. Izračun radialne sile:

$$F_r = F_t \cdot \tan \alpha_t$$

$$F_r = 2671,65 \cdot \tan 20^\circ 39'$$

$$F_r = 1006,87 \text{ N}$$

2.4. Izračun aksialne sile:

$$F_a = F_t \cdot \tan \beta$$

$$F_a = 2671,65 \cdot \tan 15^\circ$$

$$F_a = 715,87 \text{ N}$$

2.5. Izračun bočne normalne sile:

$$F_{bn} = \frac{F_t}{\cos \alpha \cdot \cos \beta}$$

$$F_{bn} = \frac{2671,65}{\cos 20^\circ \cdot \cos 15^\circ}$$

$$F_{bn} = 2943,4 \text{ N}$$

2.6. Izračun momenta na većem zobniku:

$$\omega = 2\pi \cdot n$$

$$\omega = 2\pi \cdot 5$$

$$\omega = 31,42 \text{ s}^{-1}$$

$$T_{2k} = \frac{P}{\omega}$$

$$T_{2k} = \frac{25000}{31,42}$$

$$T_{2k} = 795,67 \text{ Nm}$$

$$\frac{n_2}{n_1} = i \Rightarrow n_2 = \frac{n_1}{i}$$

$$n_2 = \frac{25}{5} = 5 \text{ s}^{-1}$$

$$T_2 = \frac{T_{2k}}{\eta}$$

$$T_2 = \frac{795,67}{0,93}$$

$$T_2 = 855,56 \text{ Nm}$$

3. Dimenzioniranje gredi:

3.1. Dimenzioniranje gredi na dopustni zasuk:

$$\phi_1 = \frac{T \cdot l_1}{G \cdot I_p} \cdot \frac{180}{\pi} \leq \phi_{dop} \quad \phi_{dop} = 0,5 \text{ m} / ^\circ \quad I_p = \frac{\pi \cdot d^4}{32}$$

3.1.1. Pogonska gred (manjša gred):

$$I_p = \frac{T_1 \cdot l \cdot 180^\circ}{G \cdot \phi_{dop} \cdot \pi}$$

$$I_p = \frac{152,9 \cdot 10^3 \cdot 1000 \cdot 180^\circ}{81000 \cdot 0,5 \cdot \pi}$$

$$I_p = 216309,25 \text{ mm}^3$$

$$d_{g1} = \sqrt[4]{\frac{32 \cdot I_p}{\pi \cdot i}} \quad d_{g1} = \sqrt[4]{\frac{32 \cdot 216309,25}{\pi}}$$

