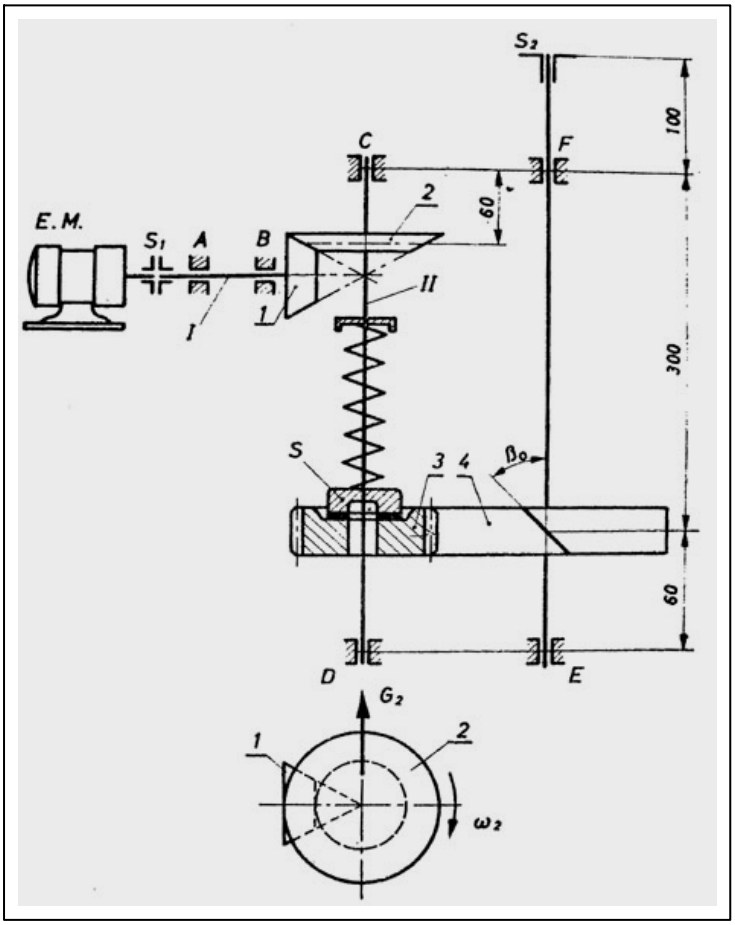
Pro\Machine

OSNOVE KONSTRUISANJA - MATURSKI RAD

Proracun zupcastog prenosnika - ZADATAK 1

Zupcasti prenosnik sastoji se od para konicnih zupcanika, para cilindricnih zupcanika sa kosim zupcima i sigurnosne frikcione spojnice. Elektromotor je snage $P_1 = 11 \cdot kW$ i broja obrtaja $n_1 = 1445 \, min^{-1}$. Radna masina je sa umerenim udarima.



Ostali odaci su:

Modul zupcastog para 1-2	$m_m = 3 \cdot mm$
Broj zubaca zupcanika 1	$z_1 = 19$
Broj zubaca zupcanika 2	$z_2 = 40$
Modul zupcastog para 3-4	$m_n = 5 \cdot mm$
Broj zubaca zupcanika 3	$z_3 = 40$
Broj zubaca zupcanika 4	$z_4 = 68$
Ugao nagiba zupca z3 i z4	$\beta_{3\text{-}4} = 15 \cdot deg$
Stepen iskoriscenja para z1-z2	$\eta_{1\text{-}2} = 0.98$
Stepen iskoriscenja para z3-z4	$\eta_{3\text{-}4} = 0.98$

1. Odrediti aktivne sile i shemu opterecenja vratila II
2. Proveriti napone kod klina na mestu zupcanika z2, ako je $d_{v2} = 50 \cdot mm$, $l_k = 50 \cdot mm$. Klin je bez nagiba visoki, a materijal vratila C.0545.
3. Izvrsiti izbor i proveru lezaja D koji prima samo radijalnu silu ako je $d_{vD} = 45 \cdot mm$, a potreban radni vek lezaja $L_h = 10 \cdot 10^3 \cdot hr$, pri radnoj temperaturi od $t = 373 \cdot K$.
4. Proveriti stepen sigurnosti vratila II na mestu lezaja D. Raditi sa momentom savijanja desno od preseka.
5. Proveriti cvrstocu bokova zubaca zupcanika z3 koji je od C.1530. Sirina zupcanika $b_{z3} = 50 \cdot mm$, a radni vek $L_{hz3} = 10 \cdot 10^3 \cdot hr$. Kvalitet izrade zupcanika IT 7.
6. Proracunati navojnu torzionu oprugu ako je koeficijent trenja kod frikcione spojnice $\mu = 0.2$. Racunski precnik $d_s = 100 \cdot mm$, odnos precnika opruge $D/d = 5$. Ugib opruge u radnom stanju $f_2 = 25 \cdot mm$. Materijal opruge je C.1730 - hladno valjani.

