UNIVERSITY OF GAZİANTEP

FACULTY OF ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

ME 308 MACHINE ELEMENT II PROJECT

SPRING DESIGN PROJECT

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INTRODUCTION

SPRINGS:

Spring is an elastic object that stores mechanical energy. A metal wire spring that functions in a spring mechanism that compresses, extends, rotates, slides, pulls, and exerts force when an equal or greater force is applied. A spring mechanism can exert pressure, rotational force, or pulling strength in a variety of ways.

What Is The Function Of Spring?

- To absorb the shock or vibration as in-car springs, railway buffers, etc.
- To measure the forces in a spring balance.
- To store energy.

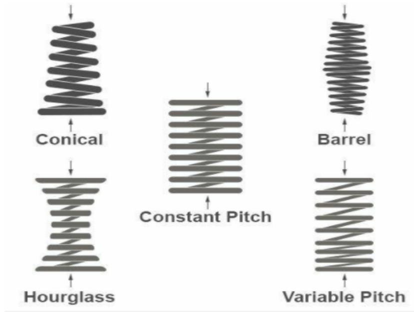
Types Of Spring:

- Compression Springs
- Extension Springs
- Torsion Springs
- Constant Springs

Compression Springs

A compression spring is an open-coil helical spring that offers resistance to a compressive force applied axially. They are usually coiled at a constant diameter, they can be coiled in other needed forms such as conical, concave etc.

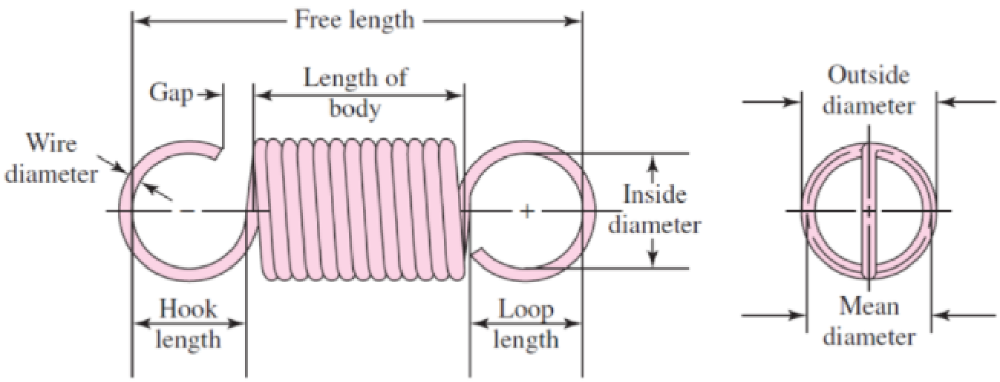
Application: Compression Springs can be used in valves, suspensions, ball point pens, on shafts, in a round hole or anywhere a pushing or compressing force needs to be applied.



Extension Springs

Extension springs have hooks on the ends so one can place them on a shaft, over a pin or through a hole. Pull force is applied, resulting in extension of the spring.

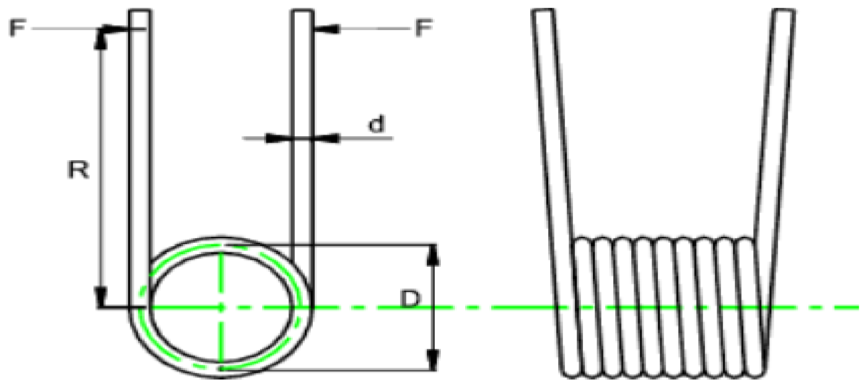
Application: Extension springs can be used in trampolines, pull levers, garage doors, screen doors or anywhere a pulling force needs to be applied.



Torsion Springs

In this type of spring the load applied to coil is a torque or twisting force. Torsion springs are subjected to bending stress and torsional stress. They can store and angular energy or statically hold a mechanism in place by deflecting the legs about the body centerline axis.