$$d_{g1} = 38,53 \text{ mm} \Rightarrow 40 \text{ mm}$$

$$T_1 = T_m \cdot \eta_l \cdot \eta_t$$

$$T_1 = 159,15 \cdot 0,98 \cdot 0,98$$

$$T_1 = 152,9 \text{ Nm}$$

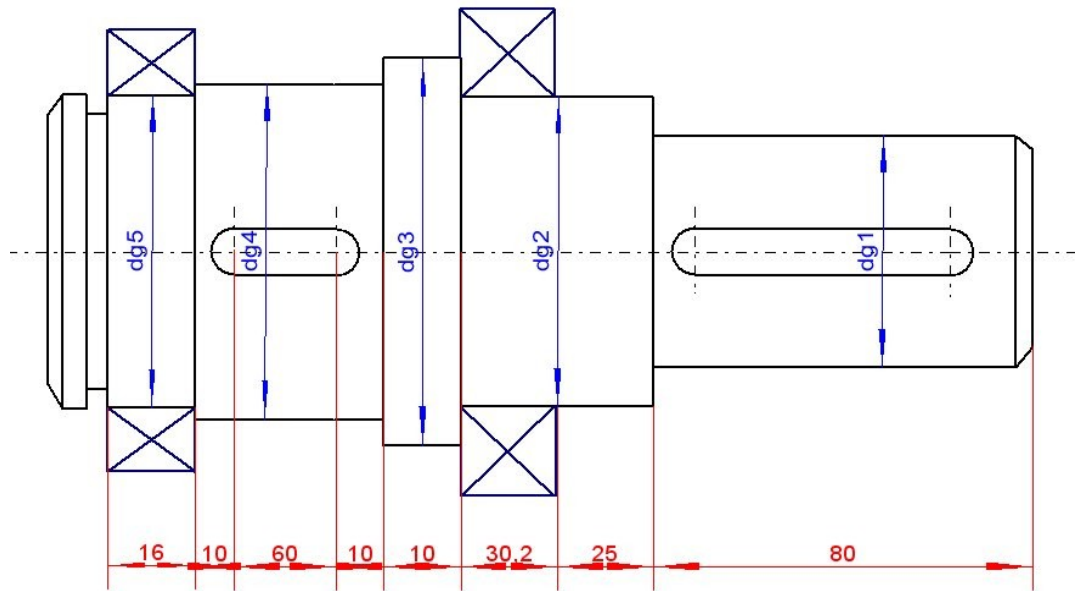
$$d_{g1} = 40 \text{ mm}$$

$$d_{g2} = 45 \text{ mm}$$

$$d_{g3} = 53 \text{ mm}$$

$$d_{g4} = 47 \text{ mm}$$

$$d_{q4} = 45 \text{ mm}$$



3.1.2. Izračun zobnika (če bo narejen skupaj z gredjo):

$$d_1 < 1,8 \cdot d_{g4} + 2,5 \text{ mm}$$

$$d_1 < 1,8 \cdot 47 + 2,5 \cdot 5$$

$$119,14 \text{ mm} < 97,1 \text{ mm}$$

Zobnik bo izdelan posebej.

3.1.3. Gnana gred (večja gred):

$$I_p = \frac{T_2 \cdot l \cdot 180^\circ}{G \cdot \phi_{dop} \cdot \pi}$$

$$I_p = \frac{711 \cdot 10^3 \cdot 1000 \cdot 180^\circ}{81000 \cdot 0,5 \cdot \pi}$$

$$I_p = 1005859,24 \text{ mm}^3$$

$$d_{g1} = \sqrt[4]{\frac{32 \cdot I_p}{\pi \cdot i}} \quad i \cdot d_{g1} = \sqrt[4]{\frac{32 \cdot 1005859,24}{\pi}}$$

