Chapter 12

Designing a Compression Spring

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

- **Creating a Simple Electrical Circuit**
- **Designing the Spring**
- **Drawing the Electrical Assembly Drawing**

Creating a Simple Electrical Circuit

In the 21st century, a designer needs to understand how to improve their product with technical enhancements by utilizing cast or extruded components, composite materials and any form of electrical circuit. We discuss the first two enrichments to manufactured goods in the World Class CAD textbook covering mechanical design, but in this course, we will apply simple to advanced electrical circuits to give our assembly better product capabilities. As in the beginning of the electronics technology over a century ago, we will design and then build with analog electrical components, using soldering and wire to connect the various specialized parts which will allow the customer to easily control the device. As we gain experience, we will incorporate digital devices that are less expensive, smaller and may be more reliable. Digital devices do require the electrical designer to have greater expertise. In every one of our designs, we will begin with a sketch that visually shares our ideas.

In our project, we will design a flashlight. Instruments that illuminate our way are very common in the industry and every architect, designer and engineer should be familiar with basic lighting circuitry. The main elements of a lighting circuit are the lamp, the switch, the bus and the power source. We would find our journey very difficult if we had an assignment where we would have to locate a building, automobile or piece of office equipment containing a lighting device that did not have the major components that we just listed. Over the years, incandescent lamps have been replaced with light emitting diodes (LED), analog switches with digital controls, wires with circuit board tracks, and chemical batteries with solar panels. In the example shown in this chapter, we will use those older analog parts, however if you desire to improve your design with more advanced components, the decision is entirely yours.