Application: Torsion springs can be used for lift gates, garage doors, mouse trap, control levers, spring hinges and many other torsion spring applications.



PROJECT DATAS

ProductionType	**Unpeened**
Material	**Chrome Vanadium**
Lenght of pipe	**4 m**
Mass of pipe	**3 kg/m**
Diameter of pipe	**20 cm**
Thickness of pipe	**2 cm**
Density of fluid	**1204 kg/m^3**
Reliability	**99.9 %**
Factory of safety	**2**
Minimum coilnumber	**7**
Y max	**14 mm**
Diameter of washer	**50 mm**
Diameter of rod	**9 mm**

Force analysis

Firstly, we must determine the forces acting on spring. Calculation of forces below.

$$m_{pipe} = 3\frac{kg}{m}\ x\ 4\ m\ \rightarrow\ m_{pipe} = 12\ kg\ \ for\ the\ section$$

$$V_{pipe} = \frac{\pi}{4}\left(D_{pipe} - 2t\right)^2 \times L = \frac{\pi}{4}(0.2 - 2\times 0.02)^2 \times 4m = 0,08042\ m^3$$

$m_{fluid} = \rho \times V_{pipe} = \frac{1204\ kg}{m^3} x0,08042\ m^3 = 96.825\ kg = 97\ kg$

$F_{max} = (m_{fluid} + m_{pipe}) \times g = (97\ kg + 12\ kg)\ x\ 9.81 = 1068\ N$

$F_{min} = \left(\frac{m_{fluid}}{2} + m_{pipe}\right) \times g = \left(\frac{97\ kg}{2} + 12\ kg\right) x\ 9.81 = 593\ N$

$F_{mean} = \frac{F_{max} + F_{min}}{2} = 830,15\ N$ $F_{alt} = \frac{F_{max} - F_{min}}{2} = 237.47\ N$

From table 10.2 Chrome Vanadium

m=0.167 A=2000

Ultimate & yield stresses

$S_{ut} = \frac{A}{d^m} = \frac{2000}{8^{0,167}} = 1413,23\ MPa$

$S_y = 0,75 S_{ut} = 0,75 \times 1413,23 = 1059,92\ MPa$

$S_{sy} = 0,577 S_y = 0,577 \times 1059,92 = 611,57\ MPa$

DESIGN OF COMPRESSION SPRING

- **Force Analysis**

$F_{max} = (m_{fluid} + m_{pipe}) \times g = (97\ kg + 12\ kg)\ x\ 9.81 = 1068\ N$

$F_{min} = \left(\frac{m_{fluid}}{2} + m_{pipe}\right) \times g = \left(\frac{97\ kg}{2} + 12\ kg\right) x\ 9.81 = 593\ N$

$F_{mean} = \frac{F_{max} + F_{min}}{2} = 830,15\ N$ $F_{alt} = \frac{F_{max} - F_{min}}{2} = 237.47\ N$

$S_{ut} = \frac{A}{d^m} = \frac{2000}{8^{0,167}} = 1413,2336\ MPa$

$S_y = 0,75S_{ut} = 0,75\times1413,2336 = 1059,9252\ MPa$

$S_{sy} = 0,577S_y = 0,577\times1059,9252 = 611,5768\ MPa$

▯ **Static Design**

Now, determine the spring diameter, wire diameter, spring rate,frequency and buckling condition according to given datas. Diameter of wire and C values are assumed.

(Assume that d = 8 mm , D = 42 mm)

$4\leq C\leq12 \qquad C = 5,25 \qquad C = \frac{D}{d}$

$0,8\leq d\leq12 \qquad d = 8\ mm \qquad and \quad D_{mean} = 50\ mm$

For this spring we have some limitations. Outside diameter of spring is not greater than diameter of washer.

$D_{washer} > D_{outer} \qquad D_{inner} > D_{rod}$

$D_{inner} = Dmean - d = 50 - 8 = 42mm$

$K_S = 1 + \frac{0,5}{C} = 1,095$

$\tau_{coil} = K_S\frac{8F_{max}D}{\pi d^3} = 1,095\times\frac{8\times1068\times42}{\pi\times8^3} = 244,259\ MPa$

$n = \frac{S_{sy}}{\tau_{coil}} = \frac{611,57}{244,259}\cong2,49 \quad n\geq2 \quad SAFE\ \surd$

