Extension Springs

SPRINGS & THINGS
Manufactured To Last

Definition

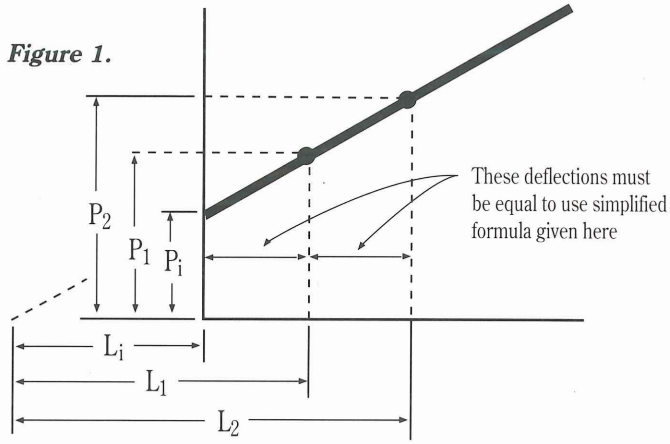
Extension springs are springs which absorb and store energy by offering resistance to a pulling force. Various types of ends are used to attach the extension spring to the source of the force.

Initial Tension

Most extension springs are wound with initial tension. This is an internal force that holds the coils tightly together. The measure of the initial tension is the load necessary to overcome the internal force and just start coil separation. Unlike a compression spring, which has zero load at zero deflection, an extension spring can have a preload at zero deflection. This is graphically illustrated in Figure 1.

This built-in load, called initial tension, can be varied within limits, decreasing as the spring index increases. Figure 3 illustrates this fact. Note that there is a range of stress (and, therefore, force) for any spring index that can be held without problems. If the designer needs an extension spring with no initial tension, the spring should be designed with space between the coils.

Figure 1.



Measuring Rate and Initial Tension

Measuring Rate

1. Extend spring to a length (L_1) such that definite coil separation occurs and measure the load (P_1).
2. Extend spring further to a second length (L_2) and again measure the load (P_2).
3. Calculate rate by dividing the load difference by the length difference in:

   $R = (P_2 - P_1)/(L_2 - L_1)$

Measuring Initial Tension—Simplified Way

1. Establish exact initial length (L_i) of spring by applying enough load to get slack out but not enough to separate coils.
2. Extend spring to length (L_1) sufficient to open coils and measure load (P_1).
3. Extend spring to length (L_2) such that second deflection equals first deflection and measure load (P_2).
4. Since the two deflections are equal, proof can be shown that initial tension is as follows:

   $P_i = 2P_1 - P_2$

Extension Spring Ends

The variety of ends that can be put on extension springs is limited only by the imagination and may include threaded inserts, reduced and expanded eyes on the side or in the center of the spring, extended loops, hooks or eyes at varying positions or distances from the body of the spring, and even rectangular or teardrop-shaped ends. (The end is a loop when the opening is less than one wire size; the end is a hook when the opening is greater than one wire size.) By far the most common, however, are the machine loop and crossover loop shown on Table 1. These ends are made with standard tools in one operation and should be specified whenever possible to minimize cost.

It should be remembered that as the space occupied by the machine loop is shortened, the transition radius is reduced and an appreciable stress concentration occurs. This contributes greatly to shortened spring life and premature failure.

Most extension spring failures occur in the area of the end. To maximize the life of the spring, the path of the wire should be smooth and gradual as it flows into the end. Tool marks and other stress concentrations should be held to a minimum. A minimum bend radius of 1½ times the wire diameter is recommended.

In the past, many ends were made as a secondary operation. Today, with modern mechanical and computer-controlled machines, many ends can be made as part of the coiling operation. Due to the large variety of machines available for coiling and looping in one operation, it is recommended that the spring manufacturer be consulted before a design is concluded.