Napomena: Ostale potrebne vrednosti usvojiti

Resenje :

Obrtni moment na vratilu I

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

$$\omega_1 = 2\cdot\pi\cdot n_1 \qquad \omega_1 = 151.32\,s^{-1}$$

$$K_A = 1.25$$

$$T_1 = \frac{P_1}{\omega_1}\cdot K_A \qquad T_1 = 90.867\,N\cdot m$$

Sile na zupcaniku z1

$$F_{t1} = \frac{2\cdot T_1}{d_{m1}}$$

$$d_{m1} = m_m\cdot z_1 \qquad d_{m1} = 57\,mm$$

$$d_{m2} = m_m\cdot z_2 \qquad d_{m2} = 120\,mm$$

$$F_{t1} = \frac{2\cdot T_1}{d_{m1}} \qquad F_{t1} = 3.188\times 10^3\,N$$

$$F_{r1} = F_{t1}\cdot\tan(\alpha_n)\cdot\cos(\delta_1)$$

$$\alpha_n = 20\cdot deg$$

$$\tan(\delta_1) = \frac{z_1}{z_2} \qquad \delta_1 = \operatorname{atan}\left(\frac{z_1}{z_2}\right) \qquad \delta_1 = 25.408\,deg$$

$$F_{r1} = F_{t1}\cdot\tan(\alpha_n)\cdot\cos(\delta_1) \qquad F_{r1} = 1.048\times 10^3\,N$$

$$F_{a1} = F_{t1}\cdot\tan(\alpha_n)\cdot\sin(\delta_1) \qquad F_{a1} = 497.9\,N$$

Sile na zupcaniku z2

$$F_{t2} = F_{t1} \qquad F_{t2} = 3.188\times 10^3\,N$$

$$F_{r2} = F_{a1} \qquad F_{r2} = 497.9\,N$$

$$F_{a2} = F_{r1} \qquad F_{a2} = 1.048\times 10^3\,N$$

Obrtni moment na vratilu II

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

$$i_{1\text{-}2} = \frac{z_2}{z_1} \qquad i_{1\text{-}2} = 2.105$$

$T_2 = T_1 \cdot i_{1\text{-}2} \cdot \eta_{1\text{-}2}$ $\qquad T_2 = 187.473\ \text{N}\cdot\text{m}$

Ugaona brzina vratila II

$$\omega_2 = \frac{\omega_1}{i_{1\text{-}2}} \qquad \omega_2 = 71.877\ \text{s}^{-1}$$

Sile na zupcaniku z3

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

$$T_3 = T_2 \qquad T_3 = 187.473\ \text{N}\cdot\text{m}$$

$$d_3 = \frac{m_n}{\cos(\beta_{3\text{-}4})} \cdot z_3 \qquad d_3 = 207.055\ \text{mm}$$

$$d_4 = \frac{m_n}{\cos(\beta_{3\text{-}4})} \cdot z_4 \qquad d_4 = 351.994\ \text{mm}$$

$$F_{t3} = \frac{2 \cdot T_3}{d_3} \qquad F_{t3} = 1.811 \times 10^3\ \text{N}$$

$$F_{r3} = \frac{F_{t3}}{\cos(\beta_{3\text{-}4})} \cdot \tan(\alpha_n)$$

$$\alpha_n = 20 \cdot \text{deg}$$

$$F_{r3} = \frac{F_{t3}}{\cos(\beta_{3\text{-}4})} \cdot \tan(\alpha_n) \qquad F_{r3} = 682.346\ \text{N}$$

$$F_{a3} = F_{t3} \cdot \tan(\beta_{3\text{-}4}) \qquad F_{a3} = 485.216\ \text{N}$$