$$d_{g1} = 56,58 \text{ mm} \Rightarrow 60 \text{ mm}$$

$$T_2 = T_1 \cdot i \cdot \eta$$

$$T_2 = 152,9 \cdot 5 \cdot 0,93$$

$$T_2 = 711 \text{ Nm}$$

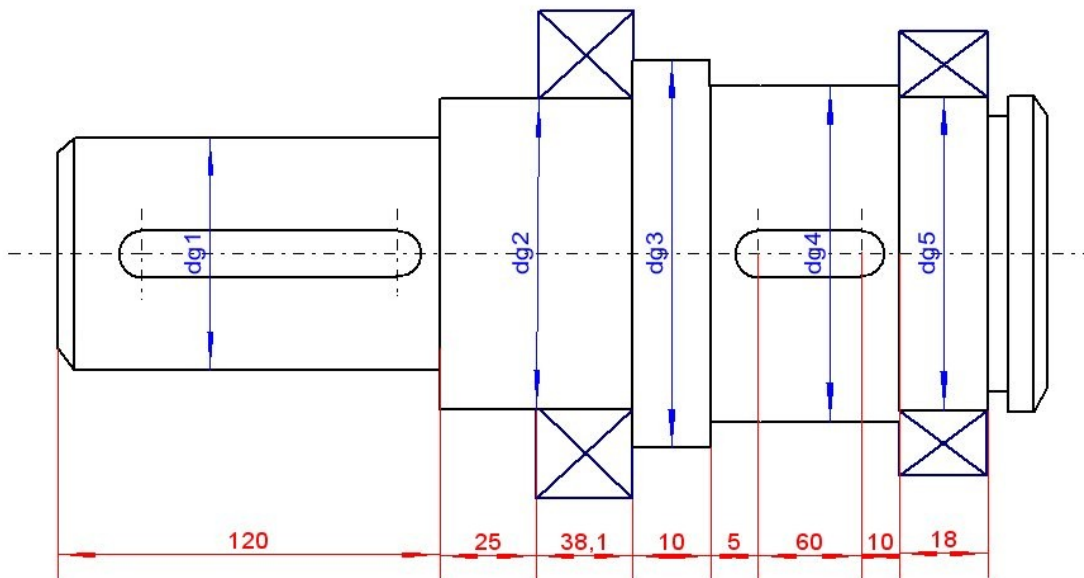
$$d_{g1} = 60 \text{ mm}$$

$$d_{g2} = 65 \text{ mm}$$

$$d_{g3} = 73 \text{ mm}$$

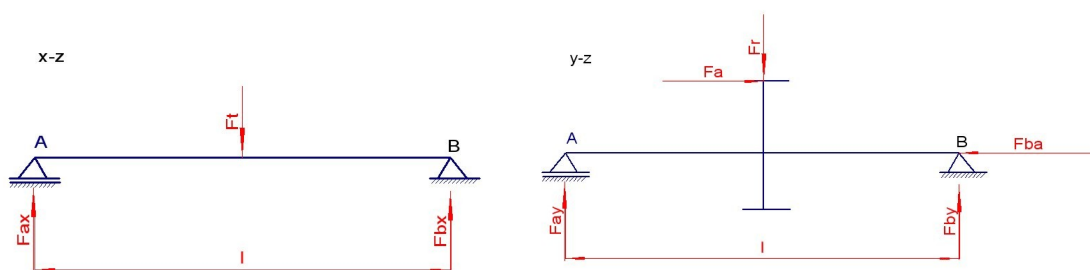
$$d_{g4} = 67 \text{ mm}$$

$$d_{g5} = 65 \text{ mm}$$



3.2. Dimenzioniranje ležajev:

3.2.1. Pogonska gred:



$$\sum F_{ix}=0;$$

$$F_{Bx} = \frac{F_T}{2}$$

$$F_{Bx} = \frac{2671,65}{2}$$

$$F_{Ax} = F_{Bx} = 1335,83 \text{ Nm}$$

$$\sum F_{iy}=0;$$

$$-F_{Ay} + F_{By} - F_R = 0$$

$$F_{By} = F_R + F_{Ay}$$

$$F_{By} = 1006,87 + 108,94$$

$$F_{By} = 1115,81 \text{ Nm}$$

$$F_{Ba} = F_a$$

$$F_{Ba} = 715,87 \text{ N}$$

$$\sum M_{iB} = 0;$$

$$-F_{Ay} \cdot l + F_r \cdot \frac{l}{2} - F_a \cdot \frac{d_1}{2} = 0$$

$$F_{Ay} \cdot l = F_r \cdot \frac{l}{2} - F_a \cdot \frac{d_1}{2}$$

$$F_{Ay} = \frac{11776,95}{108,1} = 108,94 \text{ Nm}$$

Dolžina med ležaji:

$$l = \frac{16}{2} + 10 + 60 + 10 + 10 + \frac{30,2}{2} = 113,1 \text{ mm}$$

Celotna dolžina gredi:

$$L = 15 + 10 + 60 + 10 + 10 + 30,2 + 25 + 80 + 7,65 = 247,85 \text{ mm} \quad !!!!!$$

3.2.2. Gnana gred:

Dolžina med ležaji:

$$l = \frac{38,1}{2} + 10 + 5 + 60 + 10 + \frac{18}{2} = 113,1 \text{ mm}$$

Celotna dolžina gredi:

$$L = 120 + 25 + 38,1 + 10 + 5 + 60 + 10 + 18 + 7,15 = 293,25 \text{ mm} \quad !!!!!$$

3.2.3. Izbira ležajev:

Iz priročnika izberemo ležaje glede na premer:

- Pogonska gred:

Enoredni kroglični:

$$6009 \Rightarrow C = 20,8 \text{ kN}, b = 16 \text{ mm}$$

Dvoredni kroglični s poševnim dotikom:

$$4209 \Rightarrow C = 39 \text{ kN}, b = 30,2 \text{ mm}$$

- Gnana gred:

Enoredni kroglični:

$$6013 \Rightarrow C = 30,7 \text{ kN}, b = 18 \text{ mm}$$

Dvoredni kroglični s poševnim dotikom:

$$4212 \Rightarrow C = 67,6 \text{ kN}, b = 38,1 \text{ mm}$$

4. Kontrola:

4.1. Kontrola nosilnosti ležajev:

4.1.1. Dimenzioniranje ležajev za pogonsko gred:

$$F_A = \sqrt{F_{Ax}^2 + F_{Ay}^2}$$

$$F_A = \sqrt{(1335,83)^2 + (108,94)^2}$$

$$F_A = 1340,26 \text{ N}$$

$$F_B = \sqrt{F_{Bx}^2 + F_{By}^2}$$

$$F_B = \sqrt{(1335,83)^2 + (1115,81)^2}$$

$$F_B = 1740,54 \text{ N}$$

4.1.1.1. Pomični ležaj pogonske gredi:

$$f_L = \sqrt[3]{\frac{L_h}{500}}$$

$$f_L = \sqrt[3]{\frac{20000}{500}}$$

$$f_L = 3,42$$

$$f_n = \sqrt[3]{\frac{33,3}{n}}$$

$$f_n = \sqrt[3]{\frac{33,3}{1500}}$$

$$f_n = 0,28$$

$$F_A = 1340,26 \text{ N}$$

$$x = 1$$

$$F = F_A \cdot x$$

$$F = 1340,26 \cdot 1$$

$$F = 1340,26 \text{ Nm}$$

$$C = F \cdot \frac{f_L}{f_n}$$

$$C = 1340,26 \cdot \frac{3,42}{0,28}$$

$$C = 16370,32 \text{ N} \Rightarrow 16,37 \text{ kN}$$

Iz priročnika sem izbral:

$$d = 45 \text{ mm}$$

$$D = 75 \text{ mm}$$

$$b = 16 \text{ mm}$$

$$r = 1 \text{ mm}$$

$$6009 \Rightarrow C = 20,8 \text{ kN}$$

4.1.1.2. Nepomični ležaj pogonske gredi:

$$\frac{F_{Ba}}{F_B} = \frac{715,87}{1740,54} = 0,411 < 0,86$$

$$x = 1$$

$$y = 0,73$$

$$F = V \cdot x \cdot F_B + y \cdot F_{Ba}$$

$$F = 1 \cdot 1 \cdot 1740,54 + 0,73 \cdot 715,87$$

$$F = 2263,16 \text{ N}$$

$$C = F \cdot \frac{f_l}{f_n}$$

$$C = 2263,16 \cdot \frac{3,42}{0,28}$$

$$C = 27642,88 \text{ N} \Rightarrow 27,64 \text{ kN}$$

Iz priročnika sem izbral:

$$d = 45 \text{ mm}$$

$$D = 85 \text{ mm}$$

$$b = 30,2 \text{ mm}$$

$$r = 1,1 \text{ mm}$$

$$4209 \Rightarrow C = 39 \text{ kN}$$

4.1.2. Dimenzioniranje ležajev za gnano gred:

4.1.2.1. Pomični ležaj gnane gredi:

$$f_L = \sqrt[m]{\frac{L_h}{500}} \qquad f_n = \sqrt[m]{\frac{33,3}{n_2}}$$

$$f_L = \sqrt[3]{\frac{20000}{500}} \qquad f_n = \sqrt[3]{\frac{33,3}{300}}$$

$$f_L = 3,42 \qquad f_n = 0,48$$

$$F_A = 1340,26 \text{ N}$$

$$x = 1$$

$$F = F_A \cdot x$$

$$F = 1340,26 \cdot 1$$

$$F = 1340,26 \text{ Nm}$$

$$C = F \cdot \frac{f_l}{f_n}$$

$$C = 1340,26 \cdot \frac{3,42}{0,48}$$

$$C = 9549,35 \text{ N} \Rightarrow 9,55 \text{ kN}$$

Iz priročnika sem izbral: 6013 $\Rightarrow C = 30,7 \text{ kN}$

$$d = 65 \text{ mm}$$

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

$$b = 18 \text{ mm}$$

$$r = 1,1 \text{ mm}$$

4.1.2.2. Nepomični ležaj gnane gredi:

$$F = V \cdot x \cdot F_B + y \cdot F_{Ba}$$

$$F = 1 \cdot 1 \cdot 1740,54 + 0,73 \cdot 715,87$$

$$F = 2263,16 \text{ N}$$

$$C = F \cdot \frac{f_l}{f_n}$$

$$C = 2263,16 \cdot \frac{3,42}{0,48}$$

$$C = 16125,02 \text{ N} \Rightarrow 16,13 \text{ kN}$$

Iz priročnika sem izbral:

$$d = 65 \text{ mm}$$

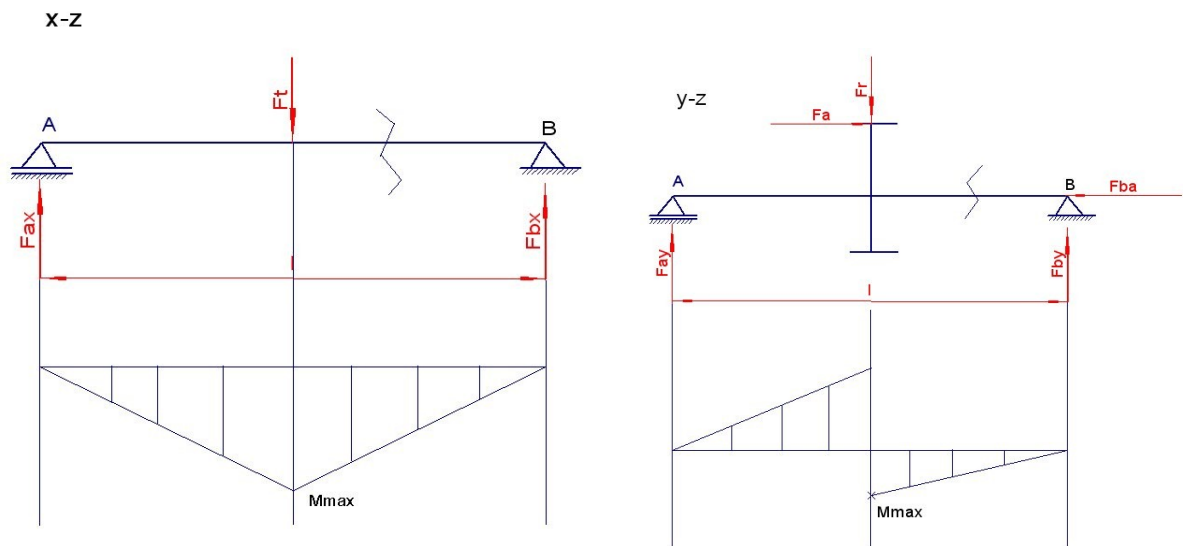
$$D = 120 \text{ mm}$$

$$b = 38,1 \text{ mm}$$

$$r = 1,5 \text{ mm}$$

$$4213 \Rightarrow C = 67,6 \text{ kN}$$

4.2. Izračun maksimalnega momenta:



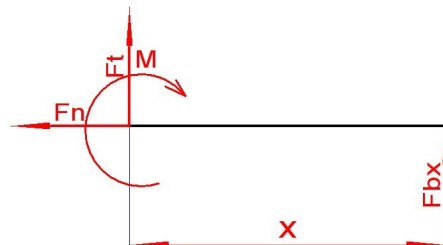
$$\sum M_{iP} = 0$$

$$F_{Bx} \cdot x - M_x = 0$$

$$M_x = F_{Bx} \cdot x$$

$$x = 0 \Rightarrow M_x = 0$$

$$x = \frac{l}{2} = \frac{113,1}{2} = 56,55 \text{ mm} \Rightarrow M_x = 75,54 \text{ Nm}$$



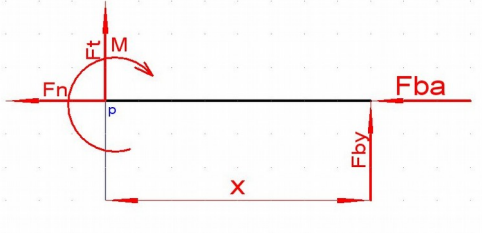
$$\sum M_{iP} = 0$$

$$F_{By} \cdot x - M_y = 0$$

$$M_y = F_{By} \cdot x$$

$$x = 0 \Rightarrow M_y = 0$$

$$x = \frac{l}{2} = \frac{113,1}{2} = 56,55 \text{ mm} \Rightarrow M_y = 63,1 \text{ Nm}$$



$$M = \sqrt{M_x^2 + M_y^2}$$

$$M = \sqrt{(75,54)^2 + (63,1)^2}$$

$$M = 98,43 \text{ Nm}$$

4.3. Izračun napetosti v gredi:

E 335 (SIST)

