Chapter 11

Designing an Extension Spring

In this chapter, we will learn the following to World Class standards:

- **Types of Common Springs**
- **Computing the Load on the Spring**
- **Computing the Maximum Length of the Extension Spring**
- **Designing the Extension Spring**
    - **Computing the Spring Index**
    - **Computing the Wahl Factor**
    - **Calculating the Number of Coils in the Extension Spring**
    - **Determining the Spring Rate**
    - **Determining the Force of the Spring when Extended**
- **Recompiling the Spring Data when Changing a Value**
- **Drawing an Extension Spring**

Types of Common Springs

In everyday products, designers need to know how to work with mechanisms that move or that exerts a force. In many cases we want the device to do simple work and return the parts of the assembly to their original configuration. There are some parts that serve in this category, and one of the most common one is the spring. In assemblies, there are extensions springs that pull on a part and there are compression springs, which push the aligned items together. A torsion springs can return a component of the assembly back to its original position angularly. In this chapter, we will learn about springs in general and about the design of the extension spring.

Where do we use the extension spring in product design? Screen doors have extensions springs that open when the door does the same, building a potential energy into the coils. When a person releases the door, the elastic component built into the spring pulls together, returning the door's extension spring back to the original shape. An artist's desk lamp has the same style of extension spring that works like the muscles in an arm, placing tension in the assembly, so the lamp, which is the load, can be held in position. When the designer uses an extension spring to place the forces in the lamp assembly arm, the directed lampshade can be held in position for years.

Figure 11.1 – Extension Spring

In some applications, we can assemble an extension spring under light load only to have the coils stretch larger under greater forces when the product is in use. In other instances, designers can assemble the spring close to the maximum length under greater loads, waiting for someone or something to trigger the release. Either way, the purpose of the extension spring is to perform work.

Some springs work in an opposite manner from the extension spring, and this type of device is the compression spring. A ballpoint pen can contain a compression spring, which places the writing point on ink cartridge into position, whether the point is positioned point externally for writing or internally stored for carrying. When clicking on the pen's top, the compression spring shortens, building forces into the metal and when the top is released, we are ready to write. To return the assembly to the original configuration, we repeat the process and the mechanism allows the writing end and ink cartridge assembly to enter the body of the ball point.

We use a torsion spring to build forces much like the extension or compression springs, but since they are working with angular forces, we can have them act in both directions. If the torsion spring is assembled under load, then when a cover is opened the lid springs into position. Designers add this assistance to rear car doors to help the user to overcome the weight and also small covers that we do not want the consumer pulling open. Other torsion springs build their energy when we open the spring and the loaded spring closes the cover without our aid. Torsion springs are often found on the axle of a hinge with the torsion arm pushing on the plastic cover.

To help us understand the importance of springs in design, we need to discover where they are used. We need to locate basic springs in our environment. We have built a list of devices that are known to have springs. Either we can conduct research on the Internet, visiting the manufacturing sites that build one of the devices, or we can disassemble one or more of these assemblies in the classroom to discover what type of spring they use.

In Figure 11.2, find one or more of the devices and determine whether they use an extension, compression or torsion spring. Maybe they have more than one type of spring in the product and we can check multiple boxes for one device.

Device	Extension	Compression	Torsion
Artist Lamp	☐	☐	☐
Ball Point Pen	☐	☐	☐
Bed Mattress	☐	☐	☐
Clock	☐	☐	☐
Computer Keyboard Keys	☐	☐	☐
Dial Telephone	☐	☐	☐
Door Handle	☐	☐	☐
Door Stop	☐	☐	☐
DVD Drive Door	☐	☐	☐
Flashlight	☐	☐	☐
Garage Door	☐	☐	☐
Pull Out Sofa	☐	☐	☐
Screen Door	☐	☐	☐
Stapler	☐	☐	☐
Toilet Paper Holder	☐	☐	☐

Figure 11.2 – Discovering Three Types of Common Springs

Now that we see where we use springs, we will start the process of designing a spring.

Computing the Load on the Spring

Most designers enjoy working with simple machines. In fact, the best designs are those that use simple solutions to solve mechanical problems. Once we model the mechanical problem, we will determine how much force the spring needs to have. Then next, we will use spring formulas to give us detail information on the construction of the device. In this lesson, we will learn how to alter a single variable in the design to affect the overall strength of the spring. Lastly, we will discover how to create an engineering drawing describing the spring.