Fatigue Design

$$Fa = \frac{Fmax - Fmin}{2} = \frac{1098 - 593}{2} = 238,5\ N$$

$$\tau_a = \frac{K_s * 8 * F_{max} * D}{\pi * d^3}$$

$$\tau_a = \frac{1,095*8*238,5*42}{\pi*8^3} = 54.33\ Mpa$$

$$S_{se} = kc * kd * ke * S_{se}'$$

$S_{se}' = 310\ Mpa$ (*For unpeened springs.)*

$kc = 0,753$ (*For reliability 99,9% (from Table 7.7))*

$kd = 1$ (kd is temperature factor.No information about temperature, so kd = 1)

$$K_{wahl} = \frac{4C - 1}{4C - 4} + \frac{0,615}{C} = \frac{4*(5,25) - 1}{4*(5,25) - 4} + \frac{0,615}{5,25}$$

$$K_{wahl} = 1,293$$

$$KC = \frac{K_{wahl}}{ks} = \frac{1,293}{1,095} = 1,181$$

$$ke = \frac{1}{KC} = \frac{1}{1,181} = 0,846$$

$$S_{se} = 0,753 * 1 * 0,849 * 310$$

$$S_{se} = 197.48\ Mpa$$

$\eta_f = \frac{S_{se}}{\tau_a} = \frac{197,48}{54,55} = 3,55$ *It means that spring have infinite life.*

Buckling Condition

$$k = \frac{\Delta F}{\Delta y} = \frac{Fmax - Fmin}{Yworking}$$

$k = \frac{d^4 x G}{8\ x D^3 x\ Na} = \frac{8^4 x 77,2 x 10^3}{8\ x 42^3 x\ 7}$ = *76,215 N/mm*

$$L_f = L_s + Y_w + Y_{clash} + Y_{initial}$$

$$L_{solid} = Nt * d$$

(Assume that Nt = 7+2 = 9 coils.)

$$L_{solid} = 9 * 8 = 72\ mm$$

$Y_{initial} = \frac{Fmin}{k} = \frac{593}{76,215} = 7,776\ mm$

ymax = ymin + yworking = 14=7,76+yworking □ *yworking = 6,23 mm*

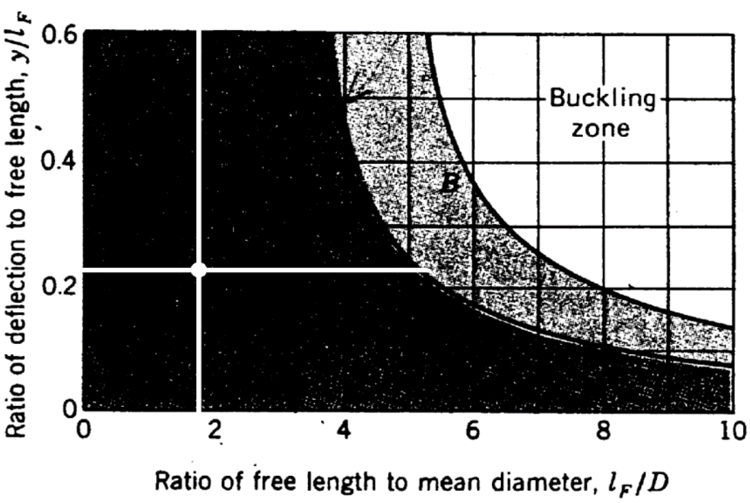
$Y_{working} = 6,23mm$

$Y_{clash} = 0,1 * Y_{working} = 0,1 * 6,23 = 0,623\ mm$

$L_f = 72 + 7,776 + 6,23 + 0,623$

$L_f = 86,63\ mm$

$\frac{L_f}{D} = \frac{86,63}{42} = 2,062 < 3,8$ □ No buckle zone!



- **PERMANENT SET**

$\tau_{solid} < S_y$

$$\tau_{solid} = \frac{K_s * 8 * F_{solid} * D}{\pi * d^3}$$

$$F_{solid} = k * \left(L_f - L_s\right)$$

$$= 76,215 * (86,63 - 72) = 1115,132\ N$$

$$\tau_{solid} = \frac{1,095*8*1115,13*42}{\pi*8^3}$$

$$\tau_{solid} = 255,61\ Mpa$$

$\eta_{solid} = \frac{S_{sy}}{\tau_{solid}} = \frac{611,57}{255,61} = 2,39 > 2$ ￿ *It is OK!*