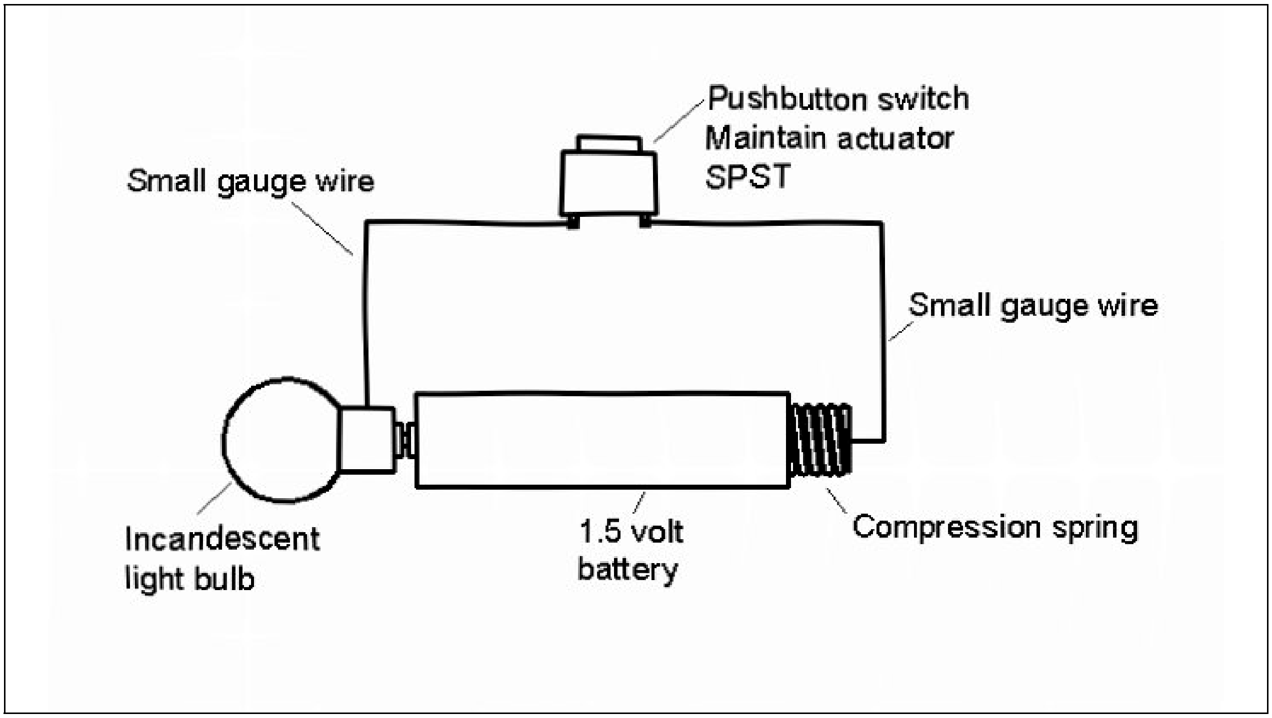

Figure 12.1 – Electrical Components of a Flashlight Sketch

Designing the Spring

To design a spring for the flashlight shown in Figure 12.1, the spring performs both a mechanical and electrical function in the design. The coils of the compressed spring will force the lamp and battery together and the material of the spring will act as a buss or wire to transmit the current from the switch to the anode (negative) end of the battery.

What materials are good conductors? The conductivity of a material is the inverse of the material's Resistivity. In the chart below, we see different materials that manufacturers use to improve conductivity. The material with the lowest resistivity is the best conductor. The substance with the best conductivity is silver, a metal that is both expensive and has a low melting point. In the list, music wire, the primary material we use in making springs is not the best conductor, but we will add nickel plating for corrosion protection and improve the conductivity at the same time.

Material	**Resistivity at 20º C**
Aluminum	$2.82\times10^{-8}\ \Omega m$
Brass	$7.0\times10^{-8}\ \Omega m$
Copper	$1.72\times10^{-8}\ \Omega m$
Gold	$2.44\times10^{-8}\ \Omega m$
Music Wire (steel)	$11.8\times10^{-8}\ \Omega m$
Nickel	$6.84\times10^{-8}\ \Omega m$
Silver	$1.47\times10^{-8}\ \Omega m$

Figure 12.2 – Material Conductivity Comparison Chart

To find the static resistivity of a metal or any material, we compute the following formula.

$$p = R \times \frac{A}{l}$$

Where p is the static resistivity measured in ohm – meters (Ωm)
R is the electrical resistance of the material measured in ohms (Ω)
A is the cross sectional area of the material measured in square meters (m^2)
l is the length of the material measured in meters

We can rearrange the formula to find the resistance R placed on a circuit by selecting any material. In most cases, we neglect to compute the resistance on a circuit from wires, but we make this computation in cases of high voltage, long distances and where energy levels are critical.

After selecting the music wire material, we learn that the force to hold the electrical connection together is dependent upon several factors, which are the conductivity of the material and the voltage being transmitted. For a nickel-plated spring, Duracell suggests that we apply 500 to 1000 grams (1.1 to 2.2 lbs) of force. The AA battery is approximately 0.5 in diameter, so we are looking a short spring about 0.375 high, 0.375 in diameter, using steel music wire around 0.0625 in diameter and can generate a maximum of 2.2 pounds in force. We are quickly able to narrow down the parameters and rapidly come up with a workable solution. As the mechanical designers narrow in on a flashlight case design, we will need to modify our electromechanical spring to fit their package.

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 28,000,000 to 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.

We will use the following formula to find the amount of force in the spring when we compress the battery between the socket and the spring.

$$P = \frac{G\,d^4\,F}{8\,N\,D^3}$$

Where P is the force is pounds
G is the torsion modulus
D is the diameter of the wire
F is the deflection
N is the number of coils in the compression spring
D is the diameter of the coil

From our initial drawing, we have a compression spring diameter of 0.375 inches that has a height of 0.375 inches. When we place the battery in the case, the spring will depress 0.125 inches. The Torsion Modulus is 12,000,000 psi. If the wire diameter is 18 gauge (0.047) and the spring has 4 coils, then the maximum compression or solid height of the compression spring would be 4 times 0.047 or 0.188. Add the 0.125 depression height to the 0.188 and we find that the unloaded or full height of the compression spring has to be 0.313 inches. Our height of 0.375 will give us a tolerance window to avoid maximum compression.