Stresses in Extension Spring Ends

Often stresses are higher in the spring ends than in the spring body. Unless special design precautions are taken, the allowable body stress must be reduced. This is especially true in dynamic applications. Hook stresses can be reduced by using forming radii, not to exceed one-half the I.D., and by reducing the end coil diameter relative to the body coils. The hook stress in torsion should not exceed 40–45 percent of tensile strength, while hook stress in bending should not exceed 75 percent of tensile strength.

The maximum bending stress in a machine loop (see Fig. 2) occurs at location B, while the maximum torsion stress occurs at T. Stresses at these locations are estimated as follows:

$$\text{Bending stress} = S_b = \frac{32R_mP}{\pi d^3}K_b + \frac{4P}{\pi d^2}$$

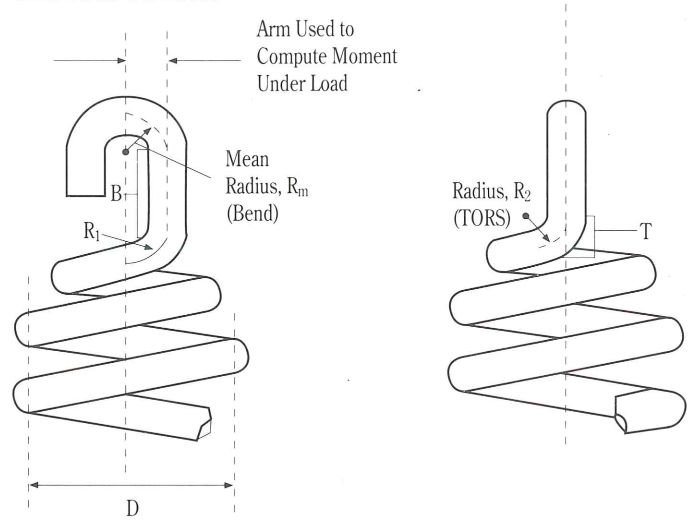
$$\text{where } K_b = \frac{4C_1^2 - C_1 - 1}{4C_1(C_1 - 1)} \text{ and } C_1 = \frac{2R_1}{d}$$

$$\text{Torsion stress} = S_T = \frac{16RmP}{\pi d^3}\frac{(4C_2 - 1)}{(4C_2 - 4)}$$

where $C_2 = 2R_2/d$

Figure 2.

Hook Stress Definitions



Solving for Initial Tension

The graph on page 21 relates the torsional stress resulting from load due to initial tension with spring index. For any spring index there is a range of stress (load) that is easily obtainable.

1. Calculate torsional stress due to initial tension (S_i) in

$$S_i = \frac{8DP_i}{\pi d^3} \text{ psi (MPa)}$$

2. For the value of S_i calculated and the known spring index D/d determine on the graph whether or not S_i appears in the preferred (shaded) area.
3. If S_i falls in the shaded area, it is safe to assume that the spring can be readily produced. If S_i is above the shaded area, reduce it by increasing the wire size. If S_i is below the shaded area, select smaller wire size. In either case, recalculation of stress, number of coils, axial space, and initial tension is necessary.

Design Method

The fundamental formulas on page 8 involving load/deflection (rate) and stress also apply to helical extension springs. The only unique property is that of solving for and including initial tension in the concept and method. Given a certain volume of space in which the spring will act and a certain maximum load (P) the basic design approach is to find a wire diameter (d) based on trial values of mean diameter (D) assumed on the basis of the available space, and a reasonable stress (S). Remember that an extension spring is not normally preset and must be designed within the torsional proportional limit of the material. This value will be about 40 percent of the tensile strength of the material.

After a wire size is determined, establish the load deflection relationship and find out if the wire size picked will allow the spring to fit in the volume of space available. Involved in this decision is the solution for rate, number of coils and initial tension. The rate is found by the load/deflection relationship. Using this rate in formula 1 solve for the number of coils. This number of coils plus the room necessary for end loops takes up a definite amount of space. The final step would then be to determine whether the available initial tension (P_i) plus the load added by deflecting to L_1, will add up to the first load required (P_1).