Note; *No permanent set occurs when compressed solid.*

- **Resonance**

$$\rho = 7800\ kg/m^3$$

$$A = \frac{\pi d^2}{4} = \frac{\pi*(8)^2}{4}$$

$$L = \pi * D * Nt$$

$$Ms = \rho * A * L = \frac{\pi*(8)^2}{4} x\ (\pi x\ 42x9)x7800x10^{-9}$$

$$Ms = 0,468\ kg$$

$$F_n = \frac{1}{2}\sqrt{\frac{k*1000}{Ms}}$$

$$F_n = \frac{1}{2}\sqrt{\frac{76215,15}{0,468} =}\ 3,188\ \frac{rad}{sec}$$

$$F_{natural} = \frac{3,188}{15} = 0,2125\ Hertz\ \text{(cycle/sec)}$$

DESIGN OF EXTENSION SPRING

(Assume that d = 11 , D = 50)

$4 \leq C \leq 12 \qquad C = 4,54 \qquad C = \frac{D}{d}$

$0,8 \leq d \leq 12 \qquad d = 11\ mm \qquad and \quad D_{mean} = 50mm$

$y_{max} = 14\ mm$

$$y_{max} = \frac{F_{max} - F_{min}}{k} \gg k = \frac{F_{max} - F_{min}}{\Delta y} = \frac{1068 - 593}{14} = 33,92\ \frac{N}{mm}$$

$$k = \frac{d^4 G}{8 D^3 N_a} \quad \ggg \quad N_a = \frac{d^4 G}{8 D^3 k} = \frac{11^4 \times 77.2 \times 10^3}{8 \times 50^3 \times 33,92} = 33,5\ coils$$

The spring material is chosen Chrome Vanadium from Table 10.2.

A=2000 Mpa *m*=0,167

$$S_{ut} = \frac{A}{d^m} = \frac{2000}{11^{0,167}} = 1340\ MPa$$

$$S_y = 0,75S_{ut} = 0,75\times1340\ MPa = 1005\ MPa$$

$$S_{sy} = 0,577S_y = 0,577\times1005\ MPa = 579,90\ MPa$$

- **Static Analysis**

1-Shear Stress in Coil:

$$K_S = 1 + \frac{0,5}{C} = 1,11$$

$$\tau_{coil} = K_S\frac{8F_{max}D}{\pi d^3} = 1,11\times\frac{8\times1068\times50}{\pi\times11^3} = 113,37\ MPa$$

$$n = \frac{S_{sy}}{\tau_{coil}} = \frac{579,90}{113,37} = 5,114 \qquad n\geq2,75 \quad SAFE \quad \surd$$

2-Normal Stres in Hook

Dinner = D-d = 50-11 = 39

rm = ri+d/2= 25

ri = Di/2 = 19,5

$$K_b = \frac{r_{mb}}{r_{ib}} = \frac{25}{19,5} = 1,282$$

$$\sigma_h = Fx(K_b\frac{16D}{\pi d^3} + \frac{4}{\pi d^2}) = 1068x(1,282\times\frac{16x50}{\pi x11^3} + \frac{4}{\pi x11^2}) = 273,18\ MPa$$

$$n = \frac{S_y}{\sigma_h} = \frac{1005}{273,18} \cong 3,67 \quad n\geq2 \quad \gg SAFE \quad \surd$$

3- Shear Stres in Hook

rm=2d+d/2 *rm = 2x11+11/2 = 27,5 mm*

ri=rm-d/2 *ri = 27,5-11/2 = 22 mm*

$$K_t = \frac{r_{mt}}{r_{it}} = \frac{27,5}{22} = 1,25$$

$$\tau_h = K_t \frac{8F_{max}D}{\pi d^3} = 1,25 \times \frac{8\times1068\times50}{\pi\times11^3} = 127,66\ MPa$$

$$n = \frac{S_{sy}}{\tau_h} = \frac{579,90}{127,66} \cong 4.54 \quad n\geq2 \quad \gg SAFE \quad \surd$$

- **Fatigue Design**

$$S_{se} = k_c \times k_d \times k_e \times S'_{e_{se}}$$

$$S_{se} = 310\ MPa\ for\ unpeened\ springs$$

$$k_c = 0,753\ for\ 99.9\%\ reliability$$

$$k_d = 1\ temperature\ factor$$

$$k_e = \frac{1}{K_c} = 0,809 \qquad K_c = \frac{\frac{4C-1}{4C-4} + \frac{0,615}{C}}{1+\frac{0,5}{C}} = 1,236$$

