

# Creating Springs in TurboCAD®

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**A. Introduction.** This article addresses the creation of *coil* springs—i.e., those with a more or less helical configuration. Other kinds of springs that are commonplace in the real world but not discussed here include leaf springs, and springs that work by compressing a gas or a liquid, and springs in which rubber or a similar material is loaded in tension, compression, direct shear, or torsion. These designs are all greatly different from coil springs and can be drawn fairly easily in TurboCAD by other methods.

**B. Scope of this article.** Although the most familiar coil-spring configuration is a helix with a cylindrical envelope shape, made with round wire, and having constant pitch, many other configurations do exist. This article explains how to create the following envelope shapes (Figure 1):

- Cylindrical
- Conical
- Hourglass
- Barrel
- Volute
- Spiral
- Garter
- Freeform

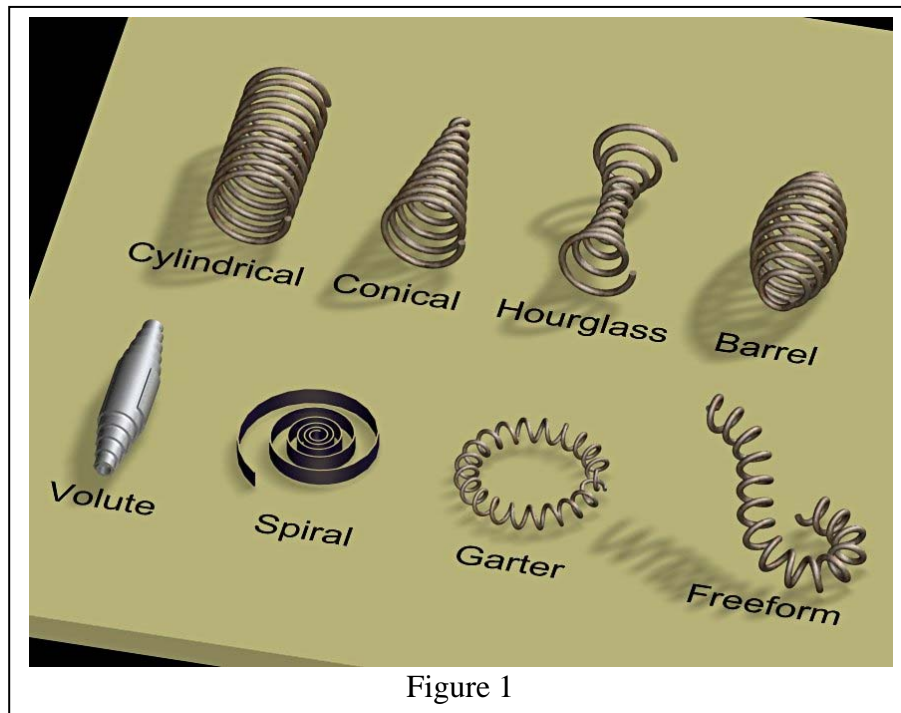
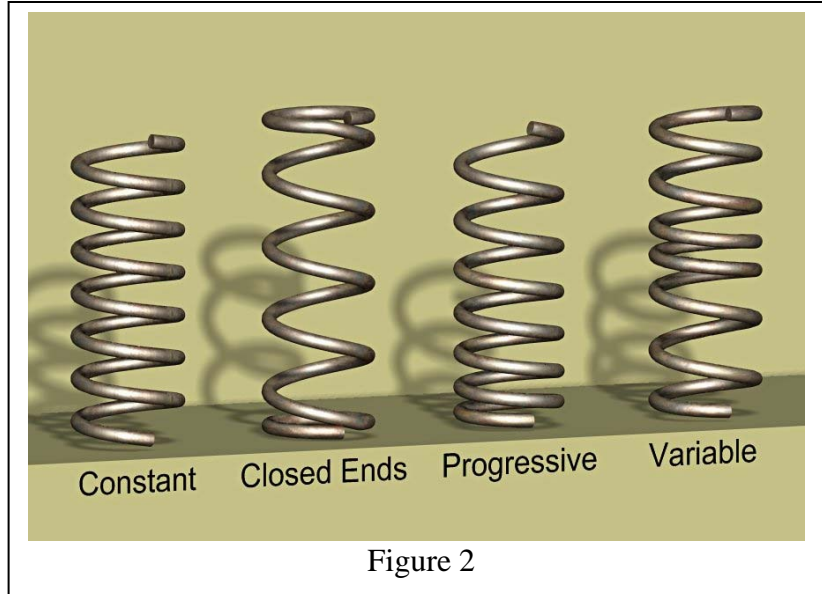


Figure 1

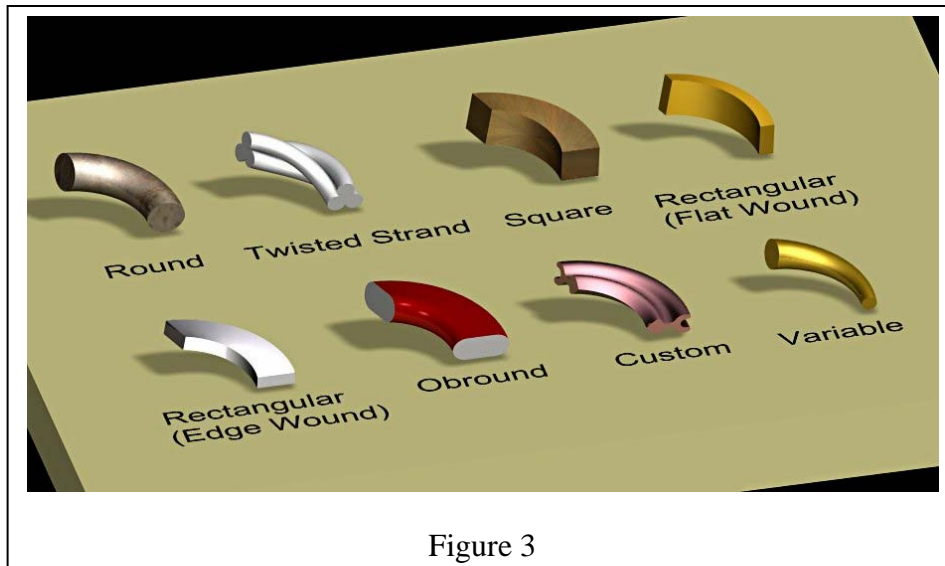
Spring pitch, or “lead”—the distance between adjacent coils—does not have to be constant. This article discusses four different pitch options, illustrated in Figure 2 and listed below.

- Constant
- Closed ends
- Progressive
- Variable



We shall also explain how to draw springs with the different wire cross sections shown in Figure 3:

- Round
- Twisted strand
- Square
- Rectangular
- Obround
- Custom
- Variable



A spring is likely to need some special end design so it can be connected to other components. Some of the most common shapes, listed below and shown in Figure 4, are addressed in the concluding section of this article:

- Off-axis
- Short hook
- Short loop
- Axial hook
- Axial eye
- Long hook

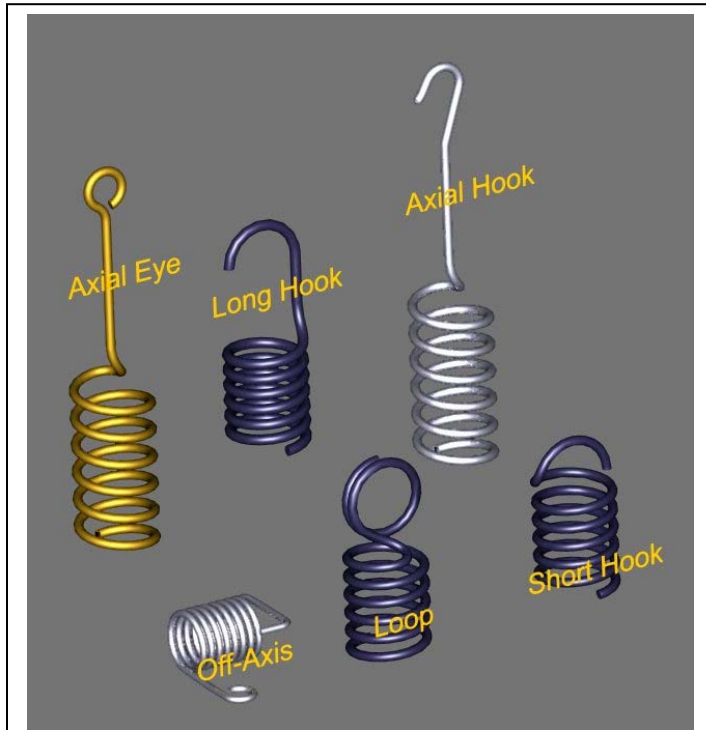


Figure 4

Several of these end designs can easily be incorporated into the spring while it is being drawn, but in most cases a better technique is to model the end fitting as a separate object and then attach it to the basic spring. The final section of this article describes several approaches to the latter alternative.

**C. Program settings.** Some of the procedures explained in this article won't work as described if your program settings are different from mine. The recommended settings are as follows, unless noted otherwise during a particular discussion.

Where to find it	What it's called	Setting
Options>Native Draw	REDSdk	Disabled
Options>Display	"Draw form-building edges"	Disabled
Options>ACIS	Degenerative faceting	Disabled
Options>Acis	Part Tree ("Create editing history")	Disabled

Where to find it	What it's called	Setting
Options>Space Units	Precision	At least 6
Options>Angle	Precision	At least 6
Inspector Bar>Selector 3D Properties	Extents CS	"User CS"
Inspector Bar>Selector 3D Properties	Inspector Bar CS	"User CS"

**D. Modeling tools.** Listed below are the five primary TurboCAD tools discussed in this article. These tools are available in late versions of TurboCAD Pro Platinum. Be aware that lesser versions of TCad may not offer all of these tools, or may not include all of the Pro capabilities of some tools.

1. The TurboCAD *Revolve* tool
2. The TCad *Helix*
3. The *Sweep* tool
4. TurboCAD's *Intersection* tool
5. The *Bend Sheet* tool

*Which tool to use for which spring?* No one of these five basic modeling procedures is the best choice for drawing all possible combinations of envelope shape, spring pitch requirement, and wire shape. Some of them, in fact, are quite limited in their versatility but are nevertheless very well suited for the configurations that they can handle. Sometimes, also, while a particular spring design can indeed be modeled by some particular technique, the procedure might be so tedious or unreliable that it really is not practical. The following outline is intended as a guide for selecting a suitable tool. Under each of the five basic tools is listed the envelope shapes that tool can model, the pitch options available for each shape, and the wire shapes that can be used for each shape and pitch combination.

1. The TurboCAD *Revolve* tool
  - 1.1. Envelope shapes: Cylindrical, conical, volute, or spiral
  - 1.2. Pitch options: Constant only
  - 1.3. Wire shapes: Any wire shape except "variable."
2. The TCad *Helix*
  - 2.1. Envelope shapes: Cylindrical, conical, volute, or spiral.
  - 2.2. Pitch Options
    - 2.2.1. Constant pitch with any of these envelopes
    - 2.2.2. Closed ends with cylindrical or conical envelope
    - 2.2.3. Variable pitch with cylindrical or conical envelope.
  - 2.3. Wire shapes

- 2.3.1. Round or stranded wire with cylindrical, conical, or spiral envelope, and any pitch.
- 2.3.2. Square, rectangular, or obround wire with cylindrical, conical, spiral, or volute envelope and constant pitch; or with cylindrical or conical envelope and closed ends or variable pitch. (Obround wire may have problems.)
- 2.3.3. Variable wire (with constant shape) with cylindrical, conical, or spiral envelope and any pitch.

### 3. The *Sweep* tool

- 3.1. Envelope shapes: Cylindrical, garter, or freeform
- 3.2. Pitch options: All four options
- 3.3. Wire shapes: All shapes except stranded or variable.

### 4. TurboCAD's *Intersection* tool

- 4.1. Envelope shapes: All shapes
- 4.2. Pitch options
  - 4.2.1. Constant pitch with any envelope
  - 4.2.2. Closed-end pitch with cylindrical, conical, hourglass, or barrel envelope
  - 4.2.3. Progressive or variable pitch with cylindrical, conical, volute, hourglass, or barrel envelope
- 4.3 Wire shapes
  - 4.3.1. Round or stranded wire with any allowable envelope and pitch combinations
  - 4.3.2. Square, rectangular, or obround wire with all envelopes except garter and freeform, and with all allowable pitch options. (Obround wire may have problems.)
  - 4.3.3. Variable (constant shape only) with any allowable envelope and pitch combination

### 5. The *Bend Sheet* tool

- 5.1. Envelope shapes: All shapes except freeform
- 5.2. Pitch options: All pitch options
- 5.3. Wire shapes: All wire shapes

## **E. Using the Tools**

### **E.1. The TurboCAD Revolve tool**

Revolving a profile is the easiest way to create a helical spring in TurboCAD. (A 3D object made with the Revolve tool is called a *Spin*, by the way.) The Revolve tool can be used to make a cylindrical helix, a conical helix, a volute spring, or a flat spiral. It works with any shape wire of constant cross section, provided that the wire is not twisted. This tool is not suitable for a barrel, hourglass, or garter spring, or a spring with nonuniform pitch.