To build a simple machine, we need to develop a model that works to the customers expectations. A good computer model can simulate the actual world situation very closely. When we design an extension spring for a screen door, we want to duplicate the real world environment where the assembly moves, and the displacement of the door needs to be in a framework of common experience. An extension spring is a good choice for the screen door assembly, since the force of the spring increases with the length of extension.

In our Computer Aided Design (CAD) program, we design a 0.75 thick wood door that is 36 inches wide by 80 inches tall. The doorknob is 32.5 inches from the bottom of the door and there is a 3/16 (0.1875) inch thick piece of polycarbonate plastic that is 72-inches tall by 28 inches wide for the window. When designing the door using the CAD software, we are going to compute the volume of each material and then use the Density Chart in Figure 11.4; we will calculate the weight of the door.

Figure 11.3 –Screen Door

The density of some common building materials are in the chart below:

Material	Density	
	English (lbs per cubic inches)	**Metric** (grams per cubic cm)
Acrylic	0.042	1.163
Aluminum, 6061	0.098	2.713
Aluminum, cast	0.097	2.685
Brass, free cutting	0.307	8.498
Cast Iron	0.252	6.975
Copper	0.323	8.941
Polycarbonate	0.043	1.190
Stainless steel	0.302	8.359
Steel, 1010	0.284	7.861
Teflon	0.078	2.159
Wood – pine	0.023	0.650
Zinc, cast	0.240	6.643

Figure 11.4 – Density Table of Common Construction Materials

In our design, our door has 674 cubic inches of wood and in the density chart; we can see that wood weighs 0.023 pounds per cubic inch. To compute the weight of the door multiply the volume times the density and the virtual door weighs 15.5 pounds.

The sheet of 0.1875 thick polycarbonate plastic is 378 cubic inches and in the density chart, we can see that polycarbonate weighs 0.043 pounds per cubic inch. To compute the weight of the glazing multiply the volume of 378 times the density of 0.043 and the virtual door weighs 16.25 pounds.

The hinge has a mass of 11.322 cubic inches and is made from low carbon 1010 steel, which weighs 0.284 pounds per cubic inch. Following the procedure shown previously, we compute the hinge weight at 3.2 pounds by multiplying 11.322 cubic inches times 0.284 lbs per cubic inch. The weight on the purchased door knob is 0.5 pounds.

We placed the data into the table in Figure 11.5 to compute the total weight of the exterior screen door.

Item	Weight
Door Knob and Screws	0.5 lbs
Door Hinge	3.2 lbs
Polycarbonate Sheet	16.25 lbs
Wood Door	15.5 lbs
Total Door Weight	**35.45 lbs**

Figure 11.5 – Density Table of Common Construction Materials

Next, we will calculate the force to move the door on the hinge. The coefficient of static friction for lubricated steel on steel for our hinge is 0.03. The normal force of the door is 35.45 lbs. Moving a 35.45 pound load on a table as shown in Figure 11.6, would be the normal force times the coefficient of static friction.

$$F_f = F_N \mu$$

$$F_f = 35.45 lbs(0.03) = 1.06 \text{ lbs}$$

The spring just needs to overcome the static friction of the steel hinge. Of course, if we lubricate the hinge, the static friction will be smaller (0.03 for lubricated steel on steel) and the spring will close the door easier. Likewise, if we do not do regular maintenance on machines, even the simplest ones, then the hinge can become rusted and the coefficient of static friction would be larger. We will use the 1.1 pounds of force to start the design process.

