Autodesk Inventor Engineer s Handbook

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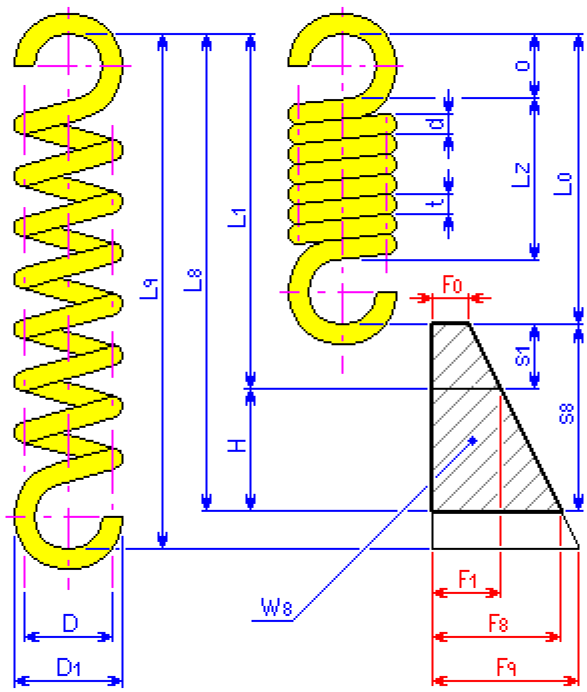
Spring Generator

Tension Spring Generator

Basic concepts

The extension spring is a helical cylindrical spring with coils adjoining each other capable of carrying the outer opposing forces actuating apart in its axis.



Dimensions

d wire diameter [mm, in]
D mean spring diameter [mm, in]
D_1 outside spring diameter [mm, in]
D_2 inside spring diameter [mm, in]
H working deflection [mm, in]
t pitch of active coils in free state [mm, in]
o eye height [mm, in]
s_x spring deflection [mm, in]
L_x spring length [mm, in]
F_x working force exerted by the spring [N, lb]
W_8 deformation energy [J, ft lb]
x index responding with the spring state

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 depressed up to coil touching (index 9)

Calculation of springs in metric units

General Calculation Formulas

Utilization factor of material

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]

Working deflection

$H = L_8 - L_1 = s_8 - s_1$ [mm]

where:

L_8 length of fully loaded spring [mm]

L_1 length of pre loaded spring [mm]

s_8 deflection of fully loaded spring [mm]

s_1 deflection of pre loaded spring [mm]

Height of spring eye

$$o = \frac{L_0 - L_z}{2} \quad [mm]$$

where:

L_0 length of free spring [mm]

L_Z length of spring coiled part [mm]

Spring index

c = D/d [-]

where:

D mean spring diameter [mm]

d wire diameter [mm]

Wahl correction factor

$$K_w = \frac{4 \cdot c - 1}{4 \cdot c - 4} + \frac{0.615}{c} \quad [-]$$

where:

c spring index [-]

L_Z length of spring coiled part [mm]

Initial tension

$$F_0 = \frac{\pi \cdot d^3 \cdot \tau_0}{8 \cdot D \cdot K_w} \quad [N]$$

where:

d wire diameter [mm]

τ_0 free state stress [MPa]

D mean spring diameter [mm]

K_w Wahl correction factor [-]

General force exerted by the spring

$$F = \frac{\pi \cdot d^3 \cdot \tau}{8 \cdot D \cdot K_w} = \frac{G \cdot s \cdot d^4}{8 \cdot D^3 \cdot n} + F_0 \quad [N]$$

where:

d wire diameter [mm]

τ torsional stress is force per unit area. of spring material in general [MPa]

D mean spring diameter [mm]

K_w Wahl correction factor [-]

G modulus of elasticity of spring material [MPa]

Spring constant

$$k = \frac{G \cdot d^4}{8 \cdot D^3 \cdot n} = \frac{F_8 - F_1}{H} \quad [N/mm]$$

where:

d wire diameter [mm]

