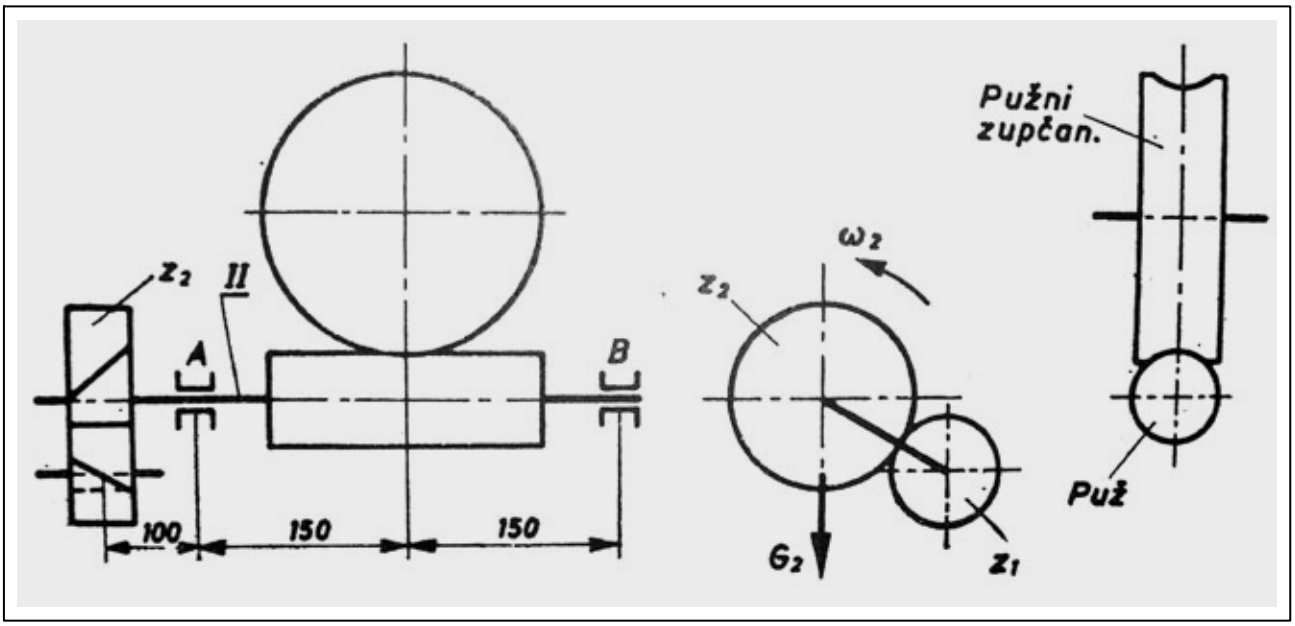
Pro\Machine

OSNOVE KONSTRUISANJA - MATURSKI RAD

Proracun zupcastog prenosnika - ZADATAK 3

Prenosnik snage sastoji se iz para cilindricnih zupcanika sa kosim zupcima i puznog para. Cilindricni zupcanici su pod uglom od $\alpha_{1\text{-}2} = 30 \cdot \text{deg}$ u odnosu na horizontalnu ravan. Zupcanik z1 prima snagu od elektromotora, a puzni tocak z4 predaje snagu radnoj masini. Rad masine je sa umerenim udarima.



dati podaci:

snaga elektromotora $P_1 = 10 \cdot \text{kW}$

broj obrtaja pogonskog zupcanika $n_1 = 1960 \cdot \text{min}^{-1}$

brojevi zubaca $z_1 = 21$ $z_2 = 36$

modul $m_{n1\text{-}2} = 4 \cdot \text{mm}$

ugao nagiba bocne linije zupca $\beta = 20 \cdot \text{deg}$

broj hodova puza $z_3 = 1$

precnik podeone kruznice puza $d_3 = 80 \cdot \text{mm}$

broj modula u precniku puza (puzni broj) $q = 10$

broj zubaca puznog zupcanika $z_4 = 40$

koeficijent trenja na puznom paru $\mu_o = 0.03$

Stepen iskoriscenja para z1-z2 $\eta_{1\text{-}2} = 0.98$

Stepen iskoriscenja para z3-z4 $\eta_{3\text{-}4} = 0.98$

Potrebno je odrediti:

1. Sve aktivne sile, smer zavojnice puza i shemu opterecenja vratila II

2. Precnik vratila II na mestu zupcanika z2 i na mestu lezaja A, ako je materijal vratila C.0545

3. Izvrsiti izbor i proveru lezaja A koji prima samo radijalno opterecenje, ako je $L_{hA} = 7500 \cdot hr$, a radna temperatura $t = 373 \cdot K$

4. Proveriti cvrstocu bokova i podnozja puznog zupcanika ako je materijal puza C.1530, a puznog zupcanika kalajna bronza. Vek rada je $L_{hz4} = 7500 \cdot hr$

5. Izracunati precnik podesenih vijaka za vezu tela i venca puznog zupcanika ako su vijci postavljeni na precniku $D_o = 260 \cdot mm$, a izradjeni su od CV 8.8

6. propisati naleganje tela i venca puznog zupcanika sa objasnjenjem i nacrtati dijagram zazora, odnosno preklopa, ako se dodir ostvaruje na precniku od $D_n = 290 \cdot mm$.

Napomena: Ostale potrebne vrednosti usvojiti

Resenje

Aktivne sile

Obrtni moment na vratilu I

$$T_1 = \frac{P_1}{\omega_1} \cdot K_A$$

$$\omega_1 = 2 \cdot \pi \cdot n_1 \qquad \omega_1 = 205.251\ s^{-1}$$

$$K_A = 1.25$$

$$T_1 = \frac{P_1}{\omega_1} \cdot K_A \qquad T_1 = 60.901\ N \cdot m$$

Sile na zupcaniku z1

$$F_{t1} = \frac{2 \cdot T_1}{d_1}$$

$$d_1 = \frac{m_{n1\text{-}2}}{\cos(\beta)} \cdot z_1 \qquad d_1 = 89.391\ mm$$

$$d_2 = \frac{m_{n1\text{-}2}}{\cos(\beta)} \cdot z_2 \qquad d_2 = 153.242\ mm$$

$$F_{t1} = \frac{2 \cdot T_1}{d_1} \qquad F_{t1} = 1.363 \times 10^3\ N$$

$$F_{r1} = \frac{F_{t1}}{\cos(\beta)} \cdot \tan(\alpha_n)$$

$$\alpha_n = 20 \cdot deg$$

$$F_{r1} = \frac{F_{t1}}{\cos(\beta)} \cdot \tan(\alpha_n) \qquad F_{r1} = 527.767\,N$$

$$F_{a1} = F_{t1} \cdot \tan(\beta) \qquad F_{a1} = 495.938\,N$$

Sile na zupcaniku z2

$$F_{t2} = F_{t1} \qquad F_{t2} = 1.363 \times 10^3\,N$$

$$F_{r2} = F_{r1} \qquad F_{r2} = 527.767\,N$$

$$F_{a2} = F_{a1} \qquad F_{a2} = 495.938\,N$$

Obrtni moment na vratilu II

$$T_2 = T_1 \cdot i_{1\text{-}2} \cdot \eta_{1\text{-}2}$$

$$i_{1\text{-}2} = \frac{z_2}{z_1} \qquad i_{1\text{-}2} = 1.714$$

$$T_2 = T_1 \cdot i_{1\text{-}2} \cdot \eta_{1\text{-}2} \qquad T_2 = 102.314\,N \cdot m$$

Ugaona brzina vratila II

$$\omega_2 = \frac{\omega_1}{i_{1\text{-}2}} \qquad \omega_2 = 119.73\,s^{-1}$$

Sile na puzu z3

$$F_{t3} = \frac{2 \cdot T_3}{d_3}$$

$$T_3 = T_2 \qquad T_3 = 102.314\,N \cdot m$$

$$d_3 = 80\,mm$$

$$F_{t3} = \frac{2 \cdot T_3}{d_3} \qquad F_{t3} = 2.558 \times 10^3\,N$$

$$F_{r3} = \frac{F_{t3} \cdot \tan(\alpha_n)}{\tan(\gamma_m + \rho)}$$

$$\alpha_n = 20 \cdot deg$$

Ugao zavojnice na srednjem cilindru puza

$$\gamma_m = \operatorname{atan}\left(\frac{z_3}{q}\right) \qquad \gamma_m = 5.711\,deg$$

