Autodesk Inventor Engineer s Handbook

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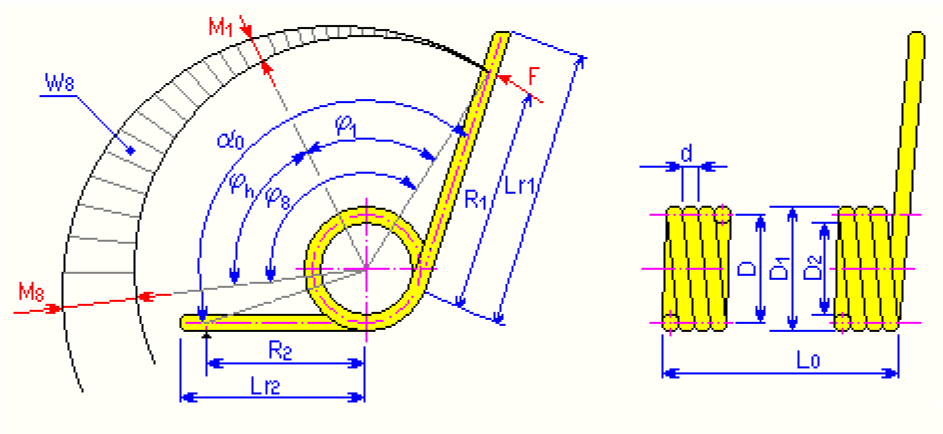
Spring Generator

Torsion Spring Generator

Basic concepts

Torsion springs have at least one and a half coils. A torsion spring is exposed to external forces acting in planes perpendicular to the coiling axis, inducing a torque in the coiling or uncoiling direction. The torque is carried by the working and the supporting arms. Active coils change their diameter during the function.



Dimensions

d wire diameter [mm, in]
D mean spring diameter [mm, in]
D_1 outside spring diameter [mm, in]
L_0 length of coiled spring part for free spring state, in general [mm, in]
R_1 arm of working force induced by the spring [mm, in]
R_2 arm of support force induced by the spring [mm, in]
M_1 torque induced by the pre loaded spring [Nm, lb ft]
M_8 torque induced by the fully loaded spring [Nm, lb ft]
W_8 deformation energy induced by the fully loaded spring [J, ft lb]
ϕ_1 angle deflection of working arm in the pre loaded state [°]
ϕ_8 angle deflection of working arm in the fully loaded state [°]
ϕ_h angle of working stroke [°]
ρ_0 angle of arms in the free state [°]
F working force induced on the R1 arm, in general [N, lb]

Coiling

1. Right (usually)
2. Left (must be notified in words)

States

1. Free: the spring is not loaded (index 0)
2. Preloaded: smallest working load is applied to the spring (index 1)
3. Fully loaded: maximum working load is applied to the spring (index 8)
4. Limit : the spring is deflected to the solid length (index 9)

NoteVariables connected with springs are presented here with their symbols, identifiers, and units and with appropriate calculation formulas and instructions.

Calculations for torsion springs in metric units

General Calculation Formulas

Outside spring diameter

$D_1 = D + d$ [mm]

where:

D mean spring diameter [mm]

d wire diameter [mm]

Inside spring diameter

$D_2 = D - d$ [mm]

where:

D mean spring diameter [mm]

d wire diameter [mm]

Torque for the preloaded spring

$$M_1 = \frac{F_1 \cdot R_1}{1000} \quad [Nm]$$

where:

F_1 working force for the preloaded spring [N]

R_1 arm of working force [mm]

Torque for the fully loaded spring

$$M_8 = \frac{F_8 \cdot R_1}{1000} \quad [Nm]$$

where:

F_8 working force (for the fully loaded spring) [N]

R_1 arm of working force [mm]

Spring index

c = D/d [-]

where:

D mean spring diameter [mm]

d wire diameter [mm]

Angle of working stroke

$\phi_h = \phi_8 - \phi_1$ [°]

where:

ϕ_8 angle deflection of working arm for the fully loaded spring [°]

ϕ_1 angle deflection of working arm for the preloaded state [°]

Minimum angle deflection of working arm

$$\varphi_1 = \frac{M_1}{k_\varphi} = \frac{M_1 \cdot \varphi_h}{M_8 - M_1} \quad [°]$$

where:

M_1 torque for the preloaded spring [Nm]

k_ϕ torsional spring rate [Nm/°]

ϕ_h angle of working stroke [°]

M_8 torque for the fully loaded spring [Nm]

Maximum angle deflection of working arm

$$\varphi_8 = \frac{M_8}{k_\varphi} = \frac{M_8 \cdot \varphi_h}{M_8 - M_1} \quad [°]$$

where:

M_1 torque for the preloaded spring [Nm]

k_ϕ torsional spring rate [Nm/°]

ϕ_h angle of working stroke [°]

M_8 torque for the fully loaded spring [Nm]

Stress concentration factor

$$K_f = \frac{4 \cdot i^2 - i - 1}{4 \cdot i \cdot (i - 1)} \quad [-]$$

where:

i	Spring index [-]
i = D/d [-]	for calculation of bending stress in active coils
$i = \frac{2 \cdot r}{d} + 1 \quad [-]$	for calculation of stress in the arm bending
r	bending radius at the arm (internal) [mm]
d	wire diameter [mm]

Spring material stress, in general

$$\sigma = \frac{32 \cdot M \cdot K_f \cdot 1000}{\pi \cdot d^3} \quad [MPa]$$

where:

M torque for the spring, in general [Nm]

K_f stress concentration factor [-]

d wire diameter [mm]

Number of spring active coils

$$n = \frac{\pi \cdot \varphi \cdot E \cdot d^4 - 1220 \cdot M \cdot (R_1 + R_2) \cdot 1000}{3660 \cdot \pi \cdot D \cdot M \cdot 1000} \quad [-]$$

where:

φ angle deflection of working arm, in general [°]

E modulus of elasticity [psi]

d wire diameter [mm]

M torque for the spring, in general [Nm]

R_1 arm of working force [mm]

R_2 arm of support force [mm]

D mean spring diameter [mm]

Spring Design Calculation

During the design of a spring, wire diameter, number of coils and the bending diameter of bend hook arm are designed to comply with the specific load, material and assembly dimensions. Design springs to suit the recommended wire diameters. For springs with a clearance between coils, the t pitch between spring threads in free state must fall within the range of $0.3\ D \leq t \leq 0.5\ D$ [mm].

The spring design is based on the ($\sigma_8 \leq u_s sA$) and ($\sigma_{8r} \leq u_s \sigma_A$) strength condition and the recommended ranges of some spring geometric dimensions.

$L_Z \leq 10\ D$ and $L_Z \leq 31.5$ in and $4 \leq D/d \leq X$ and $n \geq 1.5$ and $1.2\ d \leq t < D$ and $r \geq d$.

where:

- Spring with close-wound coils X = 16
- Spring with loose-wound coils X = 10

Spring dimensions conform to the practicable geometric solution in accordance with the specified shape and length of arms. If set in the specification, the dimensions must comply with the limit dimensions of mounting, which are the maximum allowable housing diameter and length or the maximum allowable rod diameter).

Specified maximum load, material, and spring assembly dimensions

First the input values for the calculation are checked and calculated.

Then the minimum load is calculated for specified maximum load and assembly dimensions.

$$M_1 = \frac{M_8 \cdot \varphi_1}{\varphi_8} \quad [Nm]$$

where:

M_1 torque for the preloaded spring [Nm]

M_8 torque for the fully loaded spring [Nm]

ϕ_1 angle deflection of working arm for the preloaded state [°]

ϕ_8 angle deflection of working arm for the fully loaded spring [°]

Upon completing this, the wire diameter and number of coils are designed so that after calculating the spring diameter, the strength and geometric conditions are fulfilled. If the spring diameter value is limited in the specification, then the spring design must conform. If not so, the limits of spring diameter are determined by the geometric conditions for minimum and maximum allowable wire diameter.

For springs with hook arms, suitable radii of arm bendings are designed.

All spring wire diameters with the specified strength and geometric conditions are calculated, starting with the smallest wire diameter, and working to the largest. Then the compliance with all required conditions for suitable coil numbers is tested. If all conditions are met, the design is finished with the selected values, regardless of possibly remaining compliant spring wire diameters, and a spring is designed with the smallest possible wire diameters, the lowest number of coils, and lowest spring diameters.