G modulus of elasticity of spring material [MPa]

D mean spring diameter [mm]

n number of active coils [-]

F_8 working force in fully loaded spring [MPa]

F_1 working force in minimum loaded spring [MPa]

H working deflection [mm]

Spring Design Calculation

Within the spring design, wire diameter, number of coils and spring free length L_0 are set for a specific load, material and assembly dimensions.

$$\tau_0 = \frac{300}{i} + 30 \quad [MPa]$$

If the calculated spring does not match any wire diameter for the τ_0 stress according to the formula, the spring calculation is repeated with the corrected stress value in a free state within the recommended range.

$$\frac{300}{i} \le \tau_0 \le \frac{300}{i} + 60 \quad [\mathrm{MPa}]$$

The spring without initial tension is designed for a mean recommended pitch value t = 0.35 D [mm].

If the calculated spring does not match with any wire diameter of a selected pitch, the spring calculation is repeated with the corrected pitch value within the recommended $0.3\ D \le t \le 0.4\ D$ [mm] range.

The spring design is based on the $\tau_8 \le u_s \tau_A$ strength condition and the recommended ranges of some spring geometric dimensions: $L_0 \le D$ and $L_0 \le 31.5$ in and $4 \le D/d \le 16$ and $n \ge 2$.

Specified load, material, and spring assembly dimensions

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

Next the spring length at the free state is calculated.

$$L_0 = \frac{L_1 \cdot (F_8 - F_0) - L_8 \cdot (F_1 - F_0)}{(F_8 - F_1)} \quad [\mathrm{mm}]$$

After the calculation, the wire diameter, number of coils and spring diameters are designed so that the spring hook height conforms to the selected hook type. The previously mentioned strength and geometric conditions also must be fulfilled. The spring design must conform to any spring diameter value limited in the specification. If not so, the limits of spring diameter are determined by the geometric conditions for minimum and maximum allowable wire diameter.

All spring wire diameters that conform to the strength and geometric conditions are calculated, starting with the smallest, and working to the largest. Spring hook height and number of coils are tested. If all conditions are fulfilled, the design is finished with the selected values, irrespective of other conforming spring wire diameters, and a spring is designed with the least wire diameter and the least number of coils.

The calculated spring hook height must be within the $d \le o \le 30\ d$ range. A combination of the wire diameter, number of coils, and spring diameter must result in a calculated spring hook with a height that corresponds with the height of a basic hook type. The basic hook type is selected by first investigating the full loop, then the full loop inside, and then other types of hooks.

Specified load, material, and spring diameter

First the input values for the calculation are checked.

After the check, the wire diameter, number of coils, spring free length, and assembly dimensions are designed, so that the spring hook height conforms to the selected hook type. The strength and geometric conditions also must be fulfilled. If an assembly dimension L_1 or L_8 is stated in the specification, or the working spring deflection value is limited, then the spring design must conform to this condition. If not, the limits of assembly dimensions and free spring length are determined by the geometric conditions for the specified spring diameter and minimum or maximum allowable wire diameter.

Formula for designing a spring with a specified wire diameter.

$$d = 2 \cdot \sqrt[3]{\frac{F_8 \cdot D \cdot K_w}{\pi \cdot \tau_8}} \quad [mm]$$

where the $\tau_8 = 0.85\ \tau_A$ value is used for the value of torsion stress for the spring material, in the spring fully loaded state.

If no suitable combination of spring dimensions can be designed for this wire diameter, geometric investigations proceed on all suitable spring wire diameters. They are tested, beginning with the smallest and working to the largest, for coil numbers that result in the spring hook height that conforms with the conditions. The design is finished with the selected values, irrespective of other suitable spring wire diameters, and the spring is designed with the least wire diameter and the least number of coils.