### E.1.1. Envelope shapes

#### E.1.1.1. Cylindrical envelope.

Section E.1.1.1.1 describes the basic Revolve technique, which is quick and easy but causes some distortion of the wire cross section. The distortion is slight and probably not objectionable when the spring coils are closely spaced and the helix angle is therefore small, but becomes quite noticeable when the angle increases. Section E.1.1.1.2 explains a way to prevent distortion, at the cost of a little more work.

##### E.1.1.1.1. Basic technique.

Draw the cross section of the spring wire at 1:1 scale. Next to this object (the “profile”) draw a vertical line of any length to represent the axis of the cylindrical helix. The horizontal distance of the line from the center of the profile defines the mean radius of the spring, as indicated in Figure 5. In this example, the wire is round, with a diameter of 0.0625 inch, and the desired outside diameter of the spring is 0.75 inch. Therefore the profile is a circle of 0.0625 inch diameter, and the axis is located .034375 inch from the center of the profile.

Activate the Revolve tool after drawing the profile and the axis. If you’re working with a TurboCAD Pro version, click the Revolve Properties icon, go to the 3D page, and be sure that *Create 3D Object As* is set to “Solid.” Click on the circle when prompted to “Select a 2D entity to revolve.” To specify the revolution axis, vertex-snap on one end of the vertical line, then on the other end. TurboCAD will instantly produce a *torus*, as shown in Figure 5.

To transform this object into a helical spring, double-click on it to open the Properties dialog and go to the Revolution Shape page. Enter the desired values in the *Spiral Pitch* and *Number of Coils* windows. (*Spiral Pitch* is the axial distance between adjacent coils. A positive number will make the spring grow upward from the

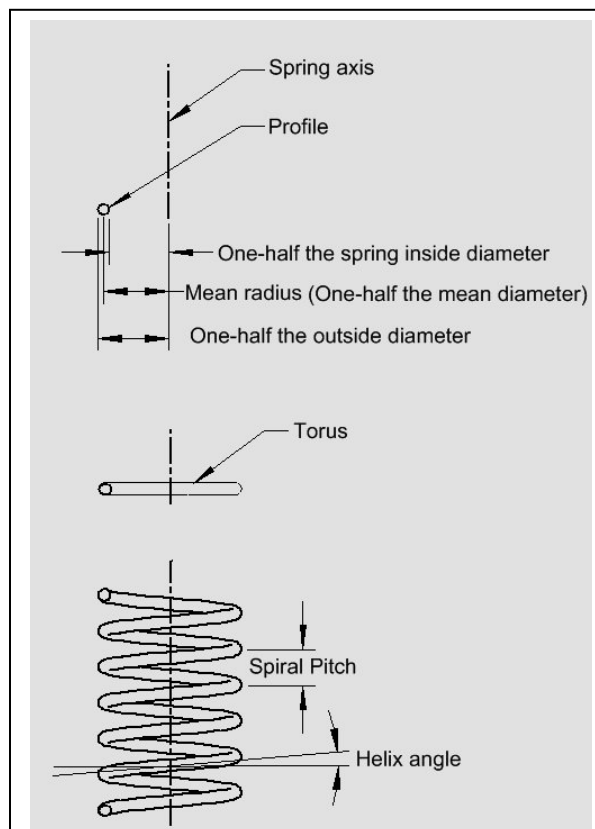


Figure 5

torus.) Click the appropriate radio button if you have a preference between Clockwise and Counterclockwise rotation. Clockwise rotation will produce a right-hand helix when *Spiral Pitch* is positive. Click OK to close the dialog. In Figure 5, *Spiral Pitch* is 0.188 inch, *Number of Coils* is 8, and rotation is Clockwise.

#### E.1.1.1.2. Preventing distortion.

All that's necessary to prevent the cross section from becoming distorted is to tilt the profile so it lies perpendicular to the length of the completed Spin. You can tilt the profile after Revolving it, or before, but the way the tool is used will be a little different for each case.

If you prefer to tilt the profile after Revolving the profile, be sure that "Use compound profile" is enabled *before* Revolving. Then switch to a side view, select the profile, and rotate it as required until it looks to be perpendicular to the Spin. The Spin will update automatically to accommodate the new orientation of the profile.

Tilting the profile before Revolving it is more precise than the eyeball method outlined above but it requires a simple calculation: the required tilt angle is the inverse tangent of *Spiral pitch* divided by 2 times pi times the mean radius of the spring, thus

$$\theta = \text{atan} (p / 2\pi R)$$

Select the profile and then enter this value in the *Rot X* field of the Inspector Bar. (Whether this should be positive or negative depends upon the location of the profile with respect to the Revolve axis and whether Clockwise or Counterclockwise rotation is specified. Use a positive *Rot X* when the profile is located to the right of the Revolve axis and "Clockwise" rotation is specified, or when the profile is to the left of the axis and the rotation is "Counterclockwise." Otherwise use a negative value for *Rot X*.) After enabling the Revolve tool and selecting the profile, be sure to enable the "Select Revolve Axis" option, and click on the vertical line to designate that axis. The result will be incorrect if you designate the revolve axis without having enabled that option.

#### E.1.1.2. Conical envelope.

Proceed exactly as for a cylindrical helix, except that after creating the torus, you must enter a nonzero value in the *Taper Angle* field of the Revolution Shape page. This angle is the taper of one side of the cone, measured from the vertical. A positive value will cause the diameter of the spring to increase away from the torus (making an inverted cone if *Spiral Pitch* is positive). In Figure 6, *Spiral Pitch* is 0.188

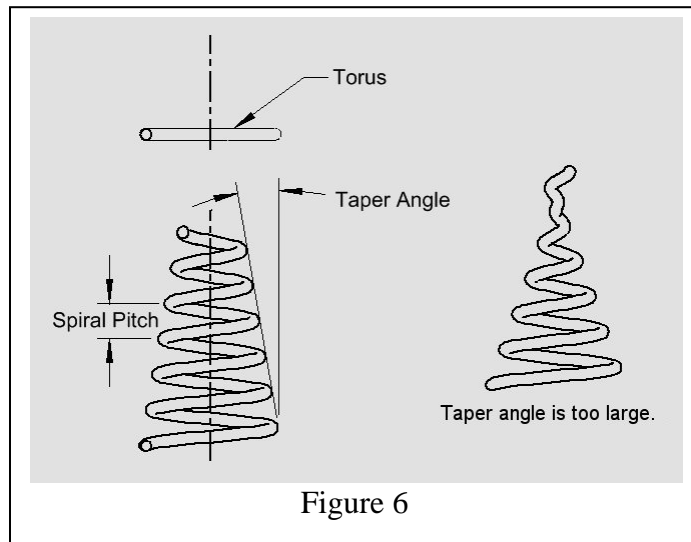
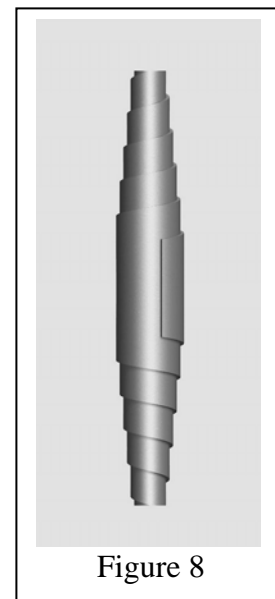
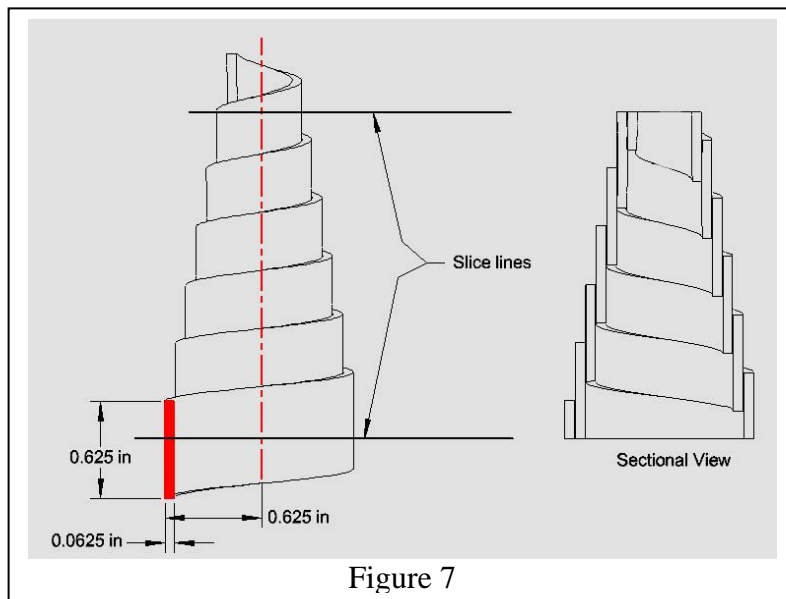


Figure 6

inch and *Taper Angle* is negative 10 degrees. If you specify too great a taper, the resulting object will be misshapen, as shown in the right-hand side of the illustration.

**E.1.1.3. Volute spring.** A volute spring is a conical-helix spring made from strip stock, wound so that successive turns overlap in the axial direction and nearly touch one another in the radial direction. The primary advantage of such a configuration is that it resists buckling when compressed, since the overlapping coils support one another. You can create a volute spring in TurboCAD in the same way you make a conical helix, except that the profile will be a tall, narrow rectangle and the *Spiral Pitch* will be significantly smaller than the height of the profile. Although the required *Taper Angle* can be calculated without much difficulty, you may find it easier to proceed by trial and error, choosing a value that makes neighboring turns almost touch one another. Be aware that unacceptable distortion will occur if the spring is excessively long and narrow. Finish the spring by 3D-Slicing to remove at least one full turn from the top and the bottom.

In Figure 7, *Number of Coils* is 6, *Spiral Pitch* is 0.375 inch, and *Taper Angle* is negative 10 degrees.



After slicing, the object can be rescaled along its axis if you want to make it taller, and you can also extend either end with the Quick Pull tool. If you need a double-ended volute, as in Figure 8, simply make a mirror copy and 3D Add the two pieces

**E.1.1.4. Spiral spring.** A spiral spring (Figure 9) is essentially a volute spring with zero *Taper Angle* and with the “Spiral” option enabled. *Spiral Pitch* is the distance between adjacent turns. The spring will spiral outward from the profile no matter how you adjust the various settings.

## E.2. The TurboCAD Helix

The TCad Helix can be used to draw cylindrical, conical, spiral and volute springs. Round wire, stranded wire, square wire, and rectangular wire shapes can be modeled. The Helix can be used as-is when the spring pitch is constant, or it can be exploded into a 3D spline and the spline edited to create nonuniform pitch.



There are two quite different ways to use a Helix or 3D spline in creating a spring. The traditional procedure is to Rail-Sweep a profile along the path. This works well for a spring fabricated from round wire or from stranded wire, but the inevitable twist in a Sweep makes it unsuitable for other shapes. The second way of using a helical path is to Extrude the path itself, and then to Shell the extrusion. This results in a spring with square or rectangular “wire” having no twist. Section E.2.3 discusses these two alternatives in greater detail.

Four mouse clicks are needed to insert a Helix into a TCad drawing. The first click locates the “helix base point” (the center of the first turn); the second click locates the “helix base radius” (starting point of the curve itself); the third click defines the “helix top radius”; and the last click establishes the “helix height.” It will be helpful later on to know just where the Helix endpoints are, and so the “helix base point” should be snapped to a Grid point and the “helix base radius” to a Grid point directly to the right of the first point. There is no need to be especially careful about placing the third and fourth points, because all of the important characteristics of the object can be edited afterward.