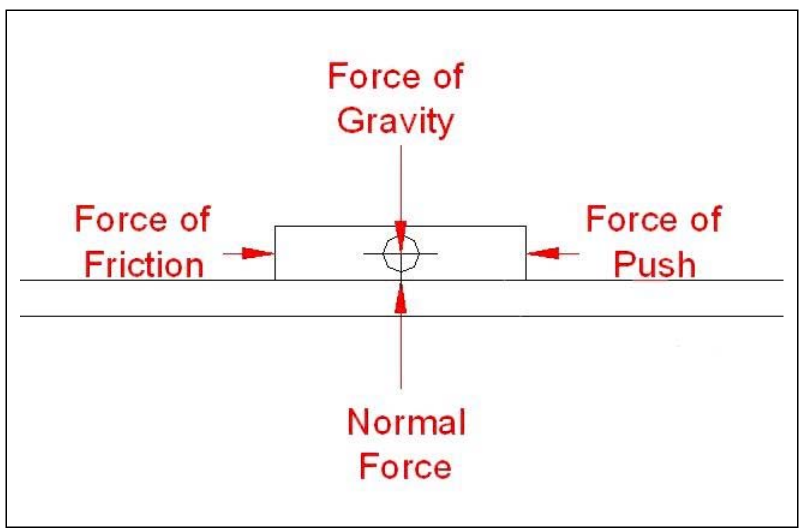


Figure 11.6 – Moving a Door on a Hinge

If the spring is placed near the center of gravity of the door and pulling in the opposite direction, then the force should be moderately above 1.0 pounds to overcome the weight of the door times the coefficient of static friction. If the spring were set closer to the hinge, then the force of the spring would have to be greater. If we move the spring to the outside limit of the door, then the force to move the door decreases.

In Figure 11.7, we calculate the 1.06 lb force acting on the lubricated hinge with an 18-inch long moment arm will have a 19.1 in-lb counterclockwise angular force. The spring's force vector is acting very close to the door (2.74 inches) and we estimate that the spring needs a 7.0-pound force to generate a 19.2 in-lb force in the clockwise direction. We figure any spring that has 7.0 pound force or greater will close the door. Another variable that will alter as the door closes and the spring force reduces is that the distance to the spring's moment arm increases by 1.0 inch to 3.75 inches as the door closes.

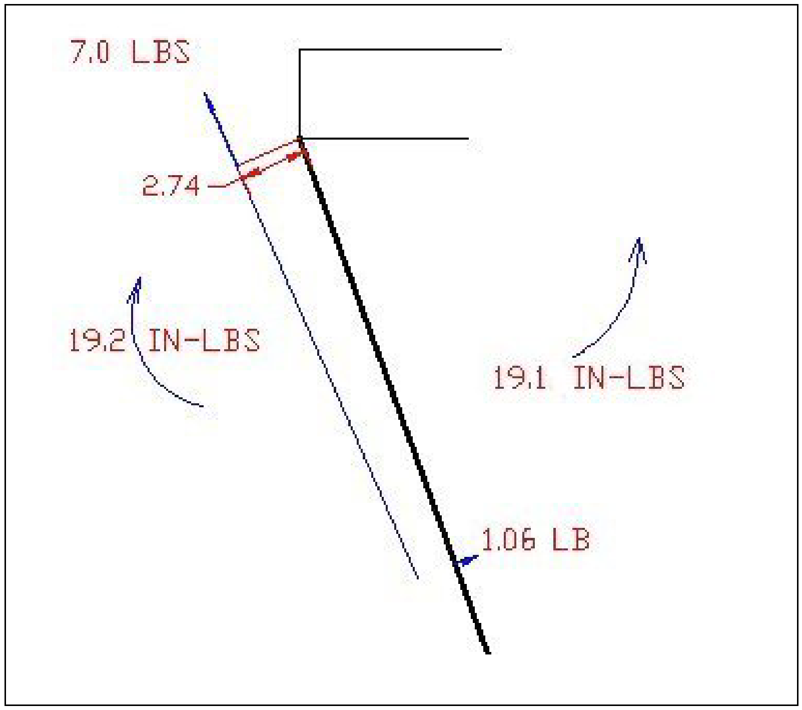


Figure 11.7 – Moving a Door on a Hinge

Check out how the moment arm changes for the spring as the door closes using the CAD file.

Computing the Maximum Length of the Extension Spring

The next step in the design of the extension spring is to determine the minimum length and the maximum length of the spring. We examine the top view of the assembly with the screen door in the closed position and the door in the open position. The extension spring is attached to the doorframe on a bracket that extends 3.75 inches to the left as shown in Figure 11.8. We attach the extension spring to the center of the screen door, approximately 1.0 inch off the back surface of the door.

As we can see in the Figure 11.8, the length of the spring in the closed position is 14.25 inches. We may want the spring to have a small amount of tension when the door is closed, so the spring is tight, so we will plan on the spring length of 14.00 inches. When the door opens 110°, the spring extends 21.05 inches. We would want the spring to have a little longer extension to account for tolerances, so we will plan the maximum extension as 22 inches.