Specified load, material, and working deflection angle

First the input values for the calculation are checked.

For specified load and working deflection angle, working arm angle deflections are calculated next.

Minimum deflection of working arm

$$\varphi_1 = \frac{M_1 \cdot \varphi_h}{M_8 - M_1} \quad [°]$$

Maximum deflection of working arm

$$\varphi_8 = \frac{M_8 \cdot \varphi_h}{M_8 - M_1} \quad [°]$$

where:

M_1 torque for the preloaded spring [Nm]

M_8 torque for the fully loaded spring [Nm]

ϕ_1 angle deflection of working arm for the preloaded state [°]

ϕ_8 angle deflection of working arm for the fully loaded spring [°]

ϕ_h angle of working stroke [°]

Next, the wire diameter and number of coils are designed so that after calculating the spring diameter, the strength and geometric conditions are fulfilled. If the spring diameter value is limited in the specification, then the spring design must conform to that condition. Otherwise, the limits of spring diameter are determined by the geometric conditions for minimum and maximum allowable wire diameter.

For springs with the hook arms, suitable radii of arm bendings are designed.

All spring wire diameters with the specified strength and geometric conditions are considered, starting from the smallest wire diameters, and working to the largest. Next, the compliance with required conditions for suitable coil numbers is tested. If all conditions are met, the design is finished with the selected values, regardless of possibly remaining compliant spring wire diameters, and the spring is designed with the smallest possible wire diameters, the lowest number of coils, and lowest spring diameters.

Specified maximum load, material, and spring diameter

First the input values for the calculation are checked.

Next, the wire diameter, number of coils and assembly dimensions are designed to meet the strength and geometric conditions. If the working deflection angle value is limited in the specification, then the spring design must conform to this condition. If not so, the limits of assembly dimensions are determined by the geometric conditions for specified spring diameter and minimum or maximum allowable wire diameter.

For springs with the hook arms, suitable radii of arm bending are computed.

All spring wire diameters with the specified strength and geometric conditions are considered, and respective designs with increasing wire diameters from the smallest to the largest are calculated. Next, the compliance with all required conditions for coil numbers is tested. If all conditions are met, the design is finished with the selected values, regardless of possibly remaining compliant spring wire diameters, and the spring is designed with the smallest possible wire diameters, the lowest number of coils, and lowest spring diameters.

Specified maximum load, material, spring diameter, and working deflection angle

First the input values for the calculation are checked.

Next, the wire diameter, number of coils, and angle deflections of working arm are optimized to meet the mentioned strength and geometric conditions. The program seeks a minimum of maximum angle deflection of working arm ϕ_8 taking into account the requirement of minimum angle deflection of working arm ϕ_1 equaling about 2°.

For springs with hook arms, suitable radii of arm bending are computed.

Finally, for specified maximum load and designed angle deflections of working arm, the minimum spring load is calculated.

$$M_1 = \frac{M_8 \cdot \varphi_1}{\varphi_8} \quad [Nm]$$

where:

M_1 torque for the preloaded spring [Nm]

M_8 torque for the fully loaded spring [Nm]

ϕ_1 angle deflection of working arm for the preloaded state [°]

ϕ_8 angle deflection of working arm for the fully loaded spring [°]

All spring wire diameters conforming with the specified strength and geometric conditions are considered, and respective designs with increasing wire diameters from the smallest to the largest are calculated Compliance with all required conditions for coil numbers is tested. If all conditions are met, the design is finished with the selected values, regardless of possibly remaining compliant spring wire diameters, and the spring is designed with the smallest possible wire diameters, the lowest number of coils, and lowest spring diameters.

Spring Check Calculation

Calculates corresponding values of assembly dimensions for the specified load, material, and spring dimensions. First the input data are checked and calculated, then the assembly dimensions are calculated using the following formulas.