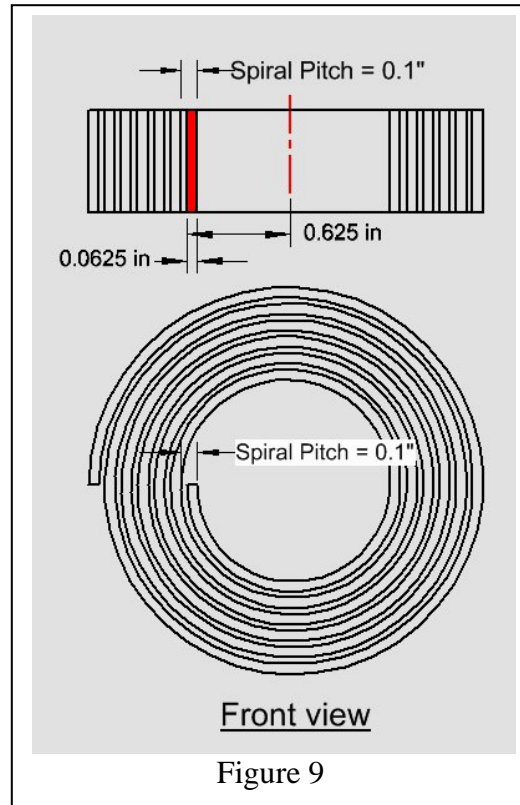
To make the new Helix fit the requirements of a particular spring, open its Properties dialog to the *Helix* page and make the necessary changes. Note that because the overall height of the Helix, the number of turns, and the height of each turn are interrelated, TCad requires that you specify the *Constrain Type*—meaning which of these three parameters shall control the others. For example, if you click the “Turns” radio button, you can enter a value in the *Turns* window and it will not change as you adjust the *Height* and *TurnHeight* values. Editing *Base Radius* and *Top Radius* is straightforward. “Counterclockwise” *Twist Orientation* produces a right-hand Helix when the height is positive.

### E.2.1, Envelope shapes

E.2.1.1, Cylindrical envelope. Specify equal values for *Base Radius* and *Top Radius*. Use the TCad Helix as-is for a spring with constant pitch. For closed ends or variable pitch, explode the Helix and edit the resulting spline as explained in E.2.2.2.1.

E.2.1.2. Conical envelope. *Base Radius* will be different from *Top Radius*, but in all other respects a conical envelope is treated the same as a cylindrical envelope.

E.2.1.3. Volute spring. Use the same Helix parameters as for a conical envelope. Since a volute spring uses rectangular “wire,” using the Helix as a sweep path is not



recommended. Extrude the Helix itself and then Shell the extrusion. Section E.2.3.3 covers this option in greater detail.

E.2.1.4. Spiral spring.

After inserting a Helix into your drawing, set *Top Radius* different from the *Base Radius*, and set *Turn Height* to zero. The result will be a flat spiral. Use this figure as the path for Rail-Sweeping a suitable 2D profile, or extrude it and then shell as explained in Section 2.3.3. If special ends are required, you can explode the Helix and edit the resulting spline before sweeping a profile. Since the Helix or spline is flat in this case, uncontrolled twist does not occur and virtually any shape of profile can be used.

E.2.2. Pitch options

E.2.2.1. Constant pitch. For a spring with constant pitch, simply Rail-Sweep a suitable profile along a TCad Helix, or extrude and shell the Helix itself.

E.2.2.2. Closed ends.

E.2.2.2.1. Cylindrical envelope.

If the spring will have closed ends or variable pitch, the Helix has to be exploded one time, thus creating a 3D spline, and then the spline must be edited. The technique is explained in the following paragraphs, in which the goal is to make the cylindrical, round-wire spring with closed ends shown in Figure 10.

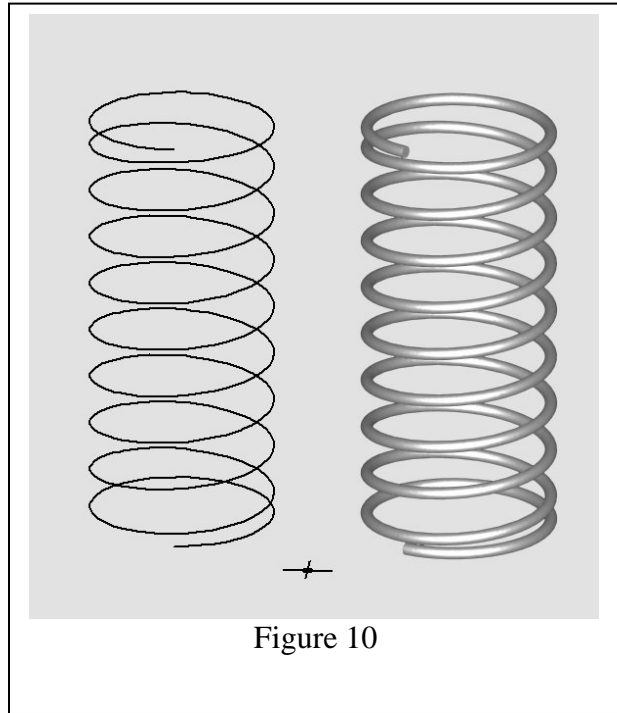


Figure 10

In this example we use a wire diameter of 0.062 inch, an outside diameter of one inch, a turn height (pitch) of 0.25 inch, a total of ten turns, and a right-hand wind. One turn at each end will be closed, which means that the height of each end turn will be made just a hair greater than the wire diameter so that the end coils almost touch. The required TCad Helix has the following properties:

Constrain Type	“Turn Height”
Height	2.5 in
Turns	10
Turn Height	0.25 in
Base Radius	0.469 in
Top Radius	0.469 in
Twist Orientation	“Counterclockwise”

Insert a TurboCAD Helix into the drawing, open its Properties dialog, and set the various parameters as tabulated above. Then explode the Helix one time to make an editable Spline.

*Note:* A peculiar characteristic of an exploded Helix is that very close to each of its two end nodes is a second node, perhaps only 0.001 inch away. These two extra nodes sometimes cause problems with later operations and should be deleted immediately after exploding the Helix. To delete one of these, go to “Right” view, select the spline with the Edit tool, with “Edit Control Points” enabled on the Inspector Bar. Draw a selection rectangle around one of the visible end nodes, as shown in the left side of Figure 11. Zoom in close enough to see that the selection actually comprises *two* nodes. Press and hold the Ctrl key, place the cursor on the inboard node of the pair, and wait for the cursor to display the “Delete node” icon as shown in the right-hand side of the illustration. Click the left mouse button and the selected node will disappear. Repeat this procedure at the other end of the spline.

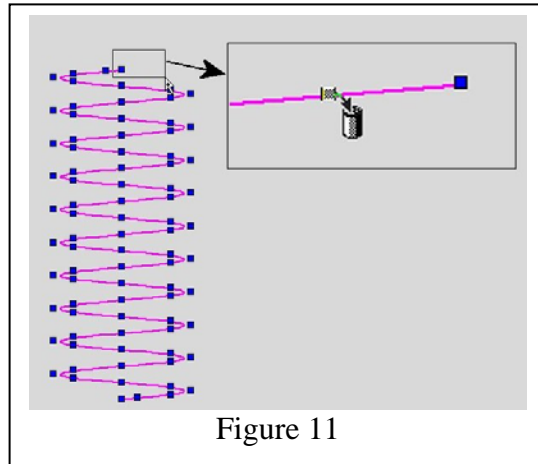


Figure 11

Here’s how to close the upper end of the spline: Select it with the Edit tool and enable both “Edit Control Points” and “Selector Mode” on the Inspector Bar. Switch to a Side view and draw a selection rectangle around the nodes that define the topmost full turn, as shown in Step 1 in Figure 12. In the Inspector Bar, be sure the “Keep aspect ratio” option is *not* enabled and set *Size Z* to a value just slightly greater than the wire diameter; e.g., 0.063 inch in this example (Step 2 in the figure). To fix the kink just beneath the selected nodes, grab the Z axis of the selection box with the mouse and drag it straight down, checking the result and repeating as necessary until the curve looks smooth (Step 3).

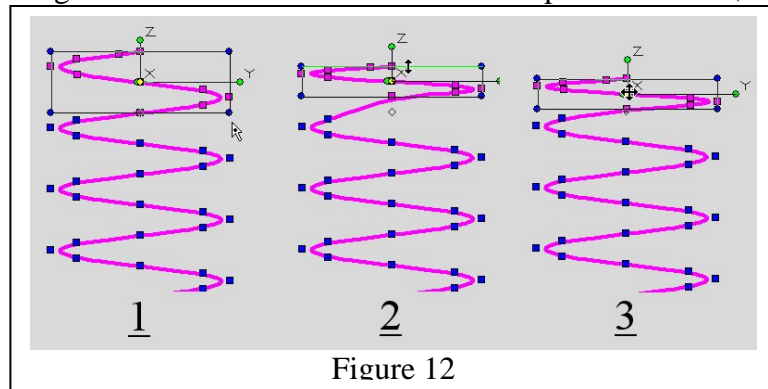


Figure 12

To fix the kink just beneath the selected nodes, grab the Z axis of the selection box with the mouse and drag it straight down, checking the result and repeating as necessary until the curve looks smooth (Step 3).

Close the lower end of the spline the same way.

To finish the spring, draw a circle of the same diameter as the spring wire (0.062 inch) and place a Point object at its center. Rail Sweep the circle along the spline, with “Use compound profile” and “Use compound path” both enabled. (Designate the Point object as the “base point of extrusion” when prompted.)

*Note:* If you see a warning that the object is selfintersecting or invalid and cannot be created, it’s most likely because the end coils have been closed too tightly.

#### E.2.2.2.2. Conical envelope.

We can draw a conical spring in TCad by inserting a conical Helix, then exploding it and editing the result to reduce the pitch of the end coils as explained earlier. However, as Figure 13 demonstrates, the result will not be a true cone. If this is objectionable, the problem can be corrected by additional editing of the spline. It's helpful to work in the Front and Right views, drawing guidelines as shown in Figure 13, then switching to Top view for additional tweaking. Figure 14 shows a corrected version of the spring in Figure 13.

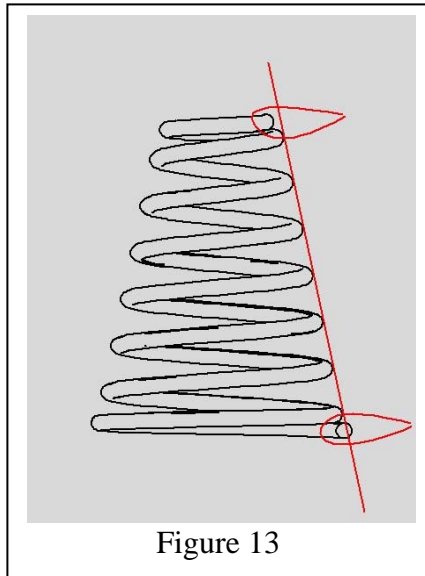


Figure 13

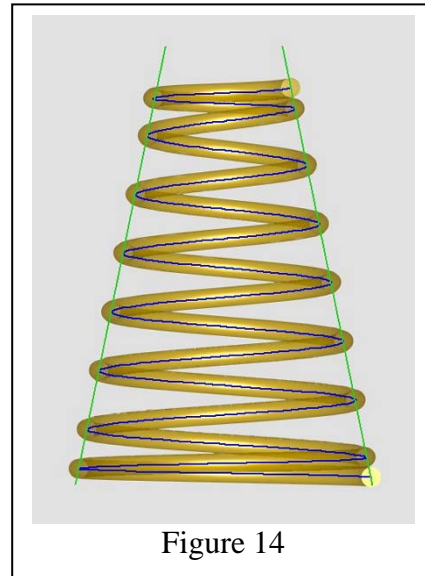


Figure 14

*Tip:* If you Rail-Sweep the profile before doing this additional editing, with “Use compound profile” and “Use compound path” enabled, the Sweep will update each time you edit the path. This provides valuable feedback for judging the accuracy of the path.

E.2.2.3. Variable pitch. If the pitch has to be varied along the length of the helix, simply explode and edit the TCad Helix as required before Rail-Sweeping (or extruding and shelling).

#### E.2.3. Wire shapes

E.2.3.1. Round wire. Rail Sweep a circular profile along the Helix or spline, as described in the preceding examples.

E.2.3.2. Stranded wire. Instead of sweeping several copies of a circular profile along the path and then trying to edit the result, a much cleaner approach is to make a profile in which the circles are merged into a single Polyline. Figure 15 illustrates profiles for 2, 3, 4, 5, and 6 wires of the same diameter.