Sile na zupcaniku z4

$$F_{t4} = F_{t3} \qquad F_{t4} = 1.811 \times 10^3\ \text{N}$$

$$F_{r4} = F_{r3} \qquad F_{r4} = 682.346\ \text{N}$$

$$F_{a4} = F_{a3} \qquad F_{a4} = 485.216\ \text{N}$$

Provera napona kod klina na mestu zupcanika z2

Obimna sila na klinu

$$F_{tk} = \frac{2 \cdot T_2}{d_{v2}} \qquad F_{tk} = 7.499 \times 10^3 \, N$$

Mere klina

$b = 14 \cdot mm$

$h = 9 \cdot mm$

$t = 5.5 \cdot mm$

$r = 0.5 \cdot mm$

Povrsinski pritisak izmedju klina i glavcine

$$p_2 = \frac{F_{tk}}{l_k \cdot t_2}$$

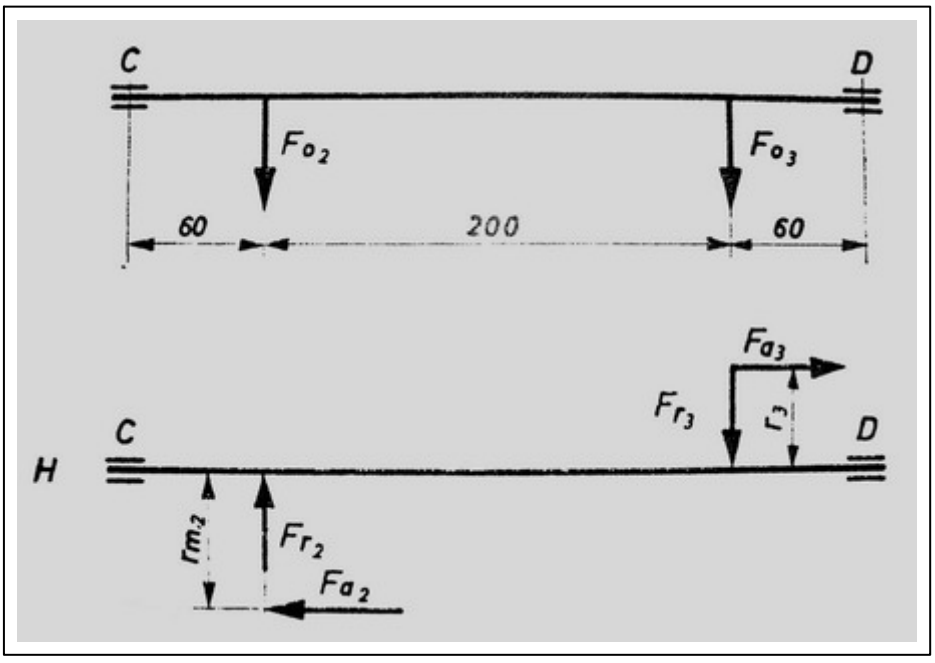
$l_k = 50\,mm$

$$t_2 = h - t \qquad t_2 = 3.5\,mm$$

$$p_2 = \frac{F_{tk}}{l_k \cdot t_2} \qquad p_2 = 42.851 \frac{N}{mm^2}$$

$$p_2 < p_{2d} = 75 \div 100 \cdot \frac{N}{mm^2}$$ **klin zadovoljava**

Izbor i provera lezista D



$l_1 = 60 \cdot mm$

$l_2 = 200 \cdot mm$

Otpor oslonca D u vertikalnoj i horizontalnoj ravni

$$\sum_V M_C = -F_{t2}\cdot l_1 - F_{t3}\cdot(l_1 + l_2) + F_{DV}\cdot(l_1 + l_2 + l_1) = 0$$

$$F_{DV} = \frac{F_{t2}\cdot l_1 + F_{t3}\cdot(l_1 + l_2)}{l_1 + l_2 + l_1} \qquad F_{DV} = 2.069\times 10^3\,N$$

$$\sum_H M_C = F_{r2}\cdot l_1 - F_{a2}\cdot\frac{d_{m2}}{2} - F_{r3}\cdot(l_1 + l_2) - F_{a3}\cdot\frac{d_3}{2} + F_{DH}\cdot(l_1 + l_2 + l_1) = 0$$

$$F_{DH} = \frac{-F_{r2}\cdot l_1 + F_{a2}\cdot\frac{d_{m2}}{2} + F_{r3}\cdot(l_1 + l_2) + F_{a3}\cdot\frac{d_3}{2}}{l_1 + l_2 + l_1} \qquad F_{DH} = 814.568\,N$$