Minimum angle deflection of working arm

$$\varphi_1 = \frac{3660 \cdot M_1 \cdot 1000 \cdot (\pi \cdot D \cdot n + R_1 / 3 + R_2 / 3)}{\pi \cdot E \cdot d^4} \quad [°]$$

where:

M_1 torque for the preloaded spring [Nm]

D mean spring diameter [mm]

n number of active coils [-]

R_1 arm of working force [mm]

R_2 arm of support force [mm]

E modulus of elasticity [MPa]

d wire diameter [mm]

Maximum angle deflection of working arm

$$\varphi_8 = \frac{3660 \cdot M_8 \cdot 1000 \cdot (\pi \cdot D \cdot n + R_1/3 + R_2/3)}{\pi \cdot E \cdot d^4} \quad [°]$$

where:

M_8 torque for the fully loaded spring [Nm]

D mean spring diameter [mm]

n number of active coils [-]

R_1 arm of working force [mm]

R_2 arm of support force [mm]

E modulus of elasticity [MPa]

d wire diameter [mm]

Angle of working stroke

$\phi_h = \phi_8 - \phi_1$ [°]

where:

M_8 torque for the fully loaded spring [Nm]
ϕ_8 angle deflection of working arm for the fully loaded spring [°]

Calculation of Working Forces

Corresponding forces produced by springs in their working states are calculated for the specified material, assembly dimensions, and spring dimensions. The input data is checked and calculated, and then the working forces are calculated using the following formulas.

Minimum working load

$$M_1 = \frac{\pi \cdot \varphi_1 \cdot E \cdot d^4}{3660 \cdot (\pi \cdot D \cdot n + R_1 / 3 + R_2 / 3) \cdot 1000} \quad [Nm]$$

$$F_1 = \frac{M_1 \cdot 1000}{R_1} \quad [N]$$

where:

M_1 torque for the preloaded spring [Nm]

D mean spring diameter [mm]

n number of active coils [-]

R_1 arm of working force [mm]

R_2 arm of support force [mm]

E modulus of elasticity [MPa]

d wire diameter [mm]

ϕ_1 angle deflection of working arm for the preloaded state [°]

Maximum working load

$$M_8 = \frac{\pi \cdot \varphi_8 \cdot E \cdot d^4}{3660 \cdot (\pi \cdot D \cdot n + R_1 / 3 + R_2 / 3) \cdot 1000} \quad [Nm]$$

$$F_8 = \frac{M_8 \cdot 1000}{R_1} \quad [N]$$

where:

M_8 torque for the fully loaded spring [Nm]

D mean spring diameter [mm]

n number of active coils [-]

R_1 arm of working force [mm]

R_2 arm of support force [mm]

E modulus of elasticity [MPa]

d wire diameter [mm]

ϕ_8 angle deflection of working arm for the fully loaded spring [°]

Calculation of spring output parameters

Common for all types of spring calculation, and calculated in the following order.

Torsional spring rate

$$k_\varphi = \frac{M_1}{\varphi_1} = \frac{M_8}{\varphi_8} = \frac{M_8 - M_1}{\varphi_h} \quad [Nm/°]$$

Space between coils for the loose spring

a = t - d [mm]

Length of spring coiled part for the loose spring

for close-wound spring
L_0 = 1.05 (n + 1) d [mm]
for loose-wound spring
L_0 = t n + d [mm]

Bending stress of the spring material in active coils for minimum working load

$$\sigma_1 = \frac{32 \cdot M_1 \cdot K_f \cdot 1000}{\pi \cdot d^3} \quad [MPa]$$

where the stress concentration factor K_f is calculated for i = D/d

Bending stress of the spring material at the arm bend for minimum working load

$$\sigma_{1r} = \frac{32 \cdot M_1 \cdot K_f \cdot 1000}{\pi \cdot d^3} \quad [MPa]$$

where the stress concentration factor K_f is calculated for i = 2r/d + 1

Bending stress of the spring material in active coils for the fully loaded state

$$\sigma_8 = \frac{32 \cdot M_8 \cdot K_f \cdot 1000}{\pi \cdot d^3} \quad [MPa]$$

where the stress concentration factor K_f is calculated for i = D/d

Bending stress of the spring material at the arm bend for the fully loaded state

$$\sigma_{8r} = \frac{32 \cdot M_8 \cdot K_f \cdot 1000}{\pi \cdot d^3} \quad [MPa]$$