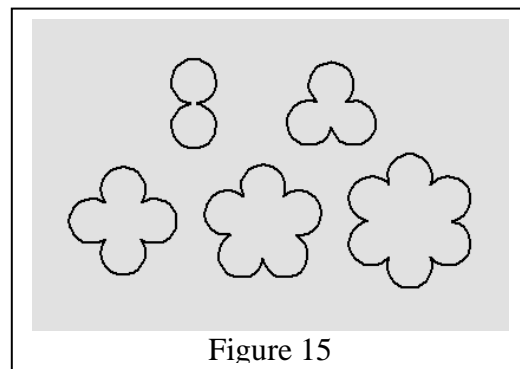


Figure 15

These were drawn by Radial-Copying the profile of a single strand and then combining the copies, using the following procedure:

Draw a circle of the same diameter as a single strand of wire, then place a copy of that circle in the same place and rescale it in the Y direction by the factor given in the following table. (The *Number of copies* here is the number of strands in the wire cross section.)

Number of copies (including the original)	Scale Y
2	0.99
3	1.14
4	1.4
5	1.68
6	1.98

When Radial Copying the original circle, the “center of the arc” will be the bottom *Quadrant Point* of the rescaled circle. After completing the radial copy, delete the rescaled circle, then select all of the remaining circles and apply Format>Create Region. Explode the Region, thus converting it into a set of *arcs*. Select the arcs in the center (see Figure 16) and delete them. Use the Join Polyline tool to combine the remaining arcs into a single Polyline.

When you create and edit a closed-end path for Rail-Sweeping this kind of profile, the pitch of the end coils should be slightly larger than a circle which circumscribes the profile, as a safeguard against the TurboCAD warning about a selfintersecting object. After completing the Sweep, open its Properties dialog and adjust the *Twist Angle* as required (remembering that one complete twist of the profile is 360 degrees).

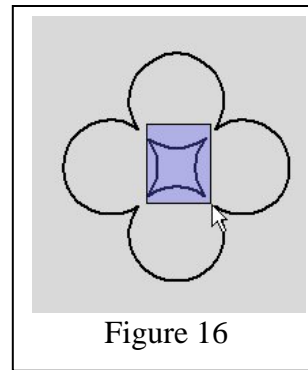


Figure 16

Figure 17 shows a closed-end spring using a three-strand profile of 0.062 inch diameter wire. Outside diameter of the spring is one inch; pitch is .375 inch, total number of turns is 10. The spring is right-hand wound and the profile is twisted 10800 degrees (30 full turns). Since the diameter of a circle that circumscribes the profile is 0.135 inch, the base radius and top radius of the initial helix must be  $[(1.00 - 0.135) \div 2]$ , or 0.4325 inch.

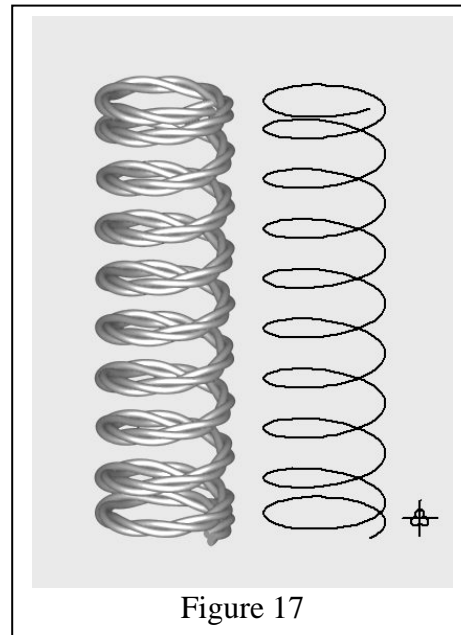


Figure 17

*Note about twist:* Although the difference is usually not noticeable, the actual twist of a Rail Sweep will not be exactly equal to the assigned *Twist Angle*, differing perhaps by as much as several hundred degrees. The reason is that, when the assigned *Twist Angle* is zero, some twist will nevertheless be present. Figure 18 demonstrates this quirk. Even though the assigned *Twist Angle* is zero, you can verify that some twist does

exist by noting that the gray wire lies on the outside of the coil in the topmost turn but has migrated to the inside about halfway down the spring. What's worse, though not obvious in this illustration, is that the actual twist is not uniform along the coil. For this reason it is not possible to remove all of the twist for the entire spring. That's why the Rail Sweep technique is not appropriate for a square or rectangular or obround cross section.

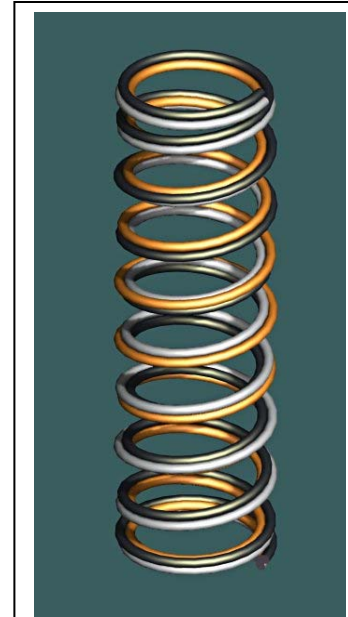


Figure 18

E.2.3.3. Square, rectangular, or obround wire. Since uncontrollable *twist* makes the Rail Sweep tool unsuitable for these wire shapes, we turn to a different way to use the TurboCAD Helix; that is, we extrude the helix itself and then shell the extrusion. This technique may be used with any envelope shape that the Helix tool can produce. To illustrate the procedure, we shall assume a cylindrical envelope with an outside diameter of 1.5 inch, having ten full turns and right-hand wind. Both end coils are closed, while the other eight turns have 0.5 inch pitch. The wire shape is obround, 0.125 inch by 0.25 inch. Anticipating that the extrusion will be shelled inward, the required TCad Helix has the following properties.

Constrain Type	Turn Height
Height	5.0 in
Turns	10
Turn Height	0.50 in
Base Radius	0.75 in
Top Radius	0.75 in
Twist Orientation	Counterclockwise

This Helix is exploded and the two extraneous nodes near the ends are deleted as prescribed earlier, then each of the two end coils is rescaled with the Edit tool so its *Size Z* is 0.126 inch. Since the height of the wire is to be 0.125 inch, we Simple Extrude the spline itself to a Height of 0.125 inch, with "Use compound profile" enabled. (Be aware that TurboCAD might refuse to extrude this object if "Use compound profile" is not enabled.) The extrusion is then shelled to a *Thickness* of negative 0.25 inch. For obround wire, the four long edges of the object are Filleted to a *Radius* of 0.06 inch (just a little smaller than one-half of the wire height). Figure 19 shows the result.

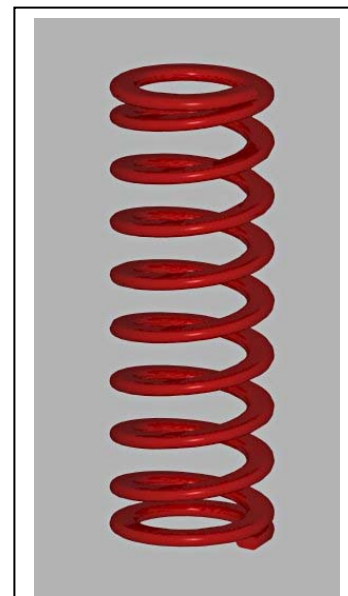


Figure 19

*Note:* One might expect that square or rectangular wire in a spring made with the extrude-and-shell technique could be transformed into hexagonal or octagonal wire by chamfering the edges. In practice, however the program is most reluctant

to perform this operation on such an object. Fortunately there is at least one other method for drawing a cylindrical helix with closed ends using hexagonal wire, or any shape at all, and that is by *bending* a suitable preform. We shall explore that procedure in Section E.5 of this article.

E.2.3.4. Variable cross section. If the spring is produced by Rail-Sweeping a profile, it can be edited to produce a tapered cross section, or one that twists along the length of the sweep, or one that tapers *and* twists. Open the Properties dialog for the Sweep and tweak the *Twist Angle*, *Draft Angle*, *Draft Start Distance*, and/or *Draft End Distance* parameters as required.

### E.3. The TurboCAD Sweep tool.

The Sweep tool behaves differently from Rail Sweep. When you use Rail Sweep, the TurboCAD Genie picks up the profile, places it on the starting point of the path, and creates a 3D object by dragging it along that path, keeping the profile normal to the path along its full length.

“Sweep,” on the other hand, leaves the profile where you put it, then extrudes it parallel to the path to make a 3D object. The traditional way to use Sweep is to orient the plane of the profile normal to the path and then place it directly on the path. Neither the orientation nor the location of the profile has to follow this convention, however. In fact, about the only firm requirement is that the plane of the profile should not be parallel to the path. Trying to Sweep in this case would probably trigger an error message stating that the object is selfintersecting and cannot be created. (Don’t be concerned if you see a message saying that the result might not be *correct*. That’s not an error.)

Figure 20 is a simple example of a Sweep operation, in which a circular profile (red) is swept along a straight path (yellow), creating the pale blue object. The plane of the profile is normal to the path, and consequently the cross section of the Sweep is circular.

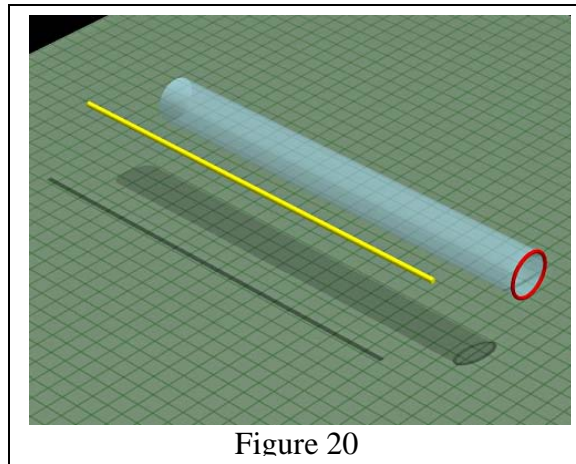


Figure 20

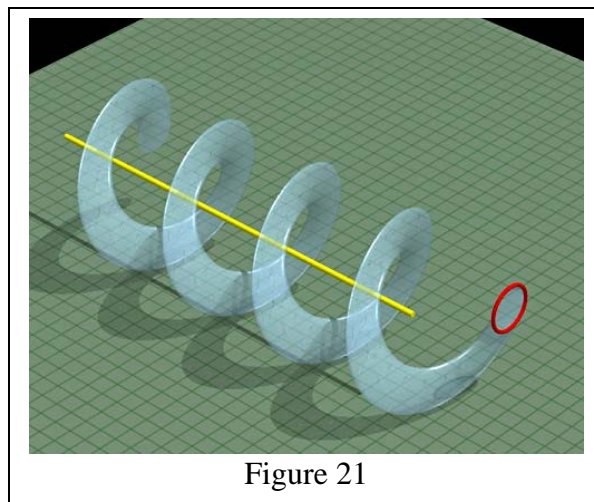
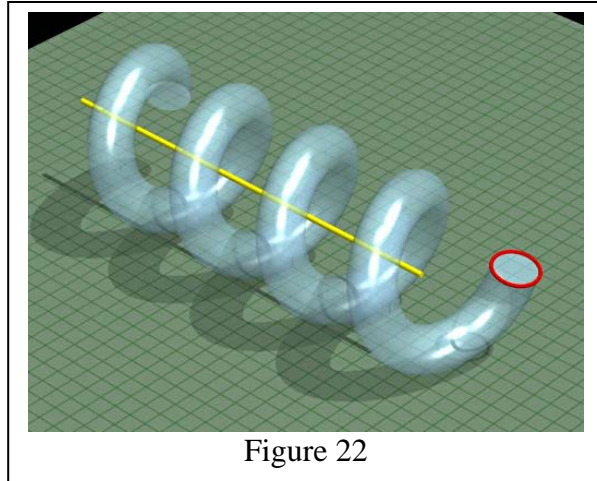


Figure 21

If a nonzero *Twist Angle* is specified, the Sweep will wind around the *path*. In Figure 21, a *Twist Angle* of 1440 degrees (four complete turns) has been applied to this same Sweep.

Notice that the cross section of the Sweep is now badly distorted: it is far from round, even though the profile is a circle.

Fortunately such distortion is easily fixed by tilting the profile so that it lies normal to the Sweep itself. For most purposes, this can be done accurately enough by moving to an edge view of the profile, switching to Workplane by View, and rotating the profile until its tilt looks right. The object in Figure 22 was corrected this way. For a more precise adjustment, tilt the profile beforehand as explained in Section E.1.1.1.2.