The calculated spring hook height must be within the $d \leq o \leq 30\ d$ range. The corresponding hook type is selected for the hook height that is calculated in this way. A combination of the wire diameter, number of coils, free spring length, and assembly dimensions must result in a calculated spring hook with a height that corresponds with the height of a basic hook type. The basic hook type is selected by first investigating the full loop, then the full loop inside, and then other types of hooks.

Specified maximum working force, determined material, assembly dimensions, and spring diameter

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

Then the wire diameter, number of coils, spring free length, and the F_1 minimum working force are designed, so that the spring hook height conforms the selected hook type. The strength and geometric conditions also must be fulfilled.

Formula for designing a spring with a specified wire diameter.

$$d = 2 \cdot \sqrt[3]{\frac{F_8 \cdot D \cdot K_w}{\pi \cdot \tau_8}} \quad [mm]$$

where the $\tau_8 = 0.9\ \tau_A$ value is used for the value of torsion stress for the spring material, in the spring fully loaded state.

If no suitable combination of spring dimensions can be designed for this wire diameter, geometric investigations proceed on all suitable spring wire diameters. They are tested, beginning with the smallest and working to the largest, for coil numbers that result in the spring hook height that conforms with the conditions. The design is finished with the selected values, irrespective of other suitable spring wire diameters, and the spring is designed with the least wire diameter and the least number of coils.

Spring Check Calculation

Calculates corresponding values of assembly dimensions and working deflection for the specified load, material, and spring dimensions.

First, the input values for the calculation are checked. Then the assembly dimensions are calculated using the following formulas.

Length of preloaded spring

$$L_1 = L_0 + \frac{8 \cdot (F_1 - F_0) \cdot n \cdot D^3}{G \cdot d^4} \quad [mm]$$

Length of fully loaded spring

$$L_8 = L_0 + \frac{8 \cdot (F_8 - F_0) \cdot n \cdot D^3}{G \cdot d^4} \quad [mm]$$

where:

L_0 length of free spring [mm]

F_1 working force in minimum loaded spring [mm]

D mean spring diameter [mm]

n number of active coils [-]

G modulus of elasticity of spring material [MPa]

d wire diameter [mm]

F_8 working force in fully loaded spring [MPa]

Working deflection

$H = L_1 - L_8$ [mm]

Calculation of Working Forces

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

Minimum working force

$$F_1 = F_0 + \frac{(L_1 - L_0) \cdot G \cdot d^4}{8 \cdot n \cdot D^3} \quad [N]$$

Maximum working force

$$F_8 = F_0 + \frac{(L_8 - L_0) \cdot G \cdot d^4}{8 \cdot n \cdot D^3} \quad [N]$$

Calculation of spring output parameters

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

Hook height factor

$$ko = \frac{o}{D_2} \quad [-]$$

Spring constant

$$k = \frac{G \cdot d^4}{8 \cdot D^3 \cdot n} \quad [N/mm]$$

Length of coiled part

Spring without initial tension

$L_z = t\ n + d$ [mm]

Spring with initial tension

$L_z = 1.03\ (n + 1)\ d$ [mm]

Pre loaded spring deflection

$s_1 = L_1 - L_0$ [mm]

Total spring deflection

$s_8 = L_8 - L_0$ [mm]

Torsional stress of spring material in the preloaded state

$$\tau_1 = \frac{8 \cdot F_1 \cdot D \cdot K_w}{\pi \cdot d^3} \quad [MPa]$$

Torsional stress of spring material in the fully loaded stress

$$\tau_8 = \frac{8 \cdot F_8 \cdot D \cdot K_w}{\pi \cdot d^3} \quad [MPa]$$

Spring limit force

$$F_9 = \frac{\pi \cdot d^3 \cdot \tau_A}{8 \cdot D \cdot K_w} \quad [N]$$

Deflection in limit state

$$s_9 = \frac{F_9 - F_0}{k} \quad [mm]$$

where:

k spring constant [N/mm]

F_9 working force of spring loaded at limit [N]