$S_{se} = 0,753\ x\ 1\ x\ 0,809\times310 = 188,774\ MPa$

$For\ infinite\ life\ condition\ \tau_a < S_{se}$

4-) Shear Stres in Coil

$$F_{alt} = \frac{F_{max}-F_{min}}{2} = \frac{1068-593}{2} = 237,5\ N$$

$$\tau_{coil} = K_S\frac{8F_{max}D}{\pi d^3} = 1,11\times\frac{8\times237,5\times50}{\pi\times11^3} = 25,21\ MPa$$

$$n = \frac{S_{Se}}{\tau_{coil}} = \frac{188,774}{25,21} = 7,62 \qquad n\geq2 \quad \gg SAFE \quad \surd$$

5- Shear Stres in Hook

rm=2d+d/2 = 27,5 mm

ri=rm-d/2 = 22 mm

$$K_t = \frac{r_{mt}}{r_{it}} = \frac{27,5}{22} = 1,25$$

$$\tau_h = K_t \frac{8F_a D}{\pi d^3} = 1,25 \times \frac{8\times237,5\times50}{\pi\times11^3} = 28,39\ MPa$$

$$n = \frac{S_{se}}{\tau_h} = \frac{188,774}{25,21} \cong 7,62 \qquad n \geq 2 \quad \gg SAFE \quad \surd$$

6-Normal Stres in Hook

S_e' = 0,5 x Sut MPa if Sut < 1400 MPa

S_e' = 0,5 x 1340 = 670 MPa

$$S_{se} = ka * kb * kc * kd * ke * S_e'$$

ka = 1 (No information about ka)

kb = $1,189d^{-0,097}$ *if 8 mm< d < 250 mm*

kb = $1,189\ x\ 11^{-0,097} = 0,942$

$k_c = 0,753\ for\ 99.9\%\ reliability$

kd = 1 (Temperature factor, no information about kd)

ke = $\frac{1}{kc}$ *= 0,809*

$$S_{se} = 1\ x\ 0,942\ x\ 0,753\ x\ 1 * 0,809 * 670 = 388,15\ MPa$$

$$\sigma_a = Fa\ x(K_b \frac{16D}{\pi d^3} + \frac{4}{\pi d^2}) = 237,5\times(1,282\ x \frac{16\ x\ 50}{\pi\ x\ 11^3} + \frac{4}{\pi\ x\ 11^2}$$

$$\sigma_a = 66,57\ MPa$$

$$F_{alt} = \frac{F_{max} + F_{min}}{2} = \frac{1068+593}{2} = 830,13\ \ N$$

$$\sigma_m = Fm\,x(K_b \frac{16D}{\pi d^3} + \frac{4}{\pi d^2}) = 830,13\times(1,282\,x \frac{16\,x\,50}{\pi\,x\,11^3} + \frac{4}{\pi\,x\,11^2}$$

$$\sigma_m = 232,72\,MPa$$

$$\frac{1}{n} = \frac{\sigma_a}{S_{se}} + \frac{\sigma_m}{Sut} = \frac{66,57}{388,15} + \frac{232,72}{1340} \cong 2,89 \quad n > 2 \qquad \gg SAFE\ \surd$$

- **Frequency**

$$f_{force} \leq \frac{f_n}{15}\left(\frac{cycle}{sec}\right) f_n = \frac{1}{2}\sqrt{\frac{k}{m_s}}$$

$$m_s = A\times L\times\rho = \frac{\pi d^2}{4} \times \pi^2\times D\times(N_a + 2)\times 10^{-9}$$

$$m_s = \frac{\pi 11^2}{4} \times \pi^2\times 50\times 35,5\times 10^{-9} x\,7800 = 4,13\,kg$$

$$f_n = \frac{1}{2}\sqrt{\frac{33924,58}{4,13}} = 45,13\,\frac{cycle}{sec}$$

$$f_{max} = \frac{45,13}{15} = 3,008\,\frac{cycle}{sec}$$

DESIGN OF TORSIONAL SPRING

Material	**Music wire**
Unloaded Angle	**25°**
Load	**0 – 2 kg**
End Conditions	**Polished**
Realibility	**99%**
Distance from Center of Coil (h)	**6 cm**
Factor of Safety	**2,5**
Expected Life	**6x**10^5

(Assume that d = 4 mm,   D = 24 mm)