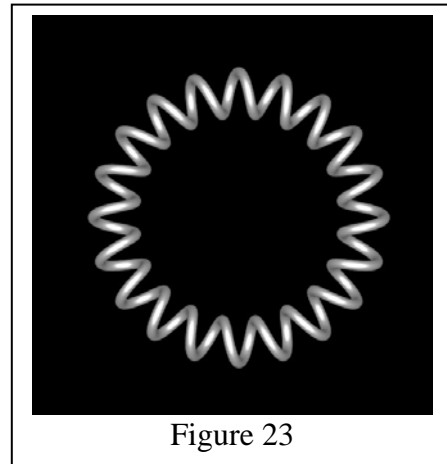


### E.3.1. Envelope shapes. The TurboCAD

Sweep tool can be used to make cylindrical or garter envelope shapes, or freeform shapes if the diameter of the coil is constant.

E.3.1.1. Cylindrical envelope. If constant pitch is needed, use a straight line for the Sweep path. For any other pitch option, please refer to section E.3.2, below. Adjust the orientation of the profile to fix any noticeable distortion of the cross section.

E.3.1.2. Garter spring. Use a full or partial circle for the Sweep path. Adjust the profile orientation as required. If the path is full circle, and the *Twist Angle* corresponds to a whole number of turns, the spring will be endless, as shown in Figure 23. If you need special ends that will hook together, use something less than a full circle path in order to leave space for those ends.



E.3.1.3. Freeform envelope. Use any curve or Polyline for the Sweep path. Path may be 2D or 3D. Be aware that pitch is likely to be nonuniform unless the path is drawn as explained in Section E.3.2, below.

### E.3.2. Pitch options.

#### E.3.2.1. Constant pitch.

Pitch will be constant if the path is a straight line or a full or partial circle, but it probably will not be constant with other kinds of path. If the path is a Spline, spacing of the Sweep coils is likely to vary along the length of the path, bunching together where the nodes of the Spline are close together and spreading apart where the nodes are widely spaced. If such a result is not acceptable, the next few paragraphs explain how to fix it.

*Uniform coil spacing along a freeform path can be expected only if that path is a 2D or 3D Spline by Fit Points, in which the nodes are equally spaced along its length.*



Unless the path is simple and short, It may not be practical to draw it from scratch with uniform node spacing. Instead of trying to draw the curve perfectly the first time, the trick is to do it in two stages. First, make a make a preliminary path without regard to node spacing, editing it as necessary to get the correct shape. Having verified that the shape is correct, trace this curve with a Spline by Fit Points, spacing the nodes uniformly, and then delete or hide the preliminary path. If the curve is fairly simple, you might be able to achieve uniform spacing by eye, but here’s a better way…

Draw a small Sphere someplace in your drawing, and then apply the “3D Pattern on Curve” tool to place copies of the sphere along the preliminary path. Specify a *count of elements* appropriate for the length and complexity of the path—not oppressively numerous but close enough together to define the curve with reasonable accuracy.

TurboCAD will do a good job of spacing the spheres uniformly. Explode the Pattern one time to separate it into a collection of separate spheres. Delete or hide the preliminary path and create a new Spline by Fit Points (2D or 3D, as appropriate), defining its nodes by snapping to the Center of Extents of each sphere in turn.

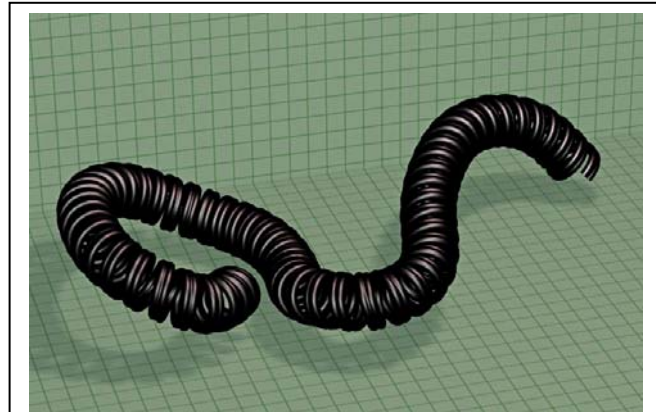


Figure 24

An example of an object created in this way is shown in Figure 24. (This is a coiled power cord, not really a spring.) Path in this example is a 3D Spline. *Twist Angle* is 21600 degrees, or 60 full turns. The turns are uniformly spaced along the axis, naturally spreading on the outside of each bend and crowding closer on the inside.

#### E.3.2.2. Nonuniform pitch.

The secret to Sweeping a cylindrical helix with non-constant pitch is to use a very special kind of path; namely, an almost-straight Spline by Control Points with nodes at carefully controlled locations. Distance between coils will be greater where the nodes are spread out and smaller where the nodes are closer together. Figure 25 shows several examples, in which the Spline node locations are indicated by short blue lines.

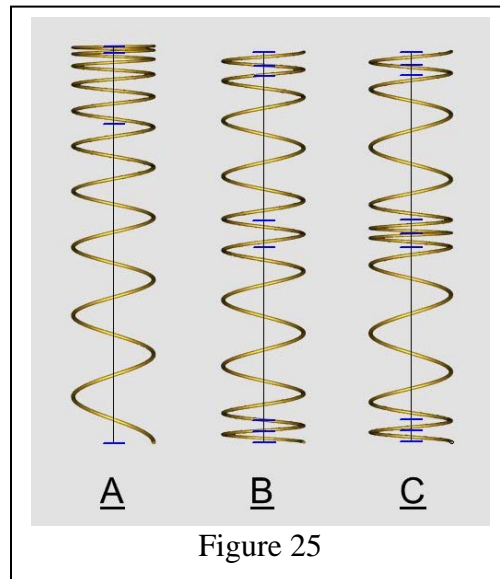


Figure 25

#### E.3.2.2.1. Closed ends.

Making a closed-end spring with the Sweep tool requires a little bit of math plus careful workmanship. For a spring with one closed coil at each end, the total number of nodes in the spline used for the Rail Sweep path must be *three* more than the total number of coils. This number includes a set that contains *one* more than the number of *open* coils, spaced at intervals equal to the pitch of the open coils. The remaining four nodes are placed two at each end, at a spacing that is calculated as explained in Step 2, below. For a specific example, we shall construct a cylindrical helical spring of 1.625 inch outside diameter with ten complete turns, made with 0.125 inch diameter wire, having the two end turns closed and the middle eight turns with a pitch of 0.50 inch. The procedure is as follows.

1. Define the axis of the spring by drawing a vertical line a little longer than the total height of the spring. Draw a short horizontal line across the vertical line, about an inch above its lower end, then Linear-Copy it, setting *Ystep* equal to the pitch of the open coils (0.50 inch in this example) and *Sets* equal to one greater than the number of open coils (*Sets* = 9 in this case).
2. Using the Parallel Line tool, draw a line immediately above and parallel to the topmost of the horizontal lines created in the previous step. Calculate the required *Offset* by subtracting 0.168 times the open pitch (“p”) from the wire diameter (“d”), then dividing the result by 1.732. Thus...

$$\text{Offset} = (d - 0.168 p) \div 1.732$$

...which in this example is 0.125 minus 0.168 times 0.5, all divided by 1.732, or .0237 inch.

*Note:* If this computation yields a zero or negative value for the *Offset*, a different tool should be used to model the spring. Edit a TurboCAD Helix as described in 2.2.2 instead, or use the Bend Sheet tool as in 5.2.

Draw another parallel above this one, using the same *Offset*. Then draw a new parallel *beneath* the lowermost horizontal line with the same *Offset* (remember that a negative sign must be entered before the numerical value to place the new parallel beneath the target). Draw one more parallel beneath the latest one, again with the same (negative) *Offset*. This set of lines (“A” in Figure 26) will serve as the framework for constructing the Sweep path in accordance with the next step...

3. Draw a 2D Spline by Control Points (Spline by Fit Points won’t do the job), carefully using the Intersection snap or the “I” SEKE to place the nodes at the intersections of the vertical line with each horizontal line (in this case, thirteen nodes altogether). Examine the Spline with the Edit tool to verify that each node is accurately placed on an intersection. (“B” in Figure 26.)
4. This new Spline will not work as-is for our purpose, because it’s straight. It has to be bent just a little bit, using the Edit tool. In Edit mode, select one of the middle nodes

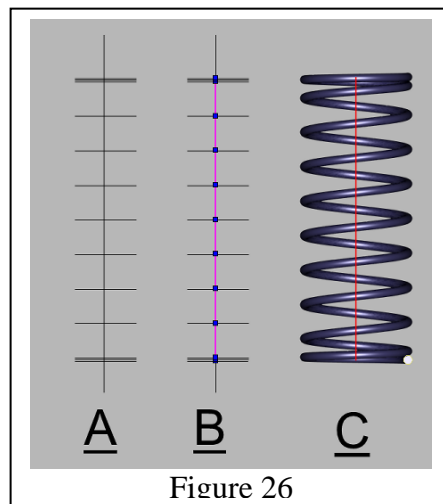


Figure 26

and move it a short distance to one side. How far? If the length of the Spline is ten inches or less, moving one node 0.001 inch is enough. For a length of ten to 20 inches, move a node 0.002 inch—and so on.

5. To create the spring itself, draw a 0.125 inch diameter circle for the profile. Place the profile beside the path, 0.75 inch away. To be sure it will Sweep without triggering the “selfintersecting” warning, the profile must be rotated out of its current plane—but not too far. If the profile is located to the right of the path, rotate it 45 degrees about the X axis; if it’s located to the left of the path, rotate it *negative* 45 degrees about the X axis. Sweep the profile along the path, with “Use compound profile” enabled. Set *Twist Angle* to 3600 degrees. Switch to a side view and adjust the tilt of the profile to make it perpendicular to the Sweep itself. “C in Figure 26 is the finished spring.

Note that since the Sweep tool will work with any constant cross section, this technique can be applied to any profile, as long as its height is consistent with the calculated node spacing on the path.

#### E.3.2.2.2. Progressive pitch change.

As a spring having “progressive” pitch is compressed, the space between the two most closely spaced coils will close, and then the smallest of the remaining open spaces will close, and so on. As the number of remaining open coils becomes smaller, the spring becomes progressively stiffer, requiring ever-greater increments of force for the same increments of compression distance.

The path for a Sweep with progressive pitch is a nearly straight Spline by Control Points with the nodes spaced progressively closer together from one end to the other. A more useful variant of this pitch option has progressively-pitched open coils and closed end coils. The following Section explains how to create it.

#### E.3.2.2.3. Progressive pitch with closed ends.

The spring modeled in this example is nearly identical to the one described in Section E.3.2.2.1, above, except for the progressive pitch. It is a cylindrical helical spring of 1.625 inch outside diameter with ten complete turns, made with 0.125 inch diameter wire, having the two end turns closed. The eight turns in the middle have a pitch that increases from 0.25 inch for the topmost open coil to 0.6875 inch (11/16”) for the lowermost, with each space 0.0625 inch (1/16”) larger than the one above it. Proceeding as in Section 3.2.2.1, we draw a set of short horizontal lines to serve as markers for placing the nodes for the open coils (except that their locations are different), and then add two additional markers at each end to control the closed coils.

1. After drawing the vertical line and the first marker, place a second copy parallel to the marker and 0.25 inch below. Put the third marker 0.3125 inch below the second. Intervals for the remaining six markers should be 0.375”, 0.4375”, 0.5”, 0.5625”, 0.625”, and 0.6875”.
2. Calculate the *Offset* for the two additional markers at the top of this array as in 3.2.2.1, using the spacing of the topmost open coil for “p” in the formula. Thus,  $Offset = (0.125 - 0.168 \times 0.25) \div 1.732$ , or 0.04792”. Place one new marker this

distance above the topmost existing marker, then put a second new one the same distance above the first one.

3. At the bottom of the marker array, use the spacing of the nearest open coil (0.6875) for “p.” The required *Offset* is then 0.00549”. Put a marker this far beneath the lowermost existing marker, then another new one the same distance below that.
4. Draw a 2D Spline by Control Points, carefully snapping to the intersection of each marker with the vertical line. Select the Spline with the Edit tool and verify that the number of nodes is correct and that each node was accurately snapped. Select a node near the middle and apply a *Delta X* of about 0.001 inch.
5. Draw the spring itself just as in the earlier example: Place a 0.125” diameter circle near the bottom of the vertical line and 0.75” to its right and rotate the circle 45 degrees about the X axis. Sweep the circle along the Spline and specify a *Twist Angle* of 3600 degrees. Finally, switch to a side view and adjust the tilt of the circle to make it perpendicular to the Sweep. Figure 27 shows the completed spring. (The lowermost three markers are too close together to be visible as separate entities.)