Ugao trenja $\rho = \operatorname{atan}(\mu_o)$ $\rho = 1.718\,deg$

$$F_{r3} = \frac{F_{t3}\cdot\tan(\alpha_n)}{\tan(\gamma_m + \rho)} \qquad F_{r3} = 7.14\times 10^3\ \mathrm{N}$$

$$F_{a3} = \frac{F_{t3}}{\tan(\gamma_m + \rho)} \qquad F_{a3} = 1.962\times 10^4\ \mathrm{N}$$

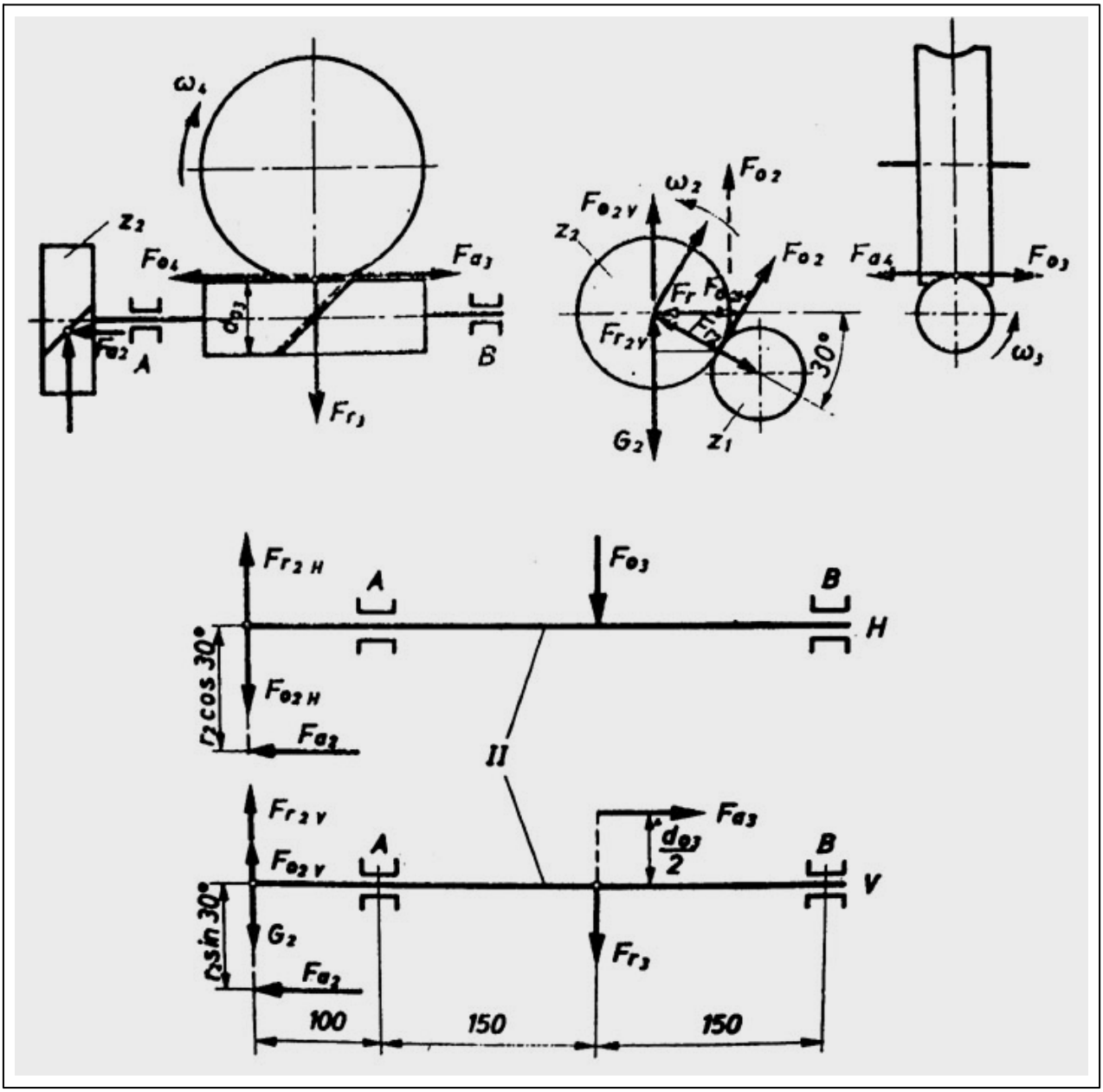
Sile na puznom zupcaniku z4

$$F_{t4} = F_{a3} \qquad F_{t4} = 1.962\times 10^4\ \mathrm{N}$$

$$F_{r4} = F_{r3} \qquad F_{r4} = 7.14\times 10^3\ \mathrm{N}$$

$$F_{a4} = F_{t3} \qquad F_{a4} = 2.558\times 10^3\ \mathrm{N}$$

Shema opterecenja vratila



Dimenzionisanje vratila

Precnik vratila na mestu zupcanika z2

$$d_{iz2} = \sqrt[3]{\frac{32 \cdot M_{i2}}{\pi \cdot \sigma_d}}$$

Moment savijanja

$$M_{2H} = F_{a2} \cdot \frac{d_2}{2} \cdot \cos(\alpha_{1\text{-}2}) \qquad M_{2H} = 32.908\,N \cdot m$$

$$M_{2V} = F_{a2} \cdot \frac{d_2}{2} \cdot \sin(\alpha_{1\text{-}2}) \qquad M_{2V} = 19\,N \cdot m$$

$$M_2 = \sqrt{M_{2V}^2 + M_{2H}^2} \qquad M_2 = 37.999\,N \cdot m$$