The 3D model of the screen door has given us the approximate weight of the door, the mounting measurements, given us data to construct a force diagram and now we are determining the length of the spring with the door closed and open. We have saved multiple versions of this drawing file to document each step of the process. We will make sure we label the drawings accurately, such as Screen Door 3D Model, Screen Door Assembly Layout, and Screen Door Force Diagram. The Screen Door Assembly drawing shows the spring measurements in the closed and open position.

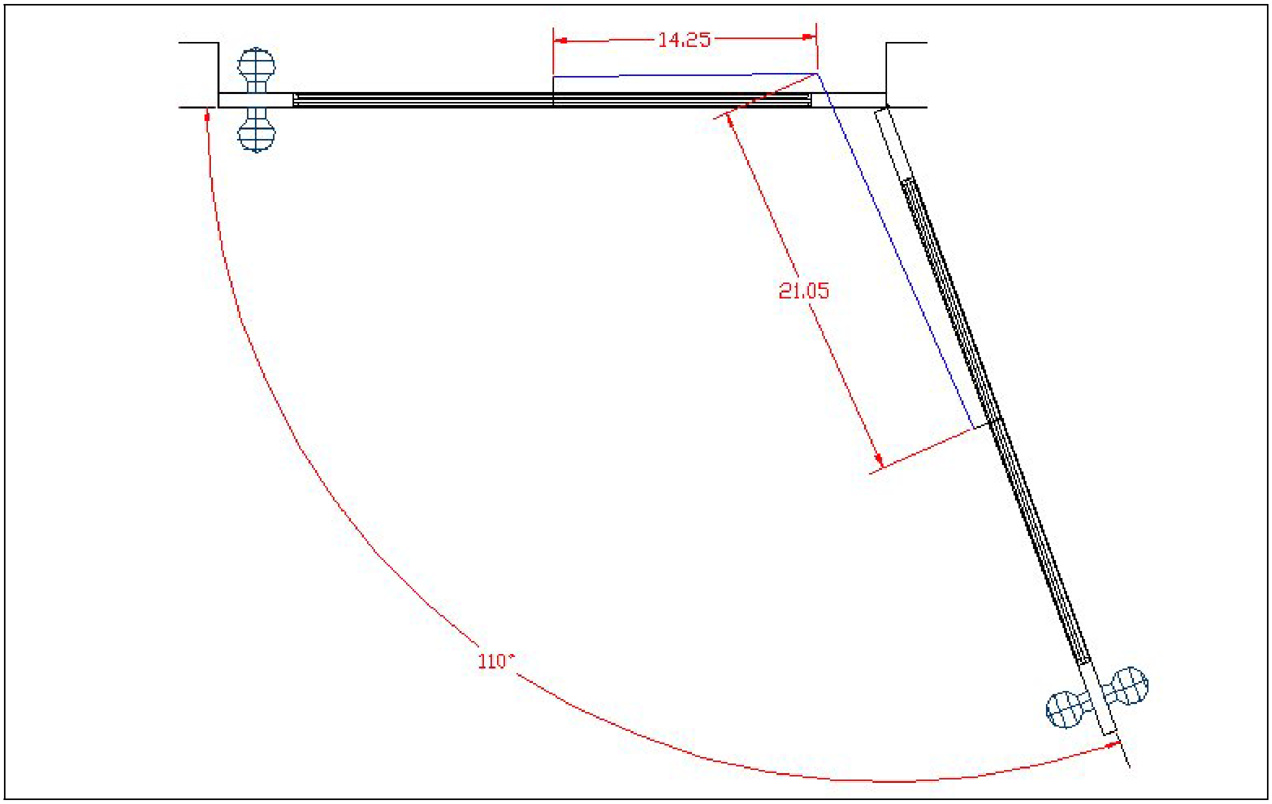


Figure 11.8 – Extension Spring on a Screen Door

Designing the Extension Spring

When the screen door is opened, the spring increases the force upon the door, which is numerically the length of the spring extension times the spring rate and adding the initial spring tension. All extension springs have an initial tension, which we will learn to compute to acquire the force on the door. The spring in action will help slow the door and may assist in keeping the assembly from reaching maximum rotation. When we open a door, some of the force we use to do the work is being stored in the spring. As our force to open the door leaves, the forces built into the spring will work to slow the opening rotation, eventually the door rotational velocity climaxing to zero. The spring's elastic coils will begin to return to their initial state and the door will begin to rotate in the opposite or closing direction with our computed 7-pound pull.