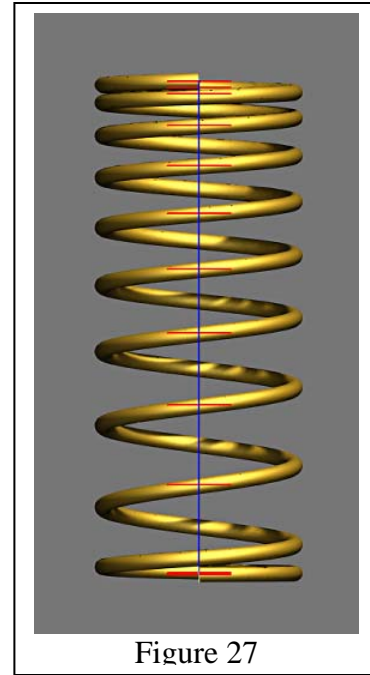


Figure 27

E.3.3. Wire shapes. Any shape profile within reason can be used, except stranded or variable. (Even though the cross section of the Sweep can be tapered by adjusting *Draft Angle*, *Draft Start Distance*, or *Draft End Distance*, the result is likely to be an unpredictable change in the number of turns or the overall height, or both.)

E.4. TurboCAD’s Intersection tool. The Intersection tool (not to be confused with 3D Intersect!) provides a somewhat exotic way to create a helical or quasi-helical 3D Spline. The techniques described in this section can create any of the eight envelope shapes depicted in Figure 1. The basic procedure is to create two different 3D objects and then apply the TurboCAD Intersection tool in order to create a 3D spline that traces their intersection. The first 3D object, which we shall call the “twist template,” defines the pitch of the spring being modeled. It is made by Rail Sweeping a straight-line profile along a suitable path and applying a *Twist Angle* to the Sweep. The second 3D object, the “mold,” defines the envelope shape, and it must be embedded in the Rail Sweep before using the Intersection tool. The resulting spline can be used as a path to Rail Sweep a suitable profile, or it can be extruded and shelled if the envelope shape is appropriate.

E.4.1. Envelope shapes.

E.4.1.1. Cylindrical envelope.

E.4.1.1.1. The first 3D object (the twist template).

For the Rail Sweep path, draw a vertical line equal in length to the desired height of the helix. For the profile, draw a horizontal line whose length is a little greater than the desired radius of the helix. Snap a Point object to one end of the second line. (See “A” in Figure 28.)

Rail-Sweep the horizontal line along the vertical line, with “Use compound profile” and “Use compound path” enabled. Apply a *Twist Angle* equal to the desired number of turns multiplied by 360. The Sweep is “B” in Figure 28.

E.4.1.1.2. The second 3D object (the mold).

The mold does not have to be a filled-in “solid” object, since the Intersection method will work just as well with a zero-thickness sheet. An easy way to create the cylindrical mold needed here is simply to Revolve a profile that consists of a single line. Draw a second vertical line somewhat longer than the desired height of the anticipated Spline, making its distance from the first vertical line (the one used as a Sweep path) equal to the radius of the Spline. Revolve this second vertical line about the first one, thus creating a hollow cylinder. The line is colored blue in Figure 28 “C” and “D.”

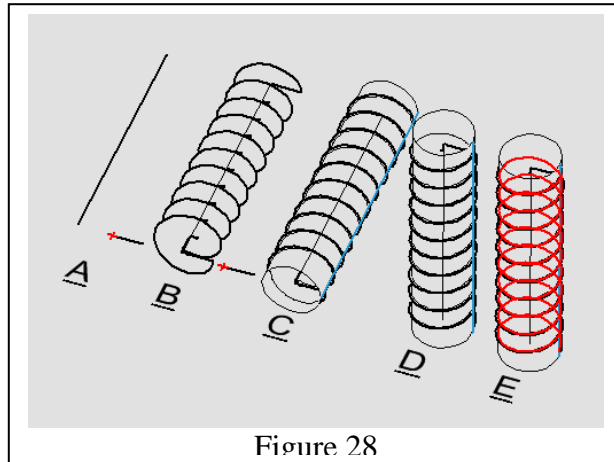


Figure 28

E.4.1.1.3. The Spline.

Although this next step might seem arbitrary, problems can easily arise later on if it’s neglected: Select both the cylinder and the Sweep (you can include the three lines and the Point, too, but you don’t have to), then enter **90°** in the *Rot X* field of the Inspector Bar, and press Enter. (Figure 28 “D.”)

Activate the “Intersection” tool (not “3D Intersect”). Click on the cylinder, then on the Sweep. The result will be a 3D spline, as shown in red in Figure 28 “E.” This spline can be used as a Sweep path, or it can be extruded and shelled. *If you fail to rotate the cylinder and Sweep as in Step (4), it will not be possible to extrude the resulting spline correctly.*

E.4.1.2. Conical, Hourglass, and Barrel envelopes.

Use exactly the same procedure as for a cylindrical envelope, except that the profile used for the mold should be an inclined straight line (for a cone), or an arc or curve. Figure 29 shows the

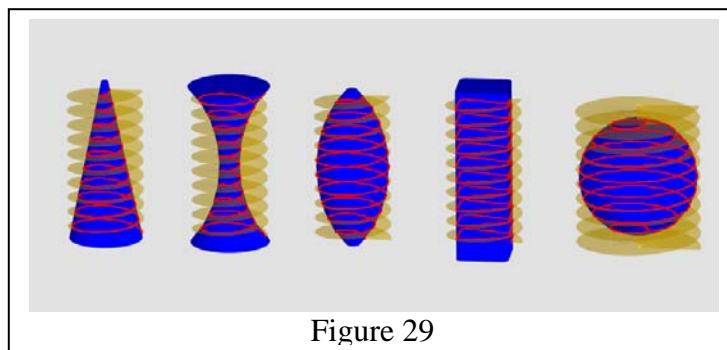


Figure 29

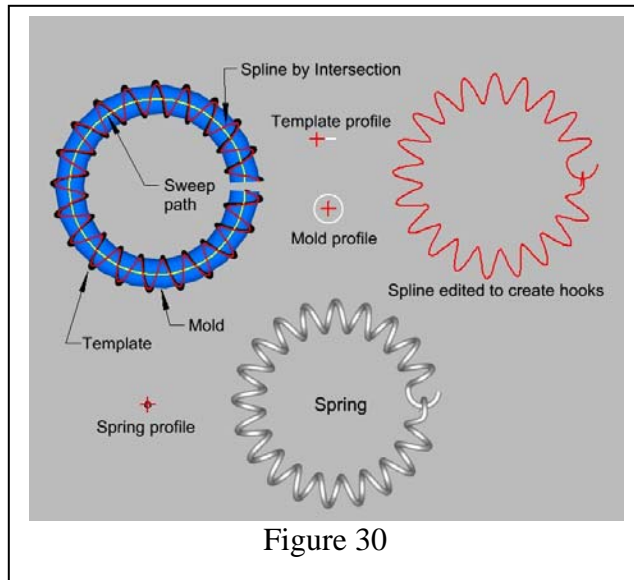
result of intersectioning identical twist templates with five differently shaped molds. (In the next few pages you'll see the term "intersection" used as a verb now and then. That's to avoid confusion with "3D Intersect," which is a different tool altogether.)

#### E.4.1.3. Volute and Spiral springs.

Draw the twist template by Rail-Sweeping a straight line along a straight-line path. Use a cone for the mold, then apply the Intersection tool to produce a 3D spline. To make a volute spring, extrude the spline and then shell the extrusion. To draw a flat spiral spring, set the *Size Z* of the spline to zero. Then, for flat wire or strip stock, extrude the flattened spline and shell the extrusion. For other wire shapes, Rail-Sweep a profile using the spline as the path. (When the path is flat, uncontrolled twist does not occur and so any reasonable shape can be used for the profile.)

#### E.4.1.4. Garter spring.

Figure 30 shows a garter spring created with the Intersection method. To draw such a spring, use a circular arc—not quite a complete circle—for the Sweep path. For the twist template, the profile should be a straight line a little longer than the tube radius of the garter. Rail-Sweep it along the path and set the required *Twist Angle*. (If you intend to make interlocking hook ends as shown in the figure, leave an adequate gap in the path and use a *Twist Angle* for a whole number of turns plus and additional 90 degrees.)



For the mold, create a torus by Rail-Sweeping a circle along the circular arc. (Making your own torus is better than using TCad's own Torus tool because your spline will have fewer nodes therefore be easier to edit if necessary.) Intersection this object with the first Sweep to make a 3D spline.

If you want interlocked hook ends, edit the spline as shown in the figure. Rail-Sweep a circle along the spline to make the finished spring.

#### E.4.1.5. Freeform envelope.

Almost any line, arc, or curve—2D or 3D—can serve as the path for making the twist template, and almost any 3D shape can be used as a mold. The path should lie entirely within the mold, and the mold should lie entirely inside the twist template.

#### E.4.2. Pitch options.

Pitch is understood to be the distance between adjacent coils of the spring or the 3D Spline. Moreover, it usually refers to the distance between adjacent coils, as measured *along the spring axis*. This is *axial pitch*. (The axis of a spring created by the Intersection method is the entity used for the Sweep path.) In the case of a volute spring or a flat spiral

spring, however, the distance between adjacent coils as measured in a plane *normal to* the spring axis is significant. This distance is *radial pitch*. Since radial pitch is a defining parameter for volute springs and flat spirals, we shall discuss it separately from axial pitch in Sections 4.2.1 and 4.2.2, below.

#### E.4.2.1. Axial pitch.

Axial pitch variation in the spline created by the Intersection method is exactly the same as the variation in Twist Angle that one sees in the first 3D object—the one created by Rail-Sweeping a straight line along a path. If the path is a straight line or a circular arc, there is no variation and the final spline will have constant axial pitch; but for other kinds of path, the pitch will be nonuniform unless special procedures are followed. (The procedures for assuring constant pitch and for introducing controlled variation in pitch were discussed in Section 3.2.)

#### E.4.2.2. Radial pitch.

This parameter is usually of interest only with a volute spring or a flat spiral, both of which use a spline created with a mold that is more or less conical. For any given twist template, the radial pitch of the spline depends upon the slope of the mold: a steep slope results in a relatively small radial pitch (i.e., closely spaced coils), and a shallow slope causes a relatively large radial pitch.

It is therefore possible to make a spiral with nonuniform pitch by intersectioning it with a mold that

has nonuniform slope. Such a mold is easy to create by Revolving something other than a simple straight line. Figure 31 shows the results of intersectioning three different mold shapes with identical twist templates.

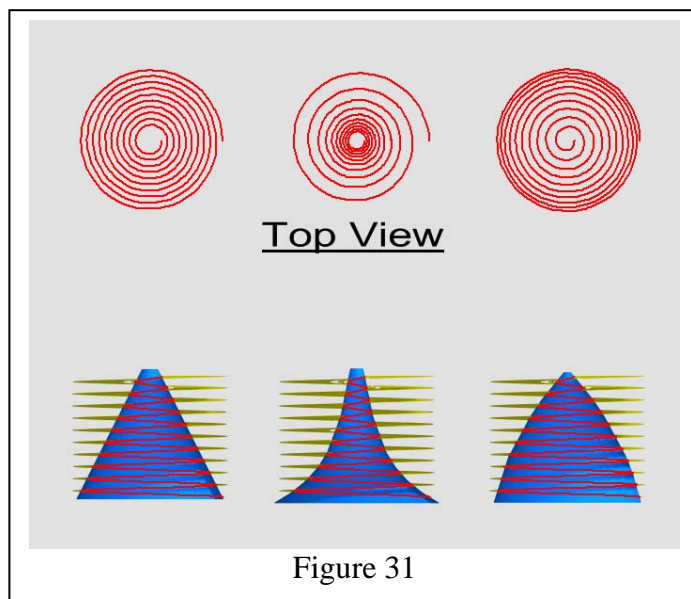


Figure 31

#### E.5. The Bend Sheet tool

Although it is normally used for sheet metal designs, TurboCAD's Bend Sheet tool is also capable of making helical springs with any shape of wire and with any pitch, either constant or variable. (Bending a wire in TCad will distort its cross section a little, but usually not enough to notice.) Furthermore, with a bit of extra effort, one can use this tool to create non-cylindrical helical springs, such as conical, barrel, hourglass, or less conventional envelope shapes.