Radijalni otpor oslonca D

$$F_D = \sqrt{F_{DV}^{\,2} + F_{DH}^{\,2}} \qquad F_D = 2.224\times 10^3\,N$$

Radni vek lezaja

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

$L_h = 10\times 10^3\,hr$

$n = n_2 \qquad n_2 = \frac{n_1}{i_{1\text{-}2}} \qquad n_2 = 686.375\,min^{-1}$

$\alpha = 3$ za kuglicni lezaj

$f_t = 1$

$F = F_D$

$$C = \frac{F}{f_t}\cdot\sqrt[3]{\frac{n_2\cdot L_h}{10^6}} \qquad C = 16.544\times 10^3\,N$$

$d_D = d_{vD} \rightarrow d_D = 45\cdot mm$

usvajam lezaj 6209 $C = 25\cdot 10^3\cdot N$

Mere lezaja

$D = 85\cdot mm$

$B = 19\cdot mm$

$r = 2\cdot mm$

Provera stepena sigurnosti vratila II na mestu lezaja D

$$S = \frac{[\sigma]}{\sigma}$$

Kriticni napon pri savijanju

$$[\sigma] = \sigma_{D(-1)M} = \sigma_{D(-1)s} \cdot \frac{\xi_1 \cdot \xi_2}{\beta_k}$$

Tab. 6.1 str. 67 OK $\sigma_{D(-1)s} = 220 \cdot \frac{N}{mm^2}$

Radijus prelaza precnika Tab. 2.2 str. 47 ME II $\rho = 1 \cdot mm$

Usvajam precnik naslona Tab.2.2 str. 47 ME II $D = 55 \cdot mm$

Odnos precnika naslona i precnika rukavca $\frac{D}{d_{vD}} = 1.222$

Odnos radijusa i precnika rukavca $\frac{\rho}{d_{vD}} = 0.022$

Geom. faktor koncentracije napona zbog prelaza pri savijanju Sl. 4.4 str. 37 OK $\alpha_k = 2.35$

Faktor osetljivosti materijala na koncentraciju napona Tab. 4.1 str. 39 OK $\eta_k = 0.65$

za $R_m = 500 \cdot \frac{N}{mm^2}$

Efektivni faktor koncentracije napona pri savijanju $\beta_k = (\alpha_k - 1) \cdot \eta_k + 1$ $\beta_k = 1.877$

Faktor stanja povrsine Tab. 4.2. str. 43 OK $\xi_1 = 1$

Faktor velicine preseka pri savijanju Tab. 4.3 str. 44 OK $\xi_2 = 0.825$

Kriticni napon pri savijanju $\sigma_{D(-1)M} = \sigma_{D(-1)s} \cdot \frac{\xi_1 \cdot \xi_2}{\beta_k}$ $\sigma_{D(-1)M} = 96.671 \frac{N}{mm^2}$

Radni napon pri savijanju

$$\sigma = \frac{M_D}{W_x}$$

Moment u preseku D $M_D = F_D \cdot \frac{B}{2}$ $M_D = 21.125\,N \cdot m$

Aksijalni otporni moment preseka D $W_x = \frac{d_{vD}^3 \cdot \pi}{32}$ $W_x = 8.946 \times 10^3\,mm^3$

Napon savijanja $\sigma = \frac{M_D}{W_x}$ $\sigma = 2.361 \frac{N}{mm^2}$

Stepen sigurnosti u preseku D

$$S = \frac{\sigma_{D(-1)M}}{\sigma}$$ $S = 40.939$

Stepen sigurnosti je dosta velik. Razlog je mali moment savijanja, a moment uvijanja je nula. Precnik rukavca d_{vD} nesmemo smanjiti, jer bi tada bio problem odabrati odgovarajuci lezaj.