where the stress concentration factor K_f is calculated for i = 2r/d + 1

Length of coiled spring part in the fully loaded state for the close-wound spring and the load coils the spring

$$L_{Z8} = L_Z + \frac{d \cdot \varphi_8}{360} \quad [mm]$$

Spring outside diameter in the fully loaded state and the load coils the spring

$$D_{18} = \frac{D_1}{1 - \frac{\varphi_8}{360 \cdot n}} \quad [mm]$$

Spring inside diameter in the fully loaded state and the load coils the spring

$$D_{28} = \frac{D_2}{1 + \frac{\varphi_8}{360 \cdot n}} \quad [mm]$$

Limit test angle deflection of working arm

$$\varphi_{max} = \varphi_8 \cdot \frac{\sigma_A}{\sigma_8} \quad [°]$$

Spring deformation energy

$$W_8 = \frac{\pi \cdot \varphi_8 \cdot M_8}{360} \quad [J]$$

Wire length

l = 3.2 D n + l_R [mm]
where the l_R is an arm length, while:
where the l_R is an arm length, while:

length of straight torsion arm

$$l_{Rt} \approx \sqrt{R^2 - \left(\frac{D}{2}\right)^2} + 2 \cdot d \quad [mm]$$

length of hook arm

$$l_{Rr} \approx R - D_1/2 + 2 \cdot d \quad [mm]$$

Spring mass

$$m = \frac{\pi \cdot l \cdot d^2 \cdot \rho}{4 \cdot 10^9} \quad [kg]$$

Check of spring load

$(\sigma_8 \le u_s \sigma_A)$ and $(\sigma_{8r} \le u_s \sigma_A)$

Meaning of used variables:

a space between active coils in the free state [mm]
d wire diameter [mm]
D mean spring diameter [mm]
D_1 spring outside diameter [mm]
D_2 spring inside diameter [mm]
E modulus of elasticity [psi]
F working force exerted by the spring (the force exerted on the R_1 arm of the working force), in general [N]
i spring index [-]
K_F stress concentration factor [-]
kϕ torsional spring rate [Nm/°]
r_1 bending radius at the working arm [mm]
r_2 bending radius at the support arm [mm]
R_1 arm of working force [mm]
R_2 arm of support force [mm]
1
l wire length [mm]
L_0 length of coiled part in the loose state, in general [mm]
m spring mass [N]
M torque for the spring, in general [Nm]
n number of active coils [-]
t pitch between coils in the loose state [mm]
u_s utilization factor of material
ρ density of spring material [lb/ft3]
φ angle deflection of working arm, in general [°]
σ bending stress of spring material, in general [psi]

σ_A allowable bending stress of spring material [psi]
M_1 torque for the preloaded spring [Nm]
M_8 torque for the fully loaded spring [Nm]
ϕ_8 angle deflection of working arm for the fully loaded spring [°]
ϕ_1 angle deflection of working arm for the preloaded state [°]
ϕ_8 angle deflection of working arm for the fully loaded spring [°]
ϕ_h angle deflection of working arm for the fully loaded spring [°]

Material

Modulus of elasticity in tension for metric units

Wire Material of Torsion Springs	*E [MPa]*
Drawn patented wire from carbon steel	20.5 10^{4}
Heat treated wire from carbon steel	20 10^{4}
Heat treated or annealed wire from alloy steel (particularly Si-Cr, Mn-Cr, Mn-Cr-V)	20 10_{4}
Wire hardened by drawing from chrome-nickel corrosion-resistant austenic steel	17.5 10_{4}
Wire hardened by drawing from tin bronze	10.5 10_{4}
Wire hardened by drawing from brass	8.5 10_{4}

Modulus of elasticity in tension for English units

Wire Material of Torsion Springs	*E [psi]*
Music wire QQ-W-470	28 500 000
Oil-tempered steel wire QQ-W-428	28 500 000
Hard drawn steel wire QQ-W-428	28 600 000
Chrome-vanadium alloy steel wire	28 500 000
Chrome-silicon alloy wire QQ-W-412	29 500 000
Stainless steel 302 and 304	28 000 000
Stainless steel 420	29 000 000
Stainless steel 431	29 500 000
Stainless steel 316	28 000 000
Stainless steel 17-7PH	29 500 000

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