F_0 spring initial tension [N]

Limit spring length

$L_9 = L_0 + s_9$ [mm]

Spring deformation energy

$$W_8 = \frac{(F_8 + F_0) \cdot s_8}{2000} \quad [J]$$

Developed wire length

$l = 3.2\ D\ n + l_0$ [mm]

Where the developed hook length l_0:

for half hook

$l_0 = \pi D + 4 o - 2 D - 2 d$ [mm]

for full loop

$l_0 = 2 (\pi D - 2 d)$ [mm]

for full loop on side

$l_0 = 2 (\pi D - 2 d)$ [mm]

for full loop inside

$l_0 = 2 (\pi D - d)$ [mm]

for raised hook

$l_0 = \pi D + 2 o - D + 3 d$ [mm]

for double twisted full loop

$l_0 = 4 \pi D$ [mm]

for double twisted full loop on side

$l_0 = 4 \pi D$ [mm]

for non-specified hook type

$l_0 = 0$ [mm]

Spring mass

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

Natural frequency of spring surge

$$f = \frac{d}{2 \cdot \pi \cdot n \cdot D^2} \cdot \sqrt{\frac{G}{2 \cdot \rho}} \cdot 10^6 \quad [\mathrm{Hz}]$$

Check of spring load

$\tau_8 \leq u_s \tau_A$

Overview of used variables:

d wire diameter [mm]
k spring constant [N/mm]
D mean spring diameter [mm]
D_1 spring outside diameter [mm]
D_2 spring inside diameter [mm]
F general force exerted by the spring [N]
G shear modulus of elasticity of spring material [MPa]
H working deflection [mm]
c spring index [-]
K_w Wahl correction factor [-]
l developed wire length [mm]
L spring length in general [mm]
L_Z length of coiled spring part [mm]
m spring mass [N]
n number of active coils [-]
o spring hook height [mm]
t pitch of active coils in free state [mm]
s spring deflection (elongation) in general [mm]
u_s utilization factor of material
ρ density of spring material [N/mm^3]
τ torsional stress is force per unit area. of spring material in general [MPa]
τ_A allowable torsion stress of spring material [MPa]

Material

Material of spring wire for metric

Wire type	*G [MPA]*	*Allowable limit torsion stress τ A*	*Density ρ* [kg.m ^{3}]
Draw patented from carbon steel	80 500	0.5 σ_{ult}	
Heat treated from carbon steel	78 500	0.6 σ_{ult}	
Heat treated or annealed from alloy steel (Si-Cr, Mn-Cr-V) 14260 and 15260	78 500	0.6 σ_{ult}	7.85 10^3
Hardened by drawing from chrome-nickel stainless austenitic steel 17242	68 500	0.5 σ_{ult}	
Hardened by drawing from tin-bronze 423016 and 423018	41 500	0.45 σ_{ult}	8.8 10^3
Hardened by drawing from brass 423210 and 423213	34 500	0.45 σ_{ult}	8.43 10^3

Material of spring wire for English

Wire type	*Modulus of Elasticity in Shear [psi]*
Hard drawn steel wire QQ-W-428	11 200000
Music wire QQ-W-470	11 200000
Oil-tempered steel wire QQ-W-428	11 200000
Chrome-silicon alloy wire QQ-W-412	11 200000
Corrosion-resisting steel wire QQ-W-423	11 200000
Chrome-vanadium alloy steel wire	11 200000
Silicon-manganese steel wire	11 200000
Valve-spring quality wire	11 200000
Stainless steel 304 and 420	11 600000
Stainless steel 316	11 600000
Stainless steel 431 and 17-7 PH	11 600000

Allowable limit torsion stress τ_A [10^3 psi]