Moment uvijanja $T_2 = 102.314\,N \cdot m$

Idealni moment savijanja

$$M_i = \sqrt{M^2 + (\alpha \cdot T)^2}$$

gde je za materijal vratila C.0545

Zatezna cvrstoca T.2.3.str.44 ME I $R_m = 500 \cdot \frac{N}{mm^2}$

Savojna dinamicka izdrzljivost pri naizmenicno promenljivom opterecenju

T.2.3.str.45 ME I $\sigma_{D(-1)s} = 220 \frac{N}{mm^2}$

Uvojna dinamicka izdrzljivost pri jednosmernom promenljivom opterecenju

T.2.3.str.45 ME I $\tau_{D(0)u} = 170 \frac{N}{mm^2}$

Koeficijent svodjenja napona $\alpha = \frac{\sigma_{D(-1)s}}{2 \cdot \tau_{D(0)u}}$ $\alpha = 0.647$

$$M_{i2} = \sqrt{M_2^2 + (\alpha \cdot T_2)^2} \qquad M_{i2} = 76.333\,N \cdot m$$

Stepen sigurnosti $S = 4$

Dozvoljeni napon na savijanje $\sigma_d = \frac{\sigma_{D(-1)s}}{S}$ $\sigma_d = 55 \frac{N}{mm^2}$

$$d_{iz2} = \sqrt[3]{\frac{32 \cdot M_{i2}}{\pi \cdot \sigma_d}} \qquad d_{iz2} = 24.18\,mm$$

Zbog zleba za klin na mestu zupcanika z2

$d_{z2r} = 1.2 \cdot d_{iz2}$ $d_{z2r} = 29.016\,mm$ usvajam standardan precnik $d_{z2} = 30mm$