Design Examples

EXAMPLE 1

Design an extension spring to meet the following requirements: Maximum O.D. of body 1.250 in., (31.75 mm) loops to fit over a 0.750 in. (19.05 mm) diameter pin, initial load $P_1 = 25 \pm 3$ lb. (111.2 ± 13.3N) at initial length $L_1 = 5.6$ in. (142.2 mm) inside loops and a final load $P_2 = 35 \pm 3$ lb. (155.7 ± 13.3N) at final length $L_2 = 6.6$ in. (167.6 mm) inside loops. The spring is subject to intermittent usage with a service life of about 10,000 cycles. The material is oil-tempered wire.

Wire Diameter

The first step is to determine a trial wire diameter which will carry the 35-lb. (155.7N) load. Assuming a tensile strength of 200,000 psi (1379 MPa) for oil-tempered wire, the trial design stress will be 0.40 (200,000) = 80,000 psi (552 MPa). Use a trial mean diameter (D) of 1.00 in. (25.4 mm), which is halfway between the maximum O.D. and minimum I.D. given.

$$d = \sqrt[3]{\frac{8PD}{\pi S}} = \sqrt[3]{\frac{8(35)(1.00)}{\pi(80{,}000)}} = .104 \text{ in. } (2.64 \text{ mm})$$

Substitute the next larger size 0.105 in. (2.67 mm) for which the minimum tensile strength is 225,000 psi (1551 MPa). Since this figure is close enough to the minimum tensile strength assumed, proceed with d = 0.105 in. (2.67 mm) as the acceptable wire diameter. The allowable design stress becomes 0.40(225,000) = 90,000 psi (621 MPa)

Spring Rate

Determine the spring rate (R) from the loads and lengths given.

$$R = \frac{(P_2 - P_1)}{(L_2 - L_1)} = \frac{(35 - 25)}{(6.6 - 5.6)} = 10.0 \text{ lb./in. } (1.75 \text{ N/mm})$$

Number of Active Coils

Transposing spring rate formula 1 and solving for the number of active coils (n_a)

$$n_a = \frac{Gd^4}{8RD^3} = \frac{11.5 \times 10^6(0.105)^4}{8(10.0)(1.00)^3} = 17.5 \text{ coils}$$

Initial tension

Using the chart on page 21, an initial tension stress S_i = 14,000 psi (96.5 MPa) is seen to be readily attainable for a spring index D/d = 1.00/0.105 = 9.5. Initial tension is calculated.

$$P_i = \frac{\pi S_i d^3}{8D} = \frac{\pi\ (14{,}000)(0.105)^3}{8(1.00)} = 6.36 \text{ lb } (28.3 \text{ N})$$

Length Characteristics

Free-length inside loops =

$$L_1 - \frac{(P_1 - P_i)}{R} = 5.6 - \frac{(25 - 6.35)}{10.0} = 3.735 \text{ in. } (94.37 \text{ mm})$$

$$\text{Body length} = d(n_a + 1) = 0.105(17.5 + 1) = 1.945 \text{ in. } (49.40 \text{ mm})$$

$$\text{Loop allowance} = (3.735 - 1.945)/2 = 0.895 \text{ in. } (22.73 \text{ mm})$$

Since .895 in. (22.73 mm) is the same as the I.D. of the body, the loops will not have to be reduced or expanded to meet the free position requirements and standard machine loops or crossover loops can be used.

Stress

Calculate the stress at maximum load as S_2

$$S_2 = \frac{8P_2D}{\pi d^3} = \frac{8(35)(1.00)}{\pi(0.105)^3} = 77{,}000 \text{ psi } (531 \text{ MPa}) \text{ (uncorrected)}$$

$$K = \frac{4(9.5) - 1}{4(9.5) - 4} + \frac{0.615}{9.5} = 1.153$$

$$S_{2k} = 1.153(77{,}000) = 89{,}000 \text{ psi } (614 \text{ MPa}) \text{ (corrected)}$$

Since this value is less than the allowable design stress of 90,000 psi (621 MPa), the body stress level is safe for this application.