*Important note:* Unless specified otherwise, the various TurboCAD operations described in this Section are performed while working in the default World coordinate system and in World Plan view.

Because spring-making is not a traditional application for Bend Sheet, I have provided Figure 32 in an attempt to illustrate how and why this tool can do the job. The picture demonstrates that a straight *preform* can be bent around a *bend line* to produce a helicoid. The task requires a flat face on the preform and a bend line on that face. Details of the process are explained in the following paragraphs.

- The object to be bent (the *preform*) must have a flat face—we'll call it the “bend face”—and the bend line must lie on that face. If the object does not naturally have a flat face, you must create it. In the examples discussed herein the bend face will be created by 3D-Subtracting a tiny 3D Box from the object. The bend face is colored yellow in Figure 32.

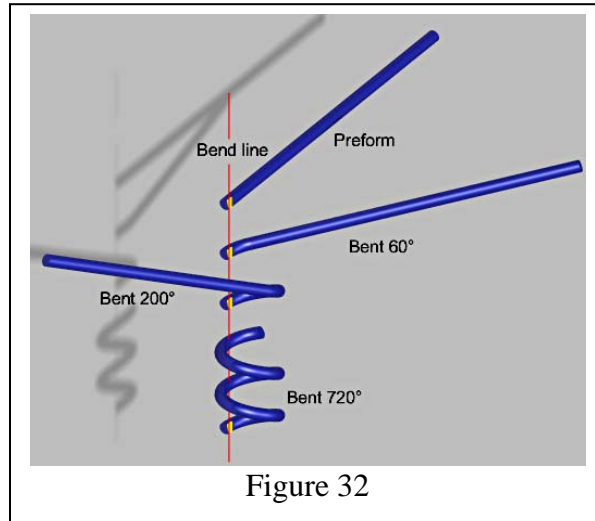


Figure 32

It need not be this large—it can even be invisible at a comfortable zoom level—but it has to be there. We shall assume in this Section that the bend face is parallel to the World XY plane and the bend line is parallel to the World Y axis.

- Except in the special case of a flat spiral spring, the long axis of the preform should *not* be normal to the bend line. Axial pitch will be proportional to the slope of the preform as viewed in the World Plan view: the steeper the slope, the more widely spaced the coils will be. If the slope is too small—that is, if the preform is too nearly horizontal—the coils will overlap when the object is bent and the object will self-intersect.
- The *Angle* parameter is used to specify the desired number of turns, at 360 degrees per turn. If the object happens to be too short for the requested number of turns, it will be bent without triggering an error, but the number of turns will be less than specified. If it's too long, part of it will remain unbent.

Since axial pitch is proportional to the slope of the preform, it follows that a spring with variable pitch can be modeled by bending a preform that has variable slope; i.e., one that is curved. Section 5.2 explores this option in detail.

The object in Figure 32 was created with no attempt at precise control of the pitch variation. But if tight control is required, it will be necessary to follow the rather exacting guidelines set forth in Section 5.2.

#### E.5.1. Envelope shapes.

##### E.5.1.1. Cylindrical envelope.

To create a cylindrical helical spring using Bend Sheet, one should be familiar with the principles of helix geometry diagrammed in Figure 33.



The preform used to create a cylindrical envelope with constant pitch is a straight object, with its axis in the World XY plane and neither parallel nor perpendicular to either axis. It is typically drawn by Rail-Sweeping a 2D profile along a straight-line path.

When creating a cylindrical spring, you will already know the desired mean radius, the required number of turns, and the axial pitch. The Plan view of Figure 33 shows how these parameters determine how the sweep path is drawn. Note that the required *Height* of the sweep path is equal to the pitch multiplied by the number of turns and the *Width* of the path is  $2\pi$  times the mean radius times the number of turns.

After drawing the preform, the next step is to establish the bend face and the bend line. Start by creating a 3D Box—rather small, with each dimension comparable to the cross section of the preform. Zoom in for better control and move the Box with the mouse so that its right-hand side barely encroaches upon the left-hand end of the preform. (Please see Figure 34.) Switch to Front view and verify that the bottom face of the Box is in the same plane as the sweep path, and then 3D-Subtract it from the sweep.

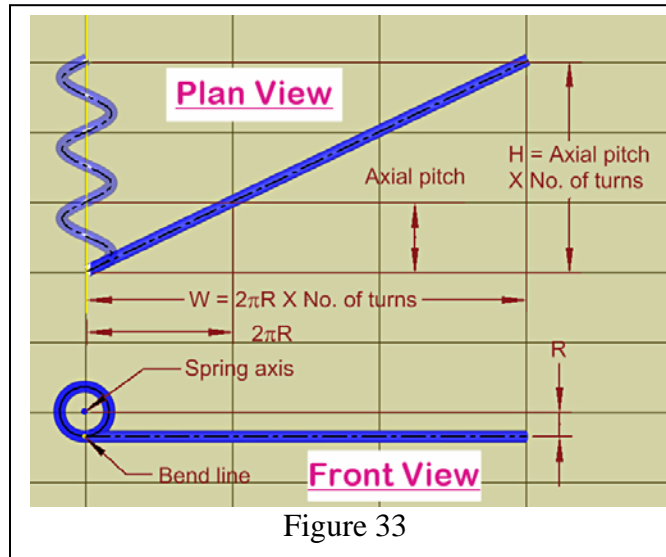


Figure 33

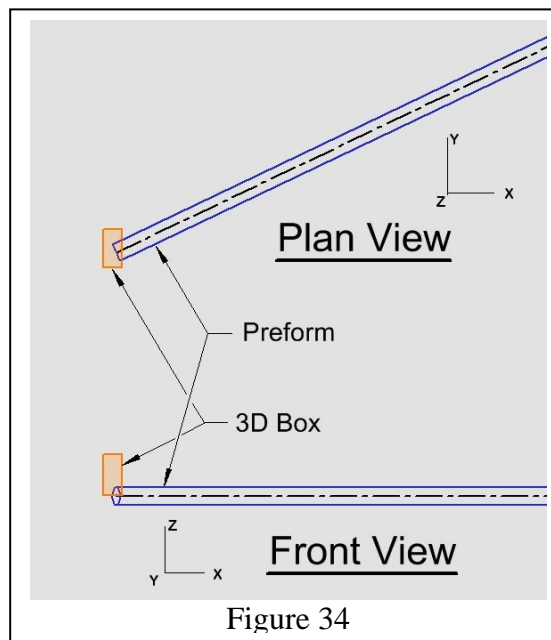


Figure 34

*Note.* If the bend face created by the foregoing method looks like an unsightly blemish on the part, the procedure can be modified somewhat to do the job without visible damage. Draw a 3D Box as before, but this time make its Y and Z dimensions considerably smaller than the cross section of the preform. Once it is positioned as explained above and then 3D-Subtracted from the preform, the bend face will be completely *inside* the latter. The program will accept this without complaint, but you will have to zoom in and switch your viewpoint to be sure that the correct face is selected when placing a bend line and when using the Bend Sheet tool.

To establish the bend line, switch back to World Plan view and draw a vertical line (i.e., parallel to the Y axis) anywhere in the drawing. Select this line and snap its Reference

Point to the endpoint of the sweep path. This new line will be the bend line. (Please see Figure 35.) To verify that the bend line is really on the bend face, establish a new Workplane by Facet, designating the bend face as that facet, then select the bend line and be sure that its reported *Pos Z* is zero. The closeup view in the figure shows the correct relationship between the preform, the sweep path, the bend face, and the bend line.

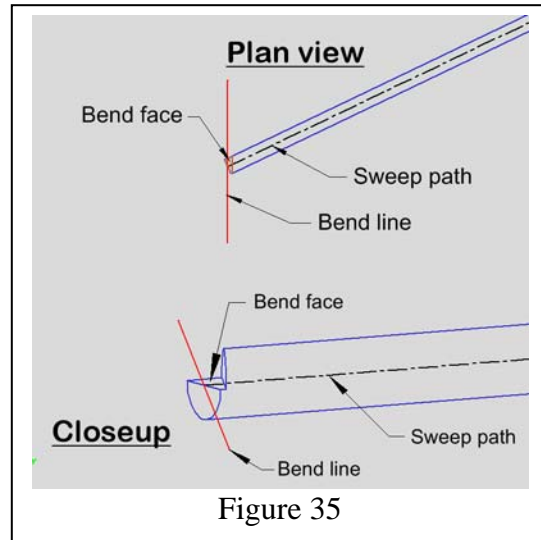


Figure 35

To transform the original preform into a coil spring, activate Bend Sheet and click on the bend face. After verifying that the correct face is selected—it will be highlighted in green—click on the bend line. The preform will be bent immediately, using whatever parameters happen to be shown in the Inspector Bar, and a preview of the bent shape will be displayed in magenta. The preview will update each time you change one of the parameters and press Enter, but the operation will not actually be completed until you click the *Finish* icon. If changes have to be made before finishing, press the TAB key to access the required field. The following paragraphs explain what these parameters actually mean.

*Radius* is the bend radius as measured from the bend face in the World Z direction. In Figure 36, the bend face is yellow and the bend line is red. (The *bend axis* is an imaginary straight line, colored white in the illustration, that lies at the center of the bend and is parallel to the bend line.)

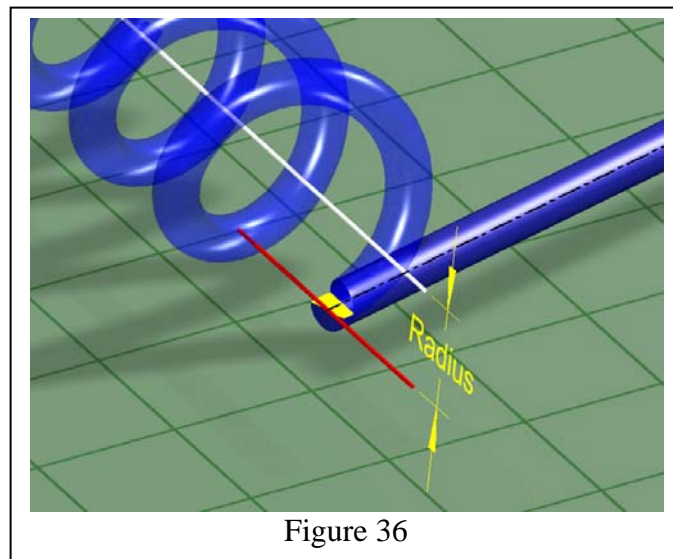


Figure 36

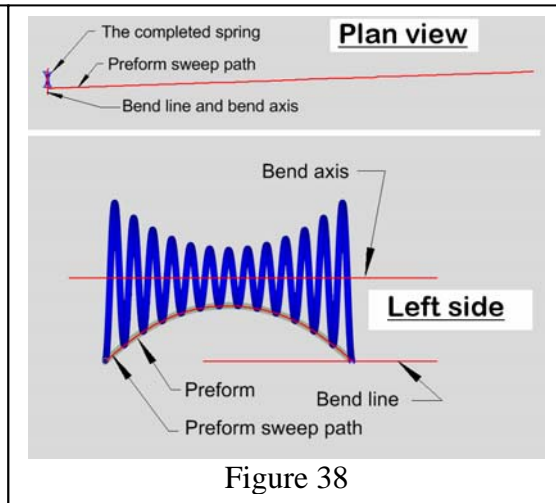
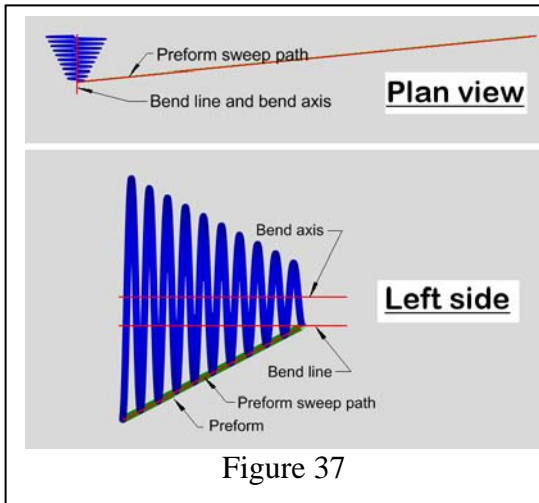
In the *Angle* field, enter a value at least equal to the desired number of turns multiplied by 360.

Enter a value of zero for *Neutral depth*. This parameter establishes the distance from the bend face to the *neutral axis*, which is an imaginary longitudinal fiber in the preform that does not become longer or shorter when the object is bent. When the bend face and bend line are in the same plane as the sweep path, the specified *Neutral depth* should be zero. This makes the length of the bent part equal to the length of the preform.