Precnik vratila na mestu lezaja A

$$d_{iA} = \sqrt[3]{\frac{32 \cdot M_{iA}}{\pi \cdot \sigma_d}}$$

Moment savijanja

$$M_{AH} = F_{a2} \cdot \frac{d_2}{2} \cdot \cos(\alpha_{1\text{-}2}) + F_{r2} \cdot \cos(\alpha_{1\text{-}2}) \cdot l_1 - F_{t2} \cdot \sin(\alpha_{1\text{-}2}) \cdot l_1 \qquad M_{AH} = 10.485\,\text{N·m}$$

$$M_{AV} = F_{a2} \cdot \frac{d_2}{2} \cdot \sin(\alpha_{1\text{-}2}) + F_{r2} \cdot \sin(\alpha_{1\text{-}2}) \cdot l_1 + F_{t2} \cdot \cos(\alpha_{1\text{-}2}) \cdot l_1 \qquad M_{AV} = 163.391\,\text{N·m}$$

$$M_A = \sqrt{M_{AV}^2 + M_{AH}^2} \qquad M_A = 163.727\,\text{N·m}$$

Moment uvijanja $\qquad T_2 = 102.314\,\text{N·m}$

Idealni moment savijanja

$$M_{iA} = \sqrt{M_A^2 + (\alpha \cdot T_2)^2} \qquad M_{iA} = 176.605\,\text{N·m}$$

$$d_{iA} = \sqrt[3]{\frac{32 \cdot M_{iA}}{\pi \cdot \sigma_d}} \qquad d_{iA} = 31.98\,\text{mm}$$

Precnik vratila treba uskladiti sa standardnim precnicima za lezaj $\qquad d_A = 35 \cdot \text{mm}$

Izbor lezaja u osloncu A

Otpor oslonca A u vertikalnoj i horizontalnoj ravni

$$\sum_V M_B = 0$$

$$-F_{a2} \cdot \frac{d_2}{2} \cdot \sin(\alpha_{1\text{-}2}) - F_{r2} \cdot \sin(\alpha_{1\text{-}2}) \cdot (l_1 + 2 \cdot l_2) - F_{t2} \cdot \cos(\alpha_{1\text{-}2}) \cdot (l_1 + 2 \cdot l_2) - F_{AV} \cdot 2 \cdot l_2 + F_{r3} \cdot l_2 - F_{a3} \cdot \frac{d_3}{2} = 0$$

$$F_{AV} = \frac{-F_{a2} \cdot \frac{d_2}{2} \cdot \sin(\alpha_{1\text{-}2}) - F_{r2} \cdot \sin(\alpha_{1\text{-}2}) \cdot (l_1 + 2 \cdot l_2) - F_{t2} \cdot \cos(\alpha_{1\text{-}2}) \cdot (l_1 + 2 \cdot l_2) + F_{r3} \cdot l_2 - F_{a3} \cdot \frac{d_3}{2}}{2 \cdot l_2}$$

$$F_{AV} = -1.034 \times 10^3\,\text{N}$$

$$\sum_H M_B = 0$$

$$-F_{a2} \cdot \frac{d_2}{2} \cdot \cos(\alpha_{1\text{-}2}) - F_{r2} \cdot \cos(\alpha_{1\text{-}2}) \cdot (l_1 + 2 \cdot l_2) + F_{t2} \cdot \sin(\alpha_{1\text{-}2}) \cdot (l_1 + 2 \cdot l_2) - F_{AH} \cdot 2 \cdot l_2 + F_{t3} \cdot l_2 = 0$$

$$F_{AH} = \frac{-F_{a2} \cdot \frac{d_2}{2} \cdot \cos(\alpha_{1\text{-}2}) - F_{r2} \cdot \cos(\alpha_{1\text{-}2}) \cdot (l_1 + 2 \cdot l_2) + F_{t2} \cdot \sin(\alpha_{1\text{-}2}) \cdot (l_1 + 2 \cdot l_2) - F_{t3} \cdot l_2}{2 \cdot l_2}$$

$$F_{AH} = -1.09 \times 10^3\,\text{N}$$

Radijalna sila u osloncu

$$F_A = \sqrt{F_{AV}^2 + F_{AH}^2} \qquad F_A = 1.502 \times 10^3\,N$$

Radni vek lezaja

$$L_h = \frac{10^6}{n}\cdot\left(\frac{C\cdot f_t}{F}\right)^{\alpha}$$

$L_{hA} = 7.5 \times 10^3\,hr$

$n = n_2 \qquad n_2 = \frac{n_1}{i_{1\text{-}2}} \qquad n_2 = 1.143 \times 10^3\,min^{-1}$