Although the required cyclic life is low, it is good practice to check the stress in the loops under maximum load.

The arm used to compute the moment under load can be decreased by reducing the end coil ID to 0.800. Then, to avoid excessive stress in the loops, let R_1 = 0.400 in. (10.16 mm) and R_2 = 3d = 0.315 in. (8.00 mm)

$$\text{Bending stress} = S_b = \frac{32RmP}{\pi d^3}K_b + \frac{4P}{\pi d^2}$$

$$K_b = \frac{4C_1^2 - C_1 - 1}{4C_1(C_1 - 1)} \text{ where } C_1 = \frac{2R_1}{d};$$

$$K_b = \frac{(4)(7.62)^2 - (7.62) - (1)}{(4)(7.62)(7.62 - 1)} = 1.11$$

$$S_b = \frac{(32)(0.4525)(35)(1.11)}{\pi(0.105)^3} + \frac{(4)(35)}{\pi(0.105)^2}$$

$$= 159{,}000 \text{ psi } (1096 \text{ MPa})$$

The bending stress is less than the allowable design stress in static applications for oil-tempered wire in bending which is 75 percent of minimum tensile stress or 0.75 × 225,000 psi = 169,000 psi (1165 MPa).

$$\text{Torsion stress} = S_t = \frac{16RmP}{\pi d^3}\frac{4C_2 - 1}{4C_2 - 4}$$

where $C_2 = 2R_2/d$

$$S_t = \frac{(16)(0.4525)(35)}{\pi(0.105)^3}\left[\frac{(4)(6) - 1}{(4)(6) - 4}\right] = 80{,}000 \text{ psi } (552 \text{ MPa})$$

EXAMPLE 2

Design an extension spring to meet the following requirements O.D. = 0.655 in.$_{max}$, (16.64 mm) free length L = 5.125 in. (130.2 mm), initial load P_1 = 50 ± 5 lb. (222 ± 22.2 N) at initial length L_1 = 5.625 in. (142.9 mm) inside hooks, P_2 = 94.5 lb.$_{max}$ (420 N) at final length L_2 = 6.250 in. (158.8 mm) inside hooks, 0.725 in. (18.42 mm) minimum hook extension. The material specified is music wire.

Wire Diameter

The first step is to determine a trial wire diameter which will carry the maximum load. Using a minimum tensile strength S_t = 250,000 psi (1724 MPa) for music wire, the trial design stress will be 0.40(250,000) = 100,000 psi (690 MPa). Assuming a trial mean diameter equal to the maximum O.D. and solving for d.

$$d = \sqrt[3]{\frac{8PD}{\pi S}} = \sqrt[3]{\frac{8(94.5)(0.655)}{\pi(100{,}000)}} = 0.120 \text{ in. } (3.05 \text{ mm})$$

Proceed with design, using the actual wire size of 0.120 in. diameter. The corrected mean diameter is determined by subtracting this wire diameter and a coil diameter tolerance of 0.010 in. (0.25 mm) (an estimate based on the coil diameter tolerances given in Table 2 on page 10 from the O.D.)

$$D = 0.655 - (0.120 + 0.010) = 0.525 \text{ in. } (13.34 \text{ mm})$$

The minimum tensile strength for 0.120 in. (3.05 mm) music wire is 263,000 psi (1813 MPa) so that allowable design stress becomes 0.40 (263,000) = 105,000 psi. (724 MPa).