• Fe 590 – 2 (ISO)

$$\sigma_{dfizm} = 240 \frac{\text{N}}{\text{mm}^2}$$

$$\tau_{tutr} = 180 \frac{\text{N}}{\text{mm}^2}$$

$$\alpha_o = \frac{\sigma_{Dfizm}}{\sqrt{3} \cdot \tau_{tutr}}$$

$$\alpha_o = \frac{240}{\sqrt{3} \cdot 180}$$

$$\alpha_o = 0,77$$

• $b = 0,5$

• $\beta_k = 2$

$$\sigma_{dop} = \frac{\sigma_{Dfizm} \cdot b}{\beta_k \cdot \gamma_D}$$

$$\sigma_{dop} = \frac{240 \cdot 0,5}{2 \cdot 1,5}$$

$$\sigma_{dop} = 40 \frac{\text{N}}{\text{mm}^2}$$

$$W = \frac{\pi \cdot d^3}{32}$$

$$W = \frac{\pi \cdot 40^3}{32}$$

$$W = 6283,19 \text{ mm}^3$$

$$\sigma_f = \frac{M}{W}$$

$$\sigma_f = \frac{98,48 \cdot 10^3}{6283,19}$$

$$\sigma_f = 15,67 \frac{\text{N}}{\text{mm}^2}$$

$$W_t = \frac{\pi \cdot d_2^3}{16}$$

$$W_t = \frac{\pi \cdot 40^3}{16}$$

$$W_t = 12566,37 \text{ mm}^3$$

$$\tau_t = \frac{T_2}{W_t}$$

$$\tau_t = \frac{159,14 \cdot 10^3}{12566,37}$$

$$\tau_t = 12,66 \frac{\text{N}}{\text{mm}^2}$$

$$\sigma_s = \sqrt{\sigma_f^2 + 3 \cdot (\alpha \cdot \tau_t)^2} \leq \sigma_{dop}$$

$$\sigma_s = \sqrt{(15,67)^2 + 3 \cdot (0,77 \cdot 12,66)^2} \leq 40$$

$$23,04 \frac{\text{N}}{\text{mm}^2} \leq 40 \frac{\text{N}}{\text{mm}^2}$$

5. Dimenzioniranje moznika:

5.1.1. Pogonska gred (manjša gred):

Izberemo iz priročnika:

$$d = 40 \text{ mm}$$

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

$$h = 8 \text{ mm}$$

$$t = 5 \text{ mm}$$

$$t_2 = 3,3 \text{ mm}$$

1. Površinski tlak:

$$p = 90 \frac{\text{N}}{\text{mm}^2}$$

$$p = \frac{4 \cdot T_1}{d \cdot h \cdot l} \leq p_{dop}$$

$$l = \frac{4 \cdot T_1}{d \cdot h \cdot p_{dop}}$$

$$l = \frac{4 \cdot 159,2 \cdot 10^3}{40 \cdot 8 \cdot 90}$$

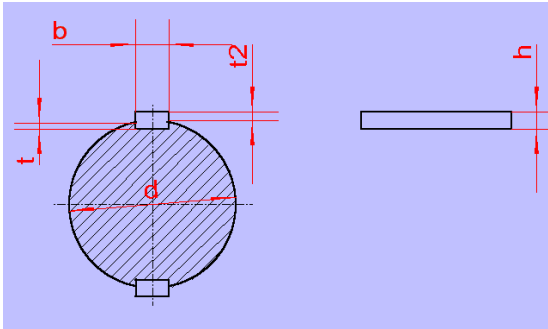
$$l = 22,11 \text{ mm}$$

$$L_m = l + b$$

$$L_m = 22,11 + 12$$

$$L_m = 34,11 \text{ mm} \Rightarrow 36 \text{ mm}$$

Dobili smo mozničnik: 12 x 8 x 36mm



Izberemo iz priročnika:

$$d = 47 \text{ mm}$$

$$b = 14 \text{ mm}$$

$$h = 9 \text{ mm}$$

$$t = 5,5 \text{ mm}$$

$$t_2 = 3,8 \text{ mm}$$

1. Površinski tlak:

$$p = 90 \frac{N}{\text{mm}^2}$$

$$p = \frac{4 \cdot T_1}{d \cdot h \cdot l} \leq p_{dop}$$

$$l = \frac{4 \cdot T_1}{d \cdot h \cdot p_{dop}}$$

$$l = \frac{4 \cdot 159,2 \cdot 10^3}{47 \cdot 9 \cdot 90}$$

$$l = 16,73 \text{ mm}$$

$$L_m = l + b$$

$$L_m = 16,73 + 14$$

$$L_m = 30,73 \text{ mm} \Rightarrow 32 \text{ mm}$$

Dobili smo mozničnik: 14 x 9 x 32mm

5.1.2. Gnana gred (večja gred):

Izberemo iz priročnika:

1. Površinski tlak:

$$\begin{aligned}
 d &= 60 \text{ mm} \\
 b &= 18 \text{ mm} \\
 h &= 11 \text{ mm} \\
 t &= 7 \text{ mm} \\
 t_2 &= 4,4 \text{ mm}
 \end{aligned}$$

$$\begin{aligned}
 p &= 90 \frac{\text{N}}{\text{mm}^2} \\
 p &= \frac{4 \cdot T_1}{d \cdot h \cdot l} \leq p_{dop} \\
 l &= \frac{4 \cdot T_1}{d \cdot h \cdot p_{dop}} \\
 l &= \frac{4 \cdot 855,56 \cdot 10^3}{60 \cdot 11 \cdot 90} \\
 l &= 57,61 \text{ mm}
 \end{aligned}$$

$$\begin{aligned}
 L_m &= l + b \\
 L_m &= 57,61 + 18 \\
 L_m &= 75,61 \text{ mm} \Rightarrow 80 \text{ mm}
 \end{aligned}$$

Dobili smo možnik: 18 x 11 x 80mm

Izberemo iz priročnika:

$$\begin{aligned}
 d &= 67 \text{ mm} \\
 b &= 20 \text{ mm} \\
 h &= 12 \text{ mm} \\
 t &= 7,5 \text{ mm} \\
 t_2 &= 4,9 \text{ mm}
 \end{aligned}$$

1. Površinski tlak:

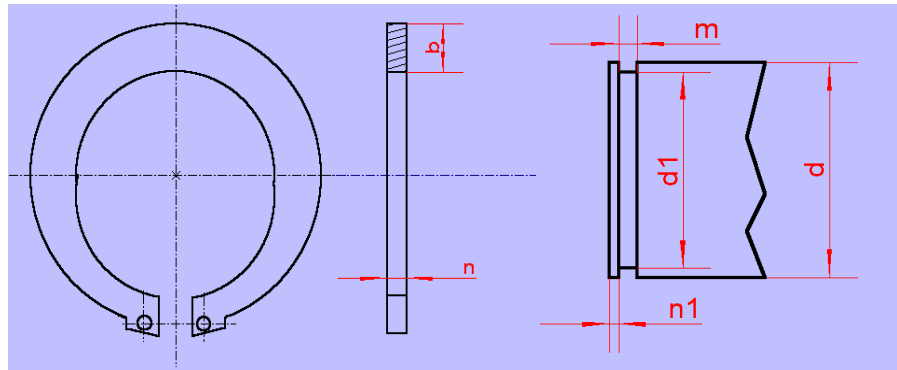
$$\begin{aligned}
 p &= 90 \frac{\text{N}}{\text{mm}^2} \\
 p &= \frac{4 \cdot T_2}{d \cdot h \cdot l} \leq p_{dop} \\
 l &= \frac{4 \cdot T_2}{d \cdot h \cdot p_{dop}} \\
 l &= \frac{4 \cdot 855,56 \cdot 10^3}{67 \cdot 12 \cdot 90} \\
 l &= 47,29 \text{ mm}
 \end{aligned}$$

$$\begin{aligned}
 L_m &= l + b \\
 L_m &= 47,29 + 20 \\
 L_m &= 67,29 \text{ mm} \Rightarrow 70 \text{ mm}
 \end{aligned}$$

Dobili smo možnik: 20 x 12 x 70mm

5.2. Dimenzioniranje vskočnika:

Zunanji vskočnik za premer 45mm:



$d_{g5} = 45\text{ mm}$ h12
 $d_5 = 42,5\text{ mm}$
 $b = 3,8\text{ mm}$
 $n = 3,8\text{ mm}$
 $m = 1,85\text{ mm}$ H13

$d_{g5} = 65\text{ mm}$ h12

$d_5 = 62\text{ mm}$

$b = 6,4\text{ mm}$

$n = 2,5\text{ mm}$

$m = 2,65\text{ mm}$ H13

Zunanji vskočnik za premer 65mm:

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