$\alpha = 3$ za kuglicni lezaj

$f_t = 1$

$F = F_A$

$$C = \frac{F}{f_t}\cdot\sqrt[3]{\frac{n_2\cdot L_{hA}}{10^6}} \qquad C = 12.038 \times 10^3\,N$$

$d_A = 35\,mm$

usvajam lezaj 6207 $C = 19.6\cdot 10^3\cdot N$

Mere lezaja

$D = 72\cdot mm$

$B = 17\cdot mm$

$r = 2\cdot mm$

Provera cvrstoce bokova i podnozja puznog zupcanika

Nosivost u odnosu na cvrstocu bokova zubaca puznog zupcanika

$$S_H = \frac{\sigma_{Hkr}}{\sigma_H}$$

Kriticni napon bokova zubaca puznog zup. $\sigma_{Hkr} = \sigma_{Hlim}\cdot Z_h\cdot Z_n$

Dinamicka izdrzljivost bokova Tab.4.6 str.135 ME II $\sigma_{Hlim} = 520\,\frac{N}{mm^2}$

za kalajnu bronzu usvojeno C.CuSn12Ni

Faktor veka $Z_h = \left(\frac{25000hr}{L_{hz4}}\right)^{\frac{1}{6}}$ $Z_h = 1.222$

Broj obrtaja gonjenog vratila $n_4 = \frac{n_3}{u_{3-4}}$

$n_3 = n_2$ $n_3 = 1.143 \times 10^3 \, min^{-1}$

prenosni odnos $u_{3-4} = \frac{z_4}{z_3}$ $u_{3-4} = 40$

$n_4 = \frac{n_3}{u_{3-4}}$ $n_4 = 28.583 \, min^{-1}$

Faktor broja obrtaja $Z_n = \left(\frac{1}{7.5min \cdot n_4 + 1} \right)^{\frac{1}{8}}$ $Z_n = 0.511$

$\sigma_{Hkr} = \sigma_{Hlim} \cdot Z_h \cdot Z_n$ $\sigma_{Hkr} = 324.714 \frac{N}{mm^2}$

Radni napon bokova zubaca $\sigma_H = Z_E \cdot Z_\rho \cdot \sqrt{\frac{T_4 \cdot K_A}{a^3}}$

Faktor elasticnosti materijala Tab.4.6 str.135 ME II $Z_E = 152.2 \sqrt{\frac{N}{mm^2}}$

Faktor dodira Tab.4.7 str.135 ME II $Z_\rho = 2.76$

kod puznih parova uvek vazi:

Precnik srednje kruznice puza $d_{m1} = q \cdot m$

Precnik srednje kruznice puznog zupcanika $d_{m2} = m \cdot (z_2 + 2 \cdot x)$

Precnik podeone kruznice puza $d_1 = d_{m1} + 2 \cdot x \cdot m$

Precnik podeone kruznice puznog zupcanika $d_2 = m \cdot z_2$

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

ako pretpostavim da je pomeranje kod puza $x = 0$

modu je $m = \frac{d_3}{q}$ $m = 8 \, mm$

pa je $d_4 = m \cdot z_4$ $d_4 = 320 \, mm$

osno rastojanje je $a = \frac{d_3 + d_4}{2}$ $a = 200 \, mm$

$\frac{d_3}{a} = 0.4$

Obrtni moment na puznom zupcaniku

$T_4 = T_3 \cdot u_{3-4} \cdot \eta_{3-4}$ $T_4 = 4.011 \times 10^3 \, N \cdot m$

$\sigma_H = Z_E \cdot Z_\rho \cdot \sqrt{\frac{T_4 \cdot K_A}{a^3}}$ $\sigma_H = 332.54 \frac{N}{mm^2}$