Provera cvrstoce zupcanika z3

Nosivost u odnosu na cvrstocu bokova zubaca

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

Kriticni napon bokova $\sigma_{Hkr} = \sigma_{Hlim}$

$$\sigma_{Hlim} = 520 \cdot \frac{N}{mm^2}$$

$$\sigma_{Hkr} = \sigma_{Hlim} \qquad \sigma_{Hkr} = 520 \frac{N}{mm^2}$$

Radni napon boka zubca $\sigma_H = Z \cdot \sqrt{\frac{F_{t3}}{b \cdot d_3} \cdot \frac{u + 1}{u} \cdot K_H}$

$F_{t3} = 1.811 \times 10^3 N$

$b_{z3} = 50\,mm$

$d_3 = 207.055\,mm$

$u = \frac{z_4}{z_3} \qquad u = 1.7$

Ukupni faktor opterecenja $K_H = K_A \cdot K_V \cdot K_{H\beta}$

$K_A = 1.25$

Faktor unutrasnjih dinamickih sila Sl. 4.47 str. 128 ME II $K_{V\beta} = 1.15$

gde je:

$\omega_3 = 2 \cdot \pi \cdot n_3$

$n_3 = n_2$

$\omega_3 = 2 \cdot \pi \cdot n_3 \qquad \omega_3 = 71.877\,s^{-1}$

$v = \frac{d_3}{2} \cdot \omega_3 \qquad v = 7.441 \frac{m}{s}$

$\frac{v \cdot z_3}{100} = 2.977 \frac{m}{s}$

za $\varepsilon\beta > 1$ $K_V = K_{V\beta}$ $K_V = 1.15$

Faktor raspodele opterecenja Tab. 4.4 str. 130 ME II $K_{H\beta} = 1.03$

za $\frac{b_{z3}}{d_3} = 0.241$

$K_H = K_A \cdot K_{V\beta} \cdot K_{H\beta} \qquad K_H = 1.481$

Uticaj elasticnosti materijala $Z = 2.5 \cdot Z_E \cdot \cos(\beta_{3\text{-}4})$

Faktor elasticnosti materijala za celik po celiku $Z_E = 189 \sqrt{\frac{N}{mm^2}}$

$Z = 2.5 \cdot Z_E \cdot \cos(\beta_{3\text{-}4})$ $Z = 456.4 \sqrt{\frac{N}{mm^2}}$

Radni napon boka zupca $\sigma_H = Z \cdot \sqrt{\frac{F_{t3}}{b_{z3} \cdot d_3} \cdot \frac{u+1}{u} \cdot K_H}$ $\sigma_H = 292.711 \frac{N}{mm^2}$

Stepen sigurnosti obzirom na bok zupca $S_H = \frac{\sigma_{Hkr}}{\sigma_H}$ $S_H = 1.78$

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

S_{Hd} = 1.2 do 2 po preporuci

$S_H > S_{Hd}$ **zadovoljava**

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

$S_F = \frac{\sigma_{FM}}{\sigma_F}$

Kriticni napon $\sigma_{FM} = Y_\Pi \cdot \sigma_{Flim}$

Faktor koncentracije napona $Y_\Pi = 2$

za $m_n = 5\,mm$

$Y_\Pi = 2$ za $m_n \le 5$ i $R_a \le 10 \cdot \mu m$

$Y_\Pi = 1.7 \div 2$ za $m_n > 5$ i/ili $R_a > 10 \cdot \mu m$

manje vrednosti uzimati za vece R_a

Trajna dinamicka izdrzljivost podnozja zubaca $\sigma_{Flim} = 205 \cdot \frac{N}{mm^2}$

Tab. 4.5 str. 133 ME II

Kriticni napon $\sigma_{FM} = Y_\Pi \cdot \sigma_{Flim}$ $\sigma_{FM} = 410 \frac{N}{mm^2}$

Faktor oblika zupca Tab.4.8 str.139 $Y_{Fa} = 2.41$

$z_n = \frac{z_3}{(\cos(\beta_{3\text{-}4}))^3}$ $z_n = 44.4$

$x_3 = 0$ usvojeno

Faktor koncentracije napona Sl.4.54 str.137 ME II $Y_{Sa} = 1.85$

Faktor polozaja $Y_\varepsilon = 0.25 + \frac{0.75}{\varepsilon_\alpha}$

usvajam $\varepsilon_\alpha = 1.5$

$Y_\varepsilon = 0.25 + \frac{0.75}{\varepsilon_\alpha}$ $Y_\varepsilon = 0.75$

Uticaj oblika kosozubih zupcanika $Y_\beta = 1 - \varepsilon_\beta \cdot \frac{\beta_{3\text{-}4}}{120\text{deg}}$

usvajam $\varepsilon_\beta = 1.5$

$Y_\beta = 1 - \varepsilon_\beta \cdot \frac{\beta_{3\text{-}4}}{120\text{deg}}$ $Y_\beta = 0.813$