Having entered the necessary values for *Radius*, *Angle*, and *Neutral depth*, ignore the *Dist from edge* window. Disable the *Left side* option and enable the *Start* option.. Click the *Finish* icon when the preview looks correct.

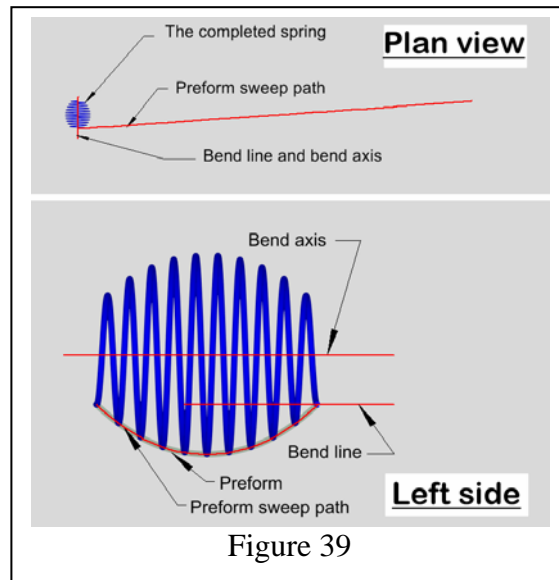
E.5.1.2. Conical, hourglass, and barrel envelopes.

The means for controlling the envelope shape of a bent object is based upon the evident fact that the distance from the bend axis to any point in the bent object depends upon the location of that point in the preform. Thus, all points in the preform that lie in the plane of the bend face will be at distance equal to *Radius* from the bend axis. Points in the preform located above the bend face (that is, in the positive Z direction) will be closer to the bend axis than the value of *Radius*, and points below the bend face will be farther from the bend axis. It follows that if the preform is tilted or curved so that some of it lies above or below the bend face, the envelope shape of the bent object will be something other than cylindrical. In fact, *the envelope shape of the bent object corresponds exactly to the shape of the preform's sweep axis as seen in a side view*. This rule is demonstrated in Figures 37, 38, and 39, which show the plan view and the Left side view (at different scales) of the preform and the bent object for each of these three envelopes.



It should be noted that the conventional definition of *Neutral depth* does not apply when bending preforms like these. Bend Sheet will not create an acceptable result unless a value close to zero is used. Consequently, since the radius of the bent part is not constant, the total length of the bent part probably will not be equal to the length of the preform. But the *Neutral depth* parameter is often useful anyway, because the endpoint of the final coil can be adjusted by tweaking *Neutral depth*, a few thousandths of an inch at a time, until the preview looks right.

The sweep path for a conical envelope is simply a straight line. Draw it in World Plan view, with its X dimension equal to



$2\pi$  times the *Radius* parameter times the number of turns. Make the Y dimension equal to the desired total height of the spring. Move the Reference Point of the line to the left-hand end and rotate it about the World Y axis until its orientation in the Left side view matches the desired envelope shape. Rail-Sweep a profile along the path, create a bend face and a bend line in the World XY plane, and apply the Bend Sheet tool.

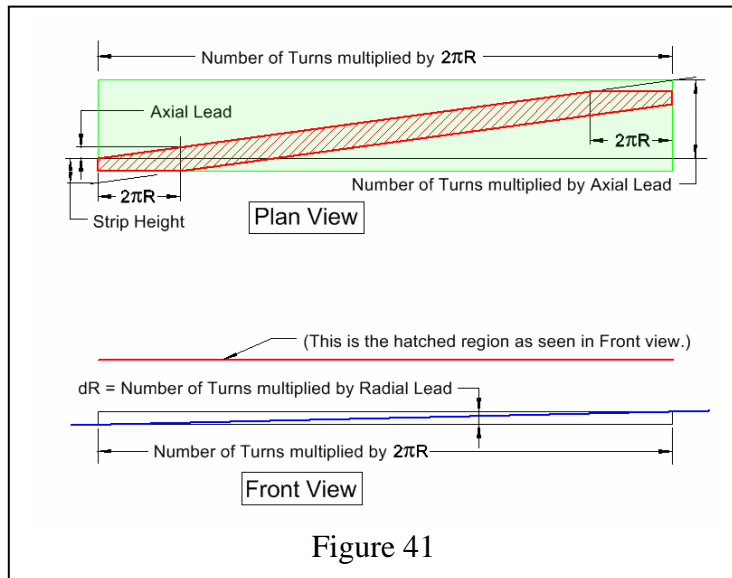
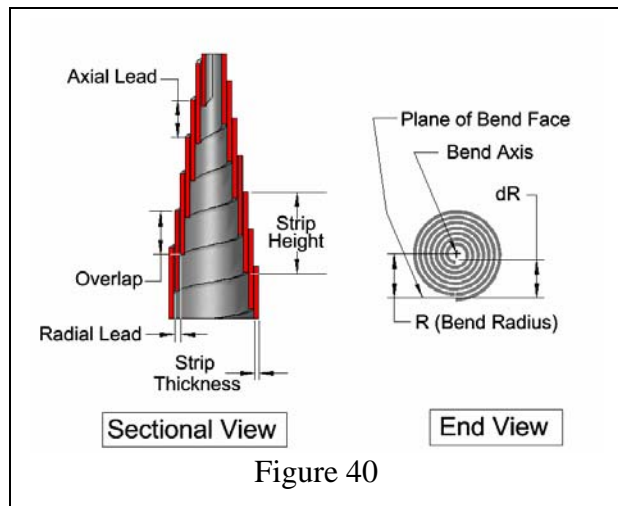
For an hourglass or barrel envelope, perhaps the most satisfactory way to create the sweep path is first to draw a straight line in the World Plan view, with its X and Y dimensions determined as for a conical envelope. Then trace this line with a 3D Spline by Control Points. Switch to a side view and select the Spline with the Edit tool. Enable “Edit Control points,” and lock the Delta X field to guard against distorting the plan-view shape of the Spline. Edit the Spline as required to make the desired hourglass or barrel envelope shape. Rail-Sweep a profile along this curve, then establish a bend face and bend line in the World XY plane.

E.5.1.3. Volute spring.

Drawing a volute spring using Sheet Bend involves more work than the methods described in earlier Sections, but the process causes little or no distortion and is considerably more versatile than any of the other techniques.

An example of a volute spring created as explained in the following paragraphs is shown in Figure 40. We assume that the required number of turns is 7; the bend radius is 0.5 inch; axial lead is 0.5 inch; strip height is 1.0 inch; strip thickness is 0.06 inch; and radial lead is 0.0625 inch.

The preform is made by 3D-Intersecting two separate extrusions, one profile created in the default World Plan view and World coordinate system, the other profile drawn in Front view using Workplane by Active View. These two objects, illustrated in Figure 41, are created as follows...



In World Plan view and the World coordinate system, begin the construction by inserting a rectangle into the drawing. Make its width equal to the number of turns in the spring, multiplied by the Radius, multiplied again by  $2\pi$ ; and make its height equal to the number

of turns multiplied by the axial lead, with the strip height added to this product. With the parameters listed above, the width should be  $(7 \times 0.5 \times 2 \times 3.14159)$ , or 21.991 inches, and the height should be  $(7 \times 0.5 + 1.0)$ , or 3.5 inches. Using this rectangle as a guide (the green rectangle in Figure 41), draw the first extrusion profile as a 2D Polyline in accordance with the dimensions given for the hatched red area in the Plan View of the illustration.

Switch to Front view and Workplane by Active View. The objects already drawn in the Plan view will appear as a line. Directly below this line, draw a rectangle of the same width as the previous one (number of turns  $\times$  Radius  $\times 2\pi$ ), and make its height equal to the number of turns multiplied by the radial lead. For the current example, the required width is 21.991 inch and the height should be  $(7 \times 0.0625)$ , or 0.4375 inch. Draw a single line from the lower left corner of this rectangle to the upper right corner, then use the Line Length tool to extend both ends a little beyond the rectangle. This single line (the blue object in the figure) will serve as the profile for the second extrusion.

Switch back to World Plan view and World CS, and extrude this second profile far enough to lie completely beneath the first profile. (Move the profile and the extrusion in the Y direction if necessary.) Shell the extrusion to a Thickness equal to the *negative* of the strip thickness (negative 0.06 inch in this example).

Shift to an isometric view to make things easier to see (Figure 42) and then extrude the first profile, with “Two sided extrude” enabled, and make the height great enough to intersect the first extrusion. Activate the 3D Intersect tool and create the Boolean intersection of the two extrusions.

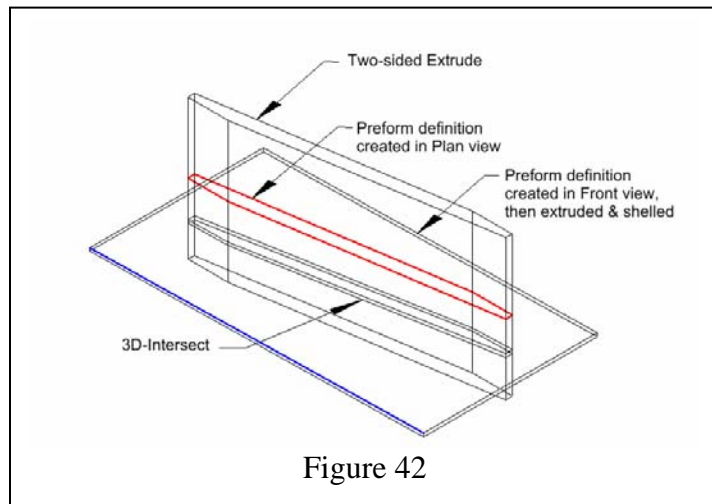


Figure 42

Finish the preform by making a bend face on the left-hand end of the upper surface. Create the bend face by subtracting a tiny 3D Box from the upper surface, sinking the box only deep enough to barely dent the object. In World Plan view, draw the bend line as close to the left end of the preform as possible (say 0.001 inch inboard of the end). Establish a Workplane by Facet, designating the bend face as the facet, and adjust the Z position of the bend line so it lies on the bend face.

Apply the Bend Sheet tool to the preform, with *Angle* at least 2520 degrees ( $7 \times 360$ ) and *Neutral depth* set to zero.

#### E.5.1.4. Spiral spring.

To construct the preform for a flat spiral spring, switch to Front view and Workplane by View. Insert a rectangle whose width is equal to the number of turns multiplied by *Radius* multiplied by  $2\pi$ , and whose height is the number of turns multiplied by the radial lead.

(Remember that *Radius* is the distance from the bend axis to the bend face, and that the spiral will grow outward from the bend face.) To create the sweep path for the preform, simply draw a line from the upper left corner of the rectangle to the lower right corner.

Finish the preform in the usual way: by Rail-Sweeping a profile; or, for a square, rectangular, or flat strip wire shape, extruding the sweep path and shelling the extrusion. Create a bend face in the World XY plane, draw the bend line, and exercise the Bend Sheet tool. Figure 43 shows a typical example.

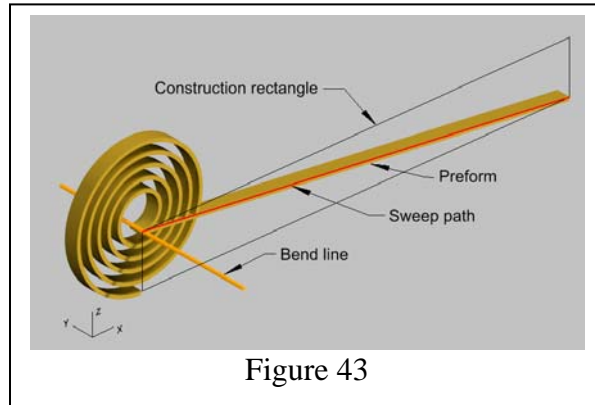


Figure 43

#### E.5.1.5. Garter spring.

A garter spring made with the Bend Sheet tool is created in two stages. The first stage is to create a spring with a cylindrical envelope, and the second stage is to bend that object into a toroid. If you want to leave room for special ends, make the height of the first-stage spring a bit less than the mean circumference of the toroid. For the second stage, use the same bend face and draw a new bend line perpendicular to the first one.

When applying Bend Sheet to the first-stage spring, use a *Radius* that will place the bend axis at the center of the desired toroid. *Neutral depth* should be zero. *Angle* should not be greater than 360 degrees. Be warned that significant distortion of the wire cross section will occur unless the mean radius of the toroid is many times greater than the radius of the cylindrical spring. This distortion is clearly visible in Figure 44.