Stepen sigurnosti obzirom na bokove zupca $S_H = \frac{\sigma_{Hkr}}{\sigma_H}$ $S_H = 0.98$

Dozvoljeni stepen sigurnosti protiv razaranja bokova zubaca $S_{Hd} = 1.2$

SHd = 1 do 1.3 preporuka **ne zadovoljava**

<u>Nosivost u odnosu na cvrstocu podnozja zubaca puznog zupcanika</u>

Stepen sigurnosti u odnosu na lom zupca $S_F = \frac{\sigma_{Fkr}}{\sigma_F}$

Kriticni napon u podnozju zupca $\sigma_{Fkr} = \sigma_{Flim}$

Dinamicka izdrzljivost podnozja puznog zupcanika $\sigma_{Flim} = 337 \frac{N}{mm^2}$

Tab.4.6 str.135 ME II

$\sigma_{Fkr} = \sigma_{Flim}$ $\sigma_{Fkr} = 337 \frac{N}{mm^2}$

Radni napon u podnozju zupca puznog zupcanika $\sigma_F = \frac{F_{t4} \cdot K_A}{b_4 \cdot m_n}$

$F_{t4} = 1.962 \times 10^4 N$

$K_A = 1.25$

str. 120 ME I $b_4 = 0.8 \cdot d_3$ $b_4 = 64\,mm$ usvajam $b_4 = 65 \cdot mm$

Modul u normalnom preseku $m_n = m \cdot \cos(\gamma_m)$ $m_n = 7.96\,mm$

$\sigma_F = 1.5 \cdot \frac{F_{t4} \cdot K_A}{b_4 \cdot m_n}$ $\sigma_F = 71.086 \frac{N}{mm^2}$

Stepen sigurnosti u odnosu na lom zupca $S_F = \frac{\sigma_{Fkr}}{\sigma_F}$ $S_F = 4.7$

Dozvoljeni stepen sigurnosti protiv loma zubaca $S_{Fd} = 1.4$ **zadovoljava**

Dimenzionisanje podesenih vijaka

<u>Napon smicanja</u> $\tau_s = \frac{F_v \cdot \xi_r}{A \cdot n} \le \tau_{sd}$

Obimna sila koja opterecuje sve vijke $F_t = \frac{2 \cdot T_4}{D_o}$ $F_t = 3.085 \times 10^4 N$

Pretpostavljam $k = 6$ vijaka

Smicuca sila na jednom vijku $F_v = \frac{F_t}{k}$ $F_v = 5.142 \times 10^3 N$

Faktor neravnomernosti opterecenja str. 101 ME I $\xi_r = 3$

Povrsina smicanja (povrsina poprecnog preseka stabla vijka) $A = \frac{D^2 \cdot \pi}{4}$

Broj povrsina smicanja $n = 1$

Dozvoljeni napon smicanja $\tau_{sd} = \frac{R_{eH}(\tau)}{S} = \frac{0.8 \cdot R_{eH}}{S}$

za dati materijal vijka $R_{eH} = 640 \cdot \frac{N}{mm^2}$

za promenljivo opterecenje str. 102 ME I $S = 4$

$\tau_{sd} = \frac{0.8 \cdot R_{eH}}{S}$ $\tau_{sd} = 128 \frac{N}{mm^2}$

$D = \sqrt{\frac{4 \cdot F_v \cdot \xi_r}{\pi \cdot n \cdot \tau_{sd}}}$ $D = 12.387\,mm$ usvajam vijak M 12 sa $D = 14 \cdot mm$

Naleganje venca i tela puznog zupcanika

Za tacno naleganje venca i tela puznog zupcanika pogodna su neizvesna naleganja koja imaju po pravilu male preklope. Biram prioritetna naleganja.

Tab. 1.3 str. 17 ME I H7 / n6 ili H7 / k6

usvajam naleganje $\phi 290\,H7/n6$

ø290 H7	+ 0.052
	0

ø290 n6	+ 0.066
	+ 0.034

Najveci moguci preklop u spoju $P_g = 0.066 \cdot mm$

Najveci moguci zazor u spoju $Z_g = 0.018 \cdot mm$