Most springs are made from steel Music Wire and we will follow suit using Hard Drawn Class 1 Spring Wire (ASTM A227). The chart shown in Figure 11.9 displays common wire diameters (d) for us to pick. The Material Chart shown in Figure 11.10 will supply us with the Torsion Modulus (G) in our computations.

As we stated previously for this spring, we will use music wire that is made from steel. The Modulus of Elasticity or Young's Modulus is the stiffness of the material and for steel; the value is 30,000,000 pounds per square inch (psi). The torsion modulus for round steel wire is between 11,000,000 to 12,000,000 psi, so we will calculate the number at 11,500,000 psi.

0.0204	0.022	0.023	0.0258	0.0286	0.030	0.032	0.035	0.0375	0.041	0.0475
0.051	0.054	0.058	0.0625	0.067	0.072	0.076	0.080	0.083	0.086	0.088
0.089	0.0915	0.093	0.094	0.095	0.098	0.099	0.1025	0.1055	0.1095	0.113
0.1205	0.125	0.128	0.135	0.138	0.142	0.1483	0.156	0.162	0.170	0.177
0.182	0.1875	0.192	0.197	0.207	0.218	0.225	0.2435	0.250	0.262	0.283

Figure 11.9 – Wire Diameter Sizes for Music Wire (ASTM A227)

Material	**Modulus of Elasticity**	**Modulus in Torsion**
Music Wire	30,000,000 psi	11,500,000 psi
Stainless Steel, 302	28,000,000 psi	10,000,000 psi

Figure 11.10 – Modulus of Rigidity

Computing the Spring Index

Music wire and stainless steel wire is available in diameters from 0.005 to 0.25, however we will check our initial choices for diameters against the spring index, which is the ratio of the mean diameter divided by the diameter of the wire.

$$c = \frac{D}{d}$$

A good spring index should range between 3 and 12. If we initially select the mean diameter of the spring to be 0.500 inches and the diameter of the wire at 0.0625, then the spring index is as follows.

$$c = \frac{0.500in.}{0.0625in.} = 8.0$$

The spring index of 8.0 is in the middle of the minimum and maximum of the spring index. A low spring index will provide a more forceful or stiffer spring. A spring with a larger index will be flimsy and provide less force.

Computing the Wahl Factor

The Wahl factor is a number developed by Wahl to account for the curvature. We use the Wahl factor to determine the initial force in an extension spring later in this chapter. The formula is:

$$k = \frac{4c-1)}{(4c-4)} + \frac{0.615}{c}$$

Then we insert the spring index of 8.0.

$$k = \frac{[4(8.0)-1]}{[4(8.0)-4]} + \frac{0.615}{8.0} = \frac{31.0}{28.0} + \frac{0.615}{8.0} = 1.1071 + 0.076875 = 1.1840$$

Calculating the Number of Coils in the Extension Spring

The ends of an extension spring typically have the same diameter as the coils. They usually extend 75% of the diameter on each end. To come up with the initial number of coils in our spring, we will subtract 0.75-inch $(2 \times 0.5 dia. \times 75\%)$ from both sides for the ends, which will leave us with 12.25 inches. Divide the 12 inches by the diameter of the wire (0.063) and we get 196 coils. For extension springs, all coils are active, when the spring is assembled and pulled.

$$\text{Length of free ends} = (2 \times D \times 75\%) = (2 \times 0.500 \times 0.75) = 0.75 \text{ in.}$$

Spring Length (L) – ends = 14.00in. – 0.75 in. = 13.25 in.

N = Length of coil ÷ d = 13.25 in. ÷ 0.0625 = 212 coils

Determining the Spring Rate

To calculate the spring rate, use the following formula below.

$$R = \frac{Gd^4}{8nD^3}$$

Now that we are using more than a couple variables in the formula, we can examine the variable table shown in Figure 11.11.