Spring Rate

Calculate the spring rate (R)

$$R = \frac{(P_2 - P_1)}{(L_2 - L_1)} = \frac{(94.5 - 50.0)}{(6.250 - 5.625)} = 71.2 \text{ lb./in. } (12.5 \text{ N/mm})$$

Initial Tension

The required initial tension (P_i) will be equal to P_1 minus the load generated by deflecting from free length (L) to L_1

$$P_i = P_1 - R(L_1 - L) = 50 - (71.2)(5.625 - 5.125)$$
$$= 14.4 \text{ lb. } (64\text{N}) \text{ (required)}$$

Using the chart on this page, an initial tension stress $S_i = 22{,}000$ psi is readily attainable for a spring with an index of $D/d = 0.525/0.120 = 4.4$

$$P_i = \frac{\pi S_i d^3}{8D} = \frac{\pi(22{,}000)(0.120)^3}{8(0.525)} = 28.4 \text{ lb. (126N) (attainable)}$$

Therefore, the required 14.4 lb. (64N) initial tension is possible, but difficult to maintain.

Number of Active Coils

Transposing spring rate formula 1 and solving for number of active coils (n)

$$n_a = \frac{Gd^4}{8RD^3} = \frac{11.5 \times 10^6(0.120)^4}{8(71.2)(0.525)^3} = 29 \text{ coils}$$

Length Characteristics

Body length $= d(n_a + 1) = 0.120(29 + 1) = 3.600$ in. (91.44 mm)
Length of hooks $= (5.125 - 3.600)/2 = 0.762$ in. (19.35 mm)
The hooks will extend 0.762 in. (19.35 mm) from the body, which satisfies the specified 0.725 in. (18.42 mm) minimum extension.

Stress

Using the stress formula and considering the Wahl curvature stress correction factor (K)

$$S_2 = \frac{8P_2D}{\pi d^3} = \frac{8(94.5)(0.525)}{\pi(0.120)^3}$$

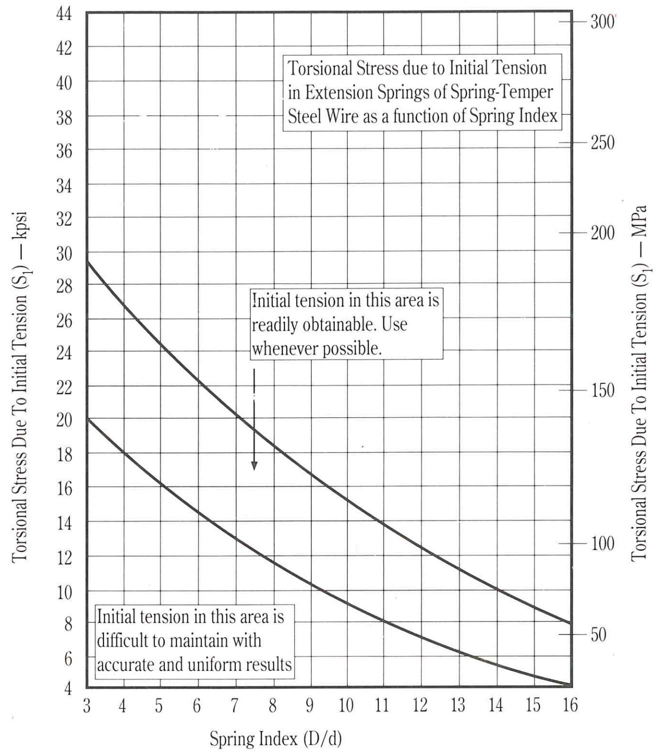
$$= 73{,}100 \text{ psi (505 MPa) (uncorrected)}$$

$$K = \frac{4(4.4) - 1}{4(4.4) - 4} + \frac{0.615}{4.4} = 1.36$$

$$S_{2k} = 1.36(73{,}000) = 99{,}400 \text{ psi (685 MPa) (corrected)}$$

Since this value is less than the allowable design stress of 105,000 psi (724 MPa), the design is safe for static application.

Figure 3.