Now that we have chosen our first values, we will computer the force the spring we have on the battery. The mean diameter of the spring D is the outside diameter minus the diameter of the wire, so 0.375 – 0.047 equals 0.328 inches. As we can see in Figure 12.3, our first set of numbers compute a force of 6.482 pounds. This value is well above what is required by the battery manufacturer for contact force.

$$P = \frac{12{,}000{,}000\ \text{lb/in}^2 \times 0.047\ \text{in}^4 \times 0.125\ \text{in}}{8 \times 4 \times 0.328\ \text{in}^3}$$

$$P = \frac{7.3195215\ \text{lb-in}^3}{1.129201664\ \text{in}^3}$$

$$P = 6.482\ \text{lb}$$

Figure 12.3 – Calculating the Force of the Compression Spring on the Battery

Now we will change the diameter of the music wire, which will also change the mean diameter of the spring, but all other parameters remain the same. The music wire will be 20 gauge (0.035 inches) and the mean diameter will become 0.375 – 0.035 equaling 0.34.

$$P = \frac{12{,}000{,}000 \text{ lb/in}^2 \times 0.035 \text{ in}^4 \times 0.125 \text{ in}}{8 \times 4 \times 0.340 \text{ in}^3}$$

$$P = \frac{2.2509375 \text{ lb-in}^3}{1.257728 \text{ in}^3}$$

$$P = 1.790 \text{ lb}$$

Figure 12.4 – Calculating the Force of the Compression Spring with 20 Gauge Music Wire

In the second attempt, we are between the 1.1 and 2.2-pound force that the battery manufacturer suggests for small direct current applications. The lesson we learn early in design is to begin with common sense parameters. We did not select a 2-inch diameter spring for a 0.5 diameter battery. We did not select 8-gauge music wire that is 0.162 diameter. We begin by selecting sizes that match the assembly and we set our goal from values specified by the manufacturer of the power source. If the small spring did not have enough force, what can a designer change?

We can select a material with a higher Torsion Modulus, but that is not always easy if we begin with music wire, which already has a very high value. Increase the diameter of the wire such as 0.035 to 0.047 and since this parameter is computed to the fourth power, we will see a difference in the force by the multiple of over three. Changing the distance deflected does not have a large affect but this will also increase the force. In the denominator of the formula, decreasing the number of coils by one or two will increase the force. Making the mean diameter of the spring smaller has a larger affect. So remember, wire size and compression spring diameter are made for large changes and material selection, number of coils and distance of spring depression are made to fine tune the design.

In Figure 12.5, we made a 3D compression spring with ends ground to be flat. When we build the prototype, we can determine the best method of attaching the wire. The nickel plating on the steel spring will allow for easy soldering. For round components, design a nest that will hold the part still when soldering the wire to the coil. After the wire is soldered to the spring, the spring assembly is placed in the flashlight body.

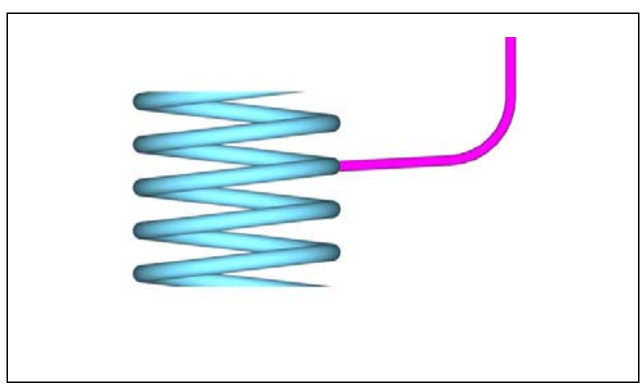

Figure 12.5 – Compression Spring

When working with spring assemblies, do not allow the team or organization that made the part or sub assembly to put multiple coiled parts in a single container together before transporting to final assembly. All of the coils and wires will twist together and we will have a technician uncoiling parts before putting them into the flashlight case. Spring manufacturers can use egg crate dividers to keep parts separate before shipping them to their assembly destination.

Drawing the Electrical Assembly Drawing

After making the spring part drawing to purchase or to have manufactured, we would create an electrical assembly in our CAD software package. In the assembly drawing, we just concentrate of those components that we are required to design. The only component that a mechanical designer or engineer may design in this problem is the spring. Most electrical designers and engineers are quite capable of designing springs that conduct electricity.