Variable	Description
c	The spring index
d	The diameter of the wire in inches
D	The mean diameter of the coil in inches
F	The normal spring load in pounds
f	The deflection at maximum load in inches
G	The modulus of rigidity of material (psi)
ID	Inside diameter in inches
k	The Wahl stress factor
L	The spring's length in inches
n	The number of active coils
N	The number of total coils
OD	Outside diameter in inches
P	The maximum allowable load in pounds
R	The spring rate measured in pounds per inch
S	The allowable fiber stress (psi)

Figure 11.11 – Descriptions of the Extension Spring Variables

The spring rate is a measurement of pounds per inch of extension. If a spring has a rate of 1.5 pounds per inch, then a free length spring that is 4 inches long will exert a 0.75-pound force when stretched to 4.5 inches.

$$R = \frac{Gd^4}{8nD^3}$$

$$R = \frac{(11{,}500{,}000)(0.0625)^4}{8(212)(0.5)^3} = \frac{11{,}500{,}000(0.0000152587890625)}{8(212)(0.125)} = \frac{175.47610}{212} = 0.828 \text{ lbs/in}$$

We compute the force the spring has on the door at the maximum opening of 21.05 inches by multiplying the spring rate times the change of length in the spring.

Determining the Force of the Spring when Extended

The initial tension in the coiled spring for a spring with the index of 8 is 14,500 psi. To compute the initial force from the tension

$$\tau_i = 14{,}500\, psi$$

The formula for the initial force is:

$$F_i = \frac{\tau_i \pi d^3}{8kD}$$

$$F_i = \frac{14500\pi(0.0625)^3}{8(1.1840)(0.500)} = \frac{11.12136}{4.736} = 2.348 lbs$$

The initial force of the spring is 2.348 pounds. To compute the force of the spring when the coils are stretched to 21.05 inches, use the following formula:

$$F = R(L_f - L_i) + F_i$$

$$F = 0.828 lbs/in(21.1in. - 14.00in.) + 2.348 lbs = 0.828(7.1) + 2.348 = 8.23 lbs$$

The spring is exerting an 8.23-pound force when we needed to have a spring with a 7.0-pound force. If we examine the formula for spring rate, we could make the diameter of the wire a little smaller, or increase the diameter of the coils to make the spring a little weaker.

$$R = \frac{Gd^4}{8nD^3}$$

For our first extension spring, we will change the spring diameter to 0.058 and recalculate the extension spring formulas.

Recompiling the Spring Data when Changing a Value

In the table shown in Figure 11.12, we see the values that we have previously discussed and have written them for easy viewing.

Variable	Description	Value
d	The diameter of the wire in inches	0.058 in.
D	The mean diameter of the coil in inches	0.500 in.
F	The normal spring load in pounds	7.0 lbs
f	The deflection at maximum load in inches	7.1 in.
G	The modulus of rigidity of material (psi)	11,500,000 lbs/ in^2
ID	Inside diameter in inches	0.442 in.
L	The spring's free length in inches	14.00 in.
OD	Outside diameter in inches	0.558 in.

Figure 11.12 – Descriptions of the Extension Spring Variables and the Initial Values

One – recalculate the spring index

$$c = \frac{D}{d}$$

$$c = \frac{0.500 in.}{0.058 in.} = 8.62$$

Two – Calculate the Wahl factor with the spring index of 8.62

$$k = \frac{4c-1)}{(4c-4)} + \frac{0.615}{c}$$

$$k = \frac{[4(8.62)-1]}{[4(8.62)-4]} + \frac{0.615}{8.62} = \frac{33.48}{30.48} + \frac{0.615}{8.62} = 1.0984 + 0.071346 = 1.1697$$

Three – Calculate the number of coils in the extension spring

Length of free ends $= (2 \times D \times 75\%) = (2 \times 0.500 \times 0.75) = 0.75$ in.

Spring Length (L) – ends = 14.00in. – 0.75 in. = 13.25 in.

N = Length of coil ÷ d = 13.25 in. ÷ 0.058 = 228 coils

Four - calculate the spring rate

$$R = \frac{Gd^4}{8nD^3}$$

$$R = \frac{(11{,}500{,}000)(0.058)^4}{8(228)(0.5)^3} = \frac{11{,}500{,}000(0.000011316496)}{8(228)(0.125)} = \frac{130.139704}{228} = 0.571 \text{ lbs/in}$$