Wire diameter [in]	*Hard drawn steel wire QQ-*	*Music wire QQ-W470*	*Oil-tempered steel wire QQ-W-428*	*Chrome-silicon alloy wire QQ-W-412*	*Corrosion-resisting steel wire QQ-W-423*	*Chrome-vanadium alloy steel wire*	*Silicon-manganese steel wire*	*Valve-spring quality wire*	*Stainless steel 304 and 420*	*Stainless steel 316*	*Stainless steel 431 and 17-7 PH*

	W-428											
0.010	150	176	157	176	145	175	158	175	138	131	158
0.012	149	171	154	175	143	174	157	174	129	154	158
0.014	148	167	152	174	141	173	156	173	134	127	150
0.016	147	164	150	174	139	172	155	172	132	125	148
0.018	146	161	148	173	137	171	154	171	130	123	145
0.02	145	159	146	173	135	170	153	170	128	121	143
0.024	143	155	142	172	131	168	151	168	124	118	140
0.026	142	153	141	171	129	167	150	167	123	116	138
0.028	141	151	140	171	128	166	149	166	122	115	136
0.030	140	149	139	170	127	165	148	165	121	114	134
0.032	139	147	138	170	126	164	147	164	120	113	132
0.034	138	145	137	169	125	163	146	163	119	112	130
0.036	137	143	136	169	124	162	145	162	118	112	129
0.038	136	142	135	168	123	161	144	161	117	111	128
0.041	135	141	133	167	122	160	144	160	116	110	127
0.0475	132	138	130	166	119	156	140	156	113	107	124
0.054	138	136	128	165	117	152	137	152	111	105	122
0.0625	123	132	125	162	115	149	134	152	109	104	119

Utilization factor of material uS

The factor gives a relationship between the torsion stress of a spring in the fully loaded state and the allowable torsion stress, such as $u_S \approx \tau_8 / \tau_A$. If a greater value is selected, less material is needed for spring production. The spring dimensions and the space for mounting are less, but the securing of spring stability during its function is lower, and vice versa. This factor is a reciprocal value of the safety rate. For common operational conditions, the value of the utilization factor of the material is recommended to be within the $u_S = 0.85 ... 0.95$ range. Lower values can be used for springs working in aggressive surroundings, at high temperatures or loaded with impacts.

Hooks of extension springs

Height of an extension spring hook

$$o = \frac{L_0 - L_z}{2} \quad [mm]$$

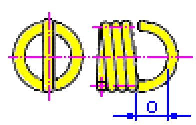
where:

L_0 length of free spring [mm]
L_Z length of spring coiled part [mm]

Most frequently used hooks of extension springs

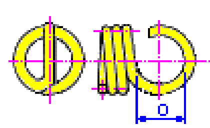
Hook type and dimension instructions *Image*

Half hook, $o = 0.55$ to $0.8\ D_2$



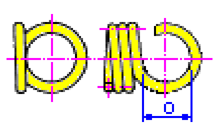
Usually: $d \leq 6.3$ mm, $D >= 3.15$ mm, $i >= 9$

Full loop, $o = 0.8$ to $1.1\ D_2$



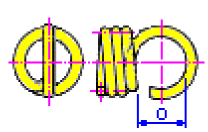
Used generally

Full loop on side, $o \approx D_2$



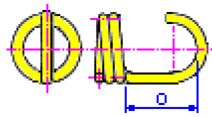
When moving the force out of spring axis does not matter

Full loop inside, $o = 1.05$ to $1.2\ D_2$



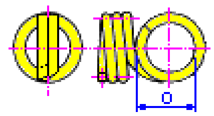
Usually: $d \leq= 10$ mm, $i >= 7$

Raised hook, $o = 1.2\ D_2$ to $30\ d$



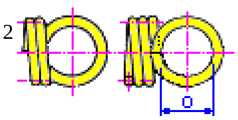
Usually for: $d = 0.5$mm to 4 mm, $o \leq 100$ mm

Double twisted full loop, $o \approx D$



Used generally

Double twisted full loop on side, $o \approx D_2$



When moving the force out of spring axis does not matter

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