$4 \leq C \leq 12 \qquad C = 6 \qquad C = \frac{D}{d}$

$0,8 \leq d \leq 12 \qquad d = 4\ mm$

From table 10.2 Music wire

m = 0.146   A = 2170

Ultimate & yieldstresses

$S_{ut} = \frac{A}{d^m} = \frac{2170}{1^{0,146}} = 1772,38\ MPa$

$S_y = 0,75 S_{ut} = 0,75 \times 1772,38 = 1329,29\ MPa$

$S_{sy} = 0,577 S_y = 0,577 \times 1329,29 = 767\ MPa$

- **Static Design**

$ko = \frac{4C^2 + C - 1}{4C(C+1)} = \frac{4x6^2 + 6 - 1}{4x6x(6-1)} = 0,866$

$ki = \frac{4C^2 - C - 1}{4C(C-1)} = \frac{4x6^2 - 6 - 1}{4x6x(6-1)}$ = 1,14

$\sigma = \frac{k\ x\ 32M}{\pi\ x\ d^3}$,   *M = Fxd=(2x9,81)x(60 mm) = 1177,2 Nmm*

$\sigma = 1,14 \frac{32\ x\ 1177,2}{\pi\ x\ 4^3} = 213,58\ MPa$

$n = \frac{S_y}{\sigma} = \frac{1329,29}{213,58} \cong 6,22 \qquad n \geq 2,5 \quad \gg SAFE \quad \surd$

Fatigue Design

$S_{se} = ka * kb * kc * kd * ke * S_{se}'$

ka = 1 (Polished , from figure 7.8)

kb = 1 (if d ≤ 8 mm)

$k_c = 0,814\ for\ 99.\%\ reliability$

kd = 1 (Temperature factor, no information about kd)

ke = $(not\ used\ since\ ki\ is\ used\ \sigma\ is\ increased.)$

S_e' *= 700 MPa if Sut ≥ 1400 MPa)*

$S_{se} = 1\ x\ 1\ x\ 0,814\ x\ 1\ x\ 700 = 569,8\ MPa$

S_{su} *= 0,60 x Sut = 0,60 x 1172,38 = 1063,42 MPa*

$c = log[\frac{(0,8\ xS_{su})^2}{Sse} = \log log\left[\frac{(0,8\ x\ 1063,42)^2}{569,8}\right] = 3,103$

$c = -\frac{1}{3}\log log\left[\frac{0,8\ x\ Ssu}{Sse}\right] = -\frac{1}{3}\log log\left[\frac{0,8\ x\ 1063,42}{569,8}\right] = -0,05802$

$S_f = 10^c\ x\ N^b = 10^{3,103}\ x\ (600000)^{-0,05802} = 585,5$

Ma = Mm = $\frac{Mmax + Mmin}{2} = \frac{1,172}{2} = 0,5886$

$\sigma o = \frac{ki\ x\ 32Ma}{\pi\ x\ d^3} = \frac{1,14\ x\ 32\ x\ 0,5886}{\pi\ x\ 4^3} = 106,94$

$n = \frac{1}{\frac{\sigma_a}{S_f} + \frac{\sigma_m}{S_e}} = \frac{1}{\frac{132,086}{585,8} + \frac{132,086}{1772,38}} = 3,33 \qquad n \geq 2,5 \qquad SAFE \qquad \surd$

θ = $\frac{25}{360} = 0,06944\ turn(revs)$

Spring Rate (k’)= $\frac{T}{\theta} = \frac{1,1772}{0,06944} = 16,95\ Nm/turn$

k'= $\frac{d^4 x E}{10{,}8DN} \rightarrow N = \frac{d^4}{10{,}8Dk'} = \frac{(0{,}004)^4 x 207 x 10^9}{10{,}8x(0{,}024)x16{,}95} = 12{,}06$

CONCLUSION

In conclusion, springs are mechanical elements. They are elastic and they generally produced from steel. Spring produce large deflection and used for a number of application. Stress and deflection in coil springs was derived. There are a number of spring configurations used in engineering. Springs usually used in our lifes make our life easier. There are very large application areas. Springs can be used in valves, suspensions, ball point pens, garage and screen doors etc.

In this project I learn many informations about springs. I learn spring production methods and design specifications. Design at a spring seems simple but it has comlex processes. When we design a spring, we follow processes carefully and we make calculations with precision. Factor of safety is one of the most important design criteria. We must not exceed the safety factor.

As a result, end of the this project I improve my engineering skills and approches. I have many information and idea about design criteria, especially about spring designs. “How is it designed ?” and “How can I design a spring ?” I can answer this types of questions.