The initial tension in the coiled spring for a spring with the index of 8.62 is 13,800 psi. To compute the initial force from the tension

$$\tau_i = 13{,}800\,psi$$

Five - determine the initial force

$$F_i = \frac{\tau_i \pi d^3}{8kD}$$

$$F_i = \frac{13800\pi(0.058)^3}{8(1.1697)(0.500)} = \frac{8.45888}{4.6788} = 1.808\,lbs$$

$$F = R(L_f - L_i) + F_i$$

$$F = 0.571\,lbs/in(21.1in. - 14.00in.) + 1.808\,lbs = 0.571(7.1) + 1.808 = 5.862\,lbs$$

The spring is exerting a 5.862-pound force when we change to a smaller diameter music wire and increase the number of coils to compensate for the length. A change in wire diameter of 0.005 inch will have a larger affect than making a small change in the diameter of the coil, which does not change the number of coils.

For our design we will use the first numbers.

Variable	Description	Value
d	The diameter of the wire in inches	0.0625 in.
D	The mean diameter of the coil in inches	0.500 in.
F	The normal spring load in pounds	8.23 lbs
f	The deflection at maximum load in inches	7.1 in.
G	The modulus of rigidity of material (psi)	11,500,000 lbs/ in^2
ID	Inside diameter in inches	0.4375 in.
L	The spring's free length in inches	14.00 in.
OD	Outside diameter in inches	0.5625 in.

Figure 11.13 – Descriptions of the Extension Spring Variables and the Values

Drawing an Extension Spring

In our Computer Aided Design (CAD) program, draw and copy a circle so that the outside diameter of the spring is 0.5625. Move the circle 0.0625 to the right. Using the tangent Object Snap and draw a line from the left side of the top circle to the left side of the bottom circle. Do the same operation on the right side. Trim out the inside of both circles and now you have coil as shown in the Figure 11.15. Polyline edit and join the four entities. Array the coil to have 212 columns at 0.0625 inches apart. Once the 212 coils are shown in the front view, draw the ends.

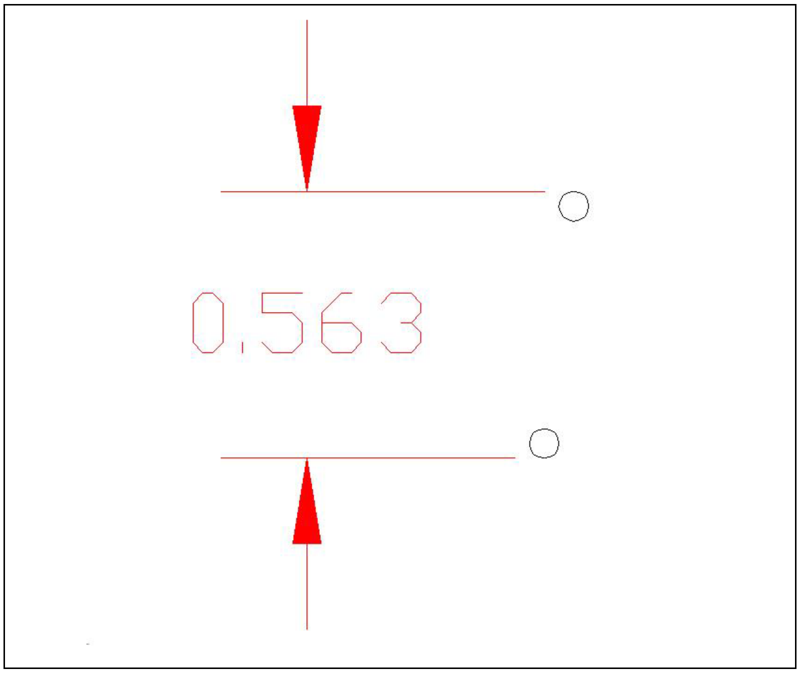


Figure 11.14 – Drawing the Coil

In Figure 11.16, we have the front view of the extension spring. The free length of the spring is shown at 14.00 inches. The outside diameter of the spring is 0.563 inches. The wire diameter is shown as 0.063. A table containing the engineering data for the spring should be added. Maintain the calculations we made for the spring in the project file. We can scan the paperwork and place the electronic file in the computer folder for this part. Place the drawing in a B size engineering border and complete the title block. Plan on nickel plating the spring to protect the music wire from corrosion.