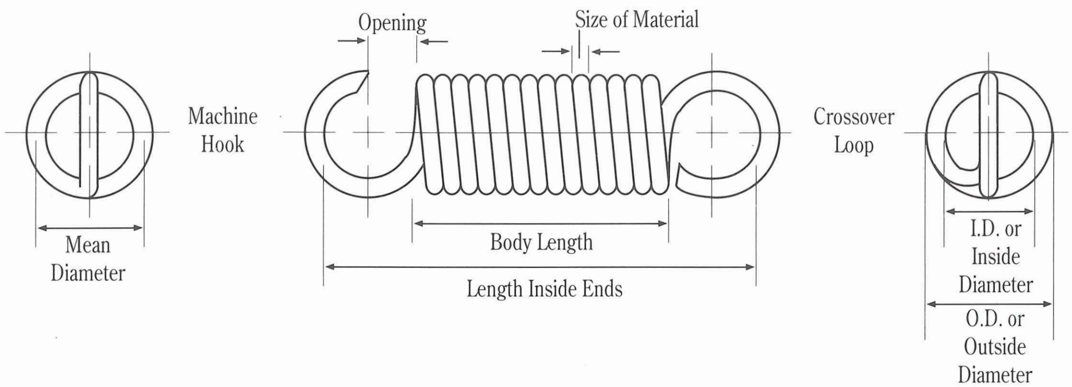


For computer programming purposes, the following is an empirical formula for determining S_i as given in the above chart.

$$S_1 = \frac{33500}{e^{0.105C}} \text{ or } \frac{33500}{10^{0.0456C}} \text{ psi: where } C = \frac{D}{d}$$

$$S_1 = \frac{231}{e^{0.105C}} \text{ or } \frac{231}{10^{0.0456C}} \text{ MPa: where } C = \frac{D}{d}$$

Extension Springs—Specification Form



Mandatory Specifications

(fill in only those required)

1. OUTSIDE DIAMETER

   a. ______ in. (mm) max. or

   b. ______ in. (mm) ± ______ in. (mm)

2. INSIDE DIAMETER

   a. ______ in. (mm) min. or

   b. ______ in. (mm) ± ______ in. (mm)

3. Load ______ lb. (N) ± ______ lb. (N) @ ______ in. (mm)

   Load ______ lb. (N) ± ______ lb. (N) @ ______ in. (mm)

   Rate ______ lb./in. (N/mm) ± ______ lb./in. (N/mm)

   between ______ in. (mm) and ______ in. (mm)

4. Maximum extended length (inside ends) without set ______ in. (mm)

5. Relative loop position, ______° max. separation of loop planes.

6. Direction of helix (L, R or optional) ______________________

7. Type of ends ______________________

Advisory Data

1. LENGTH INSIDE ENDS

   a. ______ in. (mm) max., ______ in. (mm) min. or

   b. ______ in. (mm) ± ______ in. (mm) or

   c. approx. ______ in. (mm)

2. Wire diameter ______ in. (mm)

3. Mean coil diameter ______ in. (mm)

4. No. of active coils ______

5. Body length ______ in. (mm)

6. Initial tension ______ lbs. (N)

Special Information

1. Type of material ______________________

2. Finish ______________________

3. Frequency of extension, ______ cycles/sec, and working range, ______ in. (mm) to ______ in. (mm) of length.

4. Operating temp. ______°F (°C)

5. End use or application ______________________

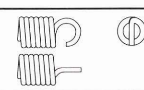
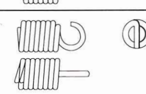
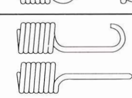
   ____

   ____

6. Other ______________________

   ____

Table 1

Loop Type		Recommended Length[a] Min.	Max.
Machine		1/2 I.D.[b]	1.1 X I.D.
Crossover		I.D.	I.D.
		Minimum Recommended Index = 7	
Side		I.D.	I.D.
Extended		1.1 X I.D.	As Required
Special: as required by design		As Required	

[a] Length is a distance from last body coil to inside of end
[b] I.D. is inside diameter of adjacent coil in spring body