In the electrical assembly, we show each part carrying current. The Bill of Material (BOM), which we place typically in the upper right corner of the drawing, shows all of the items in the assembly. Numbered callouts refer each item to the Bill of Material. The drawer is responsible for gather all the construction notes for the assembly and putting them on the drawing sheet. Remember, on new drawings; only use 50% of the available space on the sheet. We need to leave room for details and revision, which are always made during the course of the product's design life.

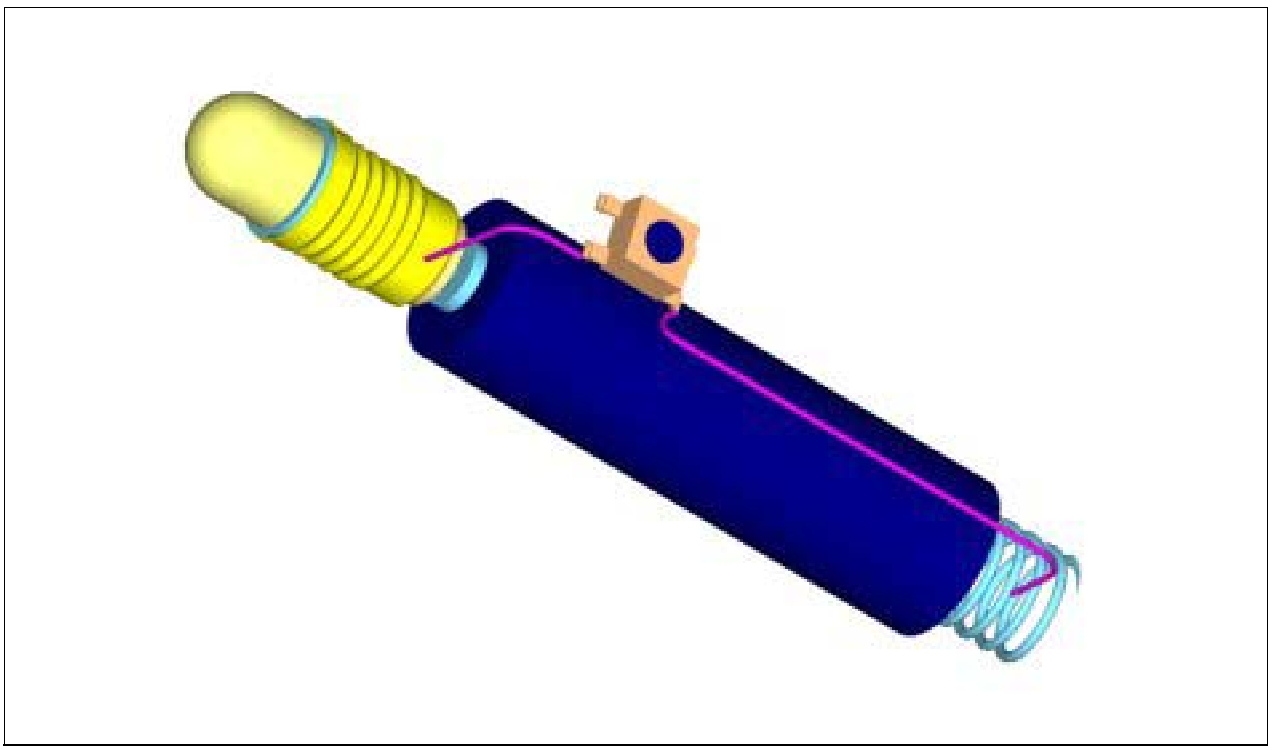

Figure 12.6 – Electrical Assembly

In Figure 12.6, we show each individual components in a three dimensional model. Our challenge in this chapter is to learn the basics of a simple lighting circuit.

*** World Class CAD Challenge 8-52 * - Design and draw a 0.5 tall and 0.25 maximum diameter compression spring to maintain contact between a battery and the lamp assembly of 1.1 to 2.2 pounds force in 120 minutes. Make the part drawing, dimension, place the border and titleblock within the time limit.**

Continue this drill four times using some other ideas, such as multiple cell battery, toggle switch and more than one lamp, each time completing the drawing under 120 minutes to maintain your World Class ranking.