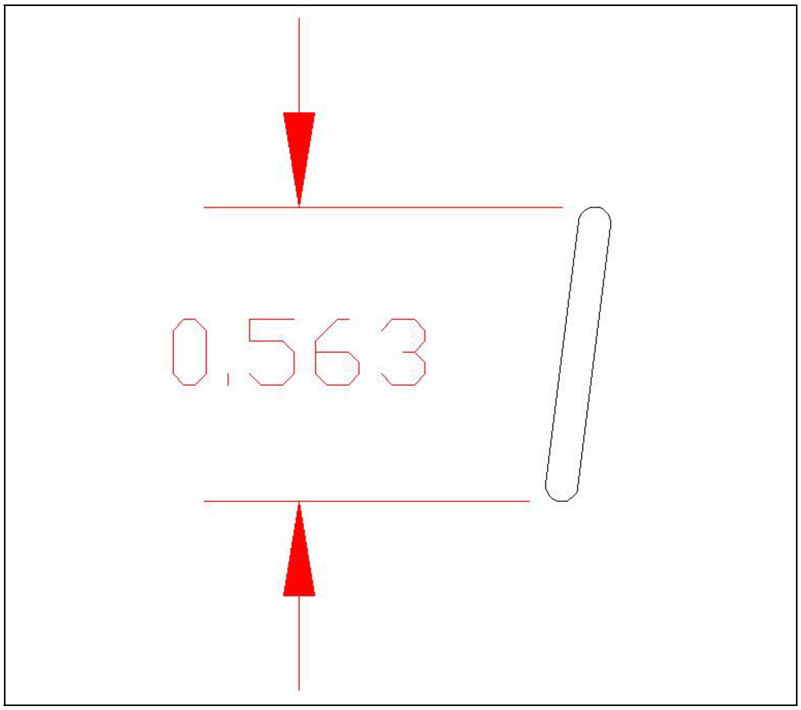
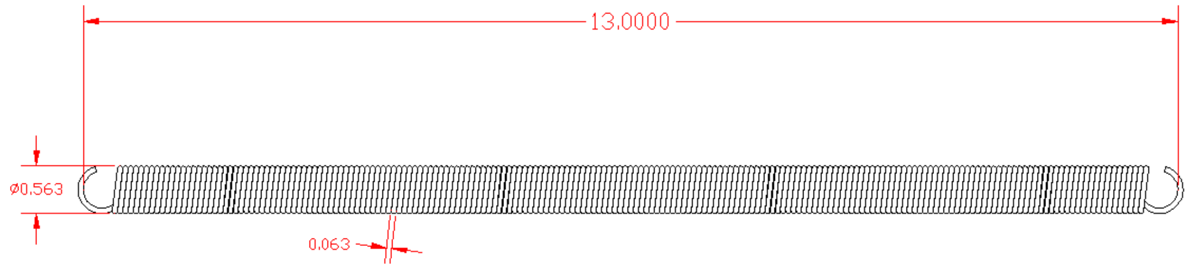


Figure 11.15 – Polyline Edit the Coil



Material	Music Wire
Torsion Modulus (G)	11,500,000 psi
Spring Index (c)	8.0
Wahl Factor (k)	1.1840
Spring Rate (R)	0.895 lbs/in
Outside Diameter (OD)	0.5625 in.
Inside Diameter (ID)	0.4375 in.
Mean Diameter (D)	0.500 in.
Wire Diameter (d)	0.0625 in.
Deflection at Load (f)	6.12 in.
Number of Coils (N)	196
Free Length (L)	13.00 in.

Figure 11.16 – Extension Spring Drawing

After completing this chapter, try the World Class CAD Challenge for extension springs.

*** World Class CAD Challenge 8-51 * - Compute the spring data for an extension spring with the following data. Make a purchasing drawing for the spring showing the front orthographic view and a table of data. Place the drawing and table in a standard "B" size border and complete the title block.**

Variable	Description	Value
d	The diameter of the wire in inches	0.024 in.
D	The mean diameter of the coil in inches	0.156 in.
F	The normal spring load in pounds	2.5 lbs
f	The deflection at maximum load in inches	1.1 in.
G	The modulus of rigidity of material (psi)	11,500,000 lbs/ in^2
ID	Inside diameter in inches	0.132 in.
L	The spring's free length in inches	1.37 in.
OD	Outside diameter in inches	0.180 in.

Continue this drill four times using some other size screw threads from Unified National Screw Thread Table in this textbook, each time completing the drawing under 5 minutes to maintain your World Class ranking.