Faktor raspodele opterecenja Tab.4.4 str.130 ME II za $K_{H\beta} = 1.03$ $K_{F\beta} = 1$

Napon u podnozju zupca $\sigma_F = Y_{Fa} \cdot Y_{Sa} \cdot Y_\varepsilon \cdot Y_\beta \cdot \frac{F_{t3}}{b_{z3} \cdot m_n} \cdot K_A \cdot K_V \cdot K_{F\beta}$ $\sigma_F = 28.289 \frac{N}{mm^2}$

Stepen sigurnosti obzirom na lom zupca $S_F = \frac{\sigma_{FM}}{\sigma_F}$ $S_F = 14.5$

Preporuka za dozvoljeni stepen sigurnosti $S_{Fd} = 1.4$

$S_F > S_{Fd}$ **zadovoljava**

Proracun navojne torzione opruge

Precnik zice opruge

$$d = \sqrt{\frac{8 \cdot F_2}{\pi \cdot \tau_{ud}} \cdot (D/d) \cdot k}$$

radno opterecenje opruge preko obimne sile na frikcionoj spojnici

$F_{ts} = \frac{2 \cdot T_2}{d_s}$ $F_{ts} = 3.749 \times 10^3 N$

(obimna sila je jednaka sili trenja) $F_{ts} = F_\mu$

normalna sila na dodirnoj povrsini, odnosno aksijalna sila u opruzi

$F_2 = \frac{F_{ts}}{\mu}$ $F_2 = 1.875 \times 10^4 N$

jer je $F_\mu = \mu \cdot F_n$

$\tau_{ud} = \frac{R_m}{S}$

Za dati materijal opruge Tab. 5.1 str. 136 ME I $R_m = 1250 \cdot \frac{N}{mm^2}$

Usvojen stepen sigurnosti opruge $S = 2$

$\tau_{ud} = \frac{R_m}{S}$ $\tau_{ud} = 625 \frac{N}{mm^2}$

$D/d = 5$

Faktor nerav. podele napona Tab. 5.4 str. 141 ME I $k = 1.29$

$d = \sqrt{\frac{8 \cdot F_2}{\pi \cdot \tau_{ud}} \cdot (D/d) \cdot k}$ $d = 22.196\,mm$

Usvajam prvi blizi standardni precnik zice opruge str. 141 ME I $d = 23 \cdot mm$

Srednji precnik opruge $D = 5 \cdot d$ $D = 115\,mm$

Broj aktivnih navoja opruge

$z = \frac{G \cdot f_2 \cdot d}{8 \cdot F_2 \cdot \left(\frac{D}{d}\right)^3}$

modul klizanja $G = 83 \cdot 10^3 \cdot \frac{N}{mm^2}$

$z = \frac{G \cdot f_2 \cdot d}{8 \cdot F_2 \cdot \left(\frac{D}{d}\right)^3}$ $z = 2.546$

Da bi krajevi opruge bili pod uglom od 180 stepeni i da bi se obezbedilo ispravno funkcionisanje oruge dodaje se jos 2.25 navojka, dakle

ukupan broj navojaka $z_u = z + 2.25$ $z_u = 4.8$

Visina nenapregnute opruge

Zbir najmanjih rastojanja izmedju elasticnih zavojaka

$s_a = 1 \cdot mm + 0.03 \cdot mm^{-1} \cdot d^2 \cdot z$ $s_a = 41.4\,mm$ usvajam $s_a = 45 \cdot mm$

Spoljasnji precnik opruge $D_s = D + d$ $D_s = 138\,mm$

Unutrasnji precnik opruge $D_u = D - d$ $D_u = 92\,mm$

Duzina blokirane opruge $L_{BL} = z_u \cdot d$ $L_{BL} = 110.3\,mm$

Duzina opruge pri dejstvu sile F_2 $L_2 = L_{BL} + s_a$ $L_2 = 155.3\,mm$

Slobodna duzina opruge $L_o = L_2 + f_2$ $L_o = 180.3\,mm$

Korak zavojnice $H = \frac{L_o - d}{z}$ $H = 61.791\,mm$

Duzina zice opruge $L = z_u \cdot \sqrt{D^2 \cdot \pi^2 + H^2} + 1.5 \cdot D$ $L = 1.9 \times 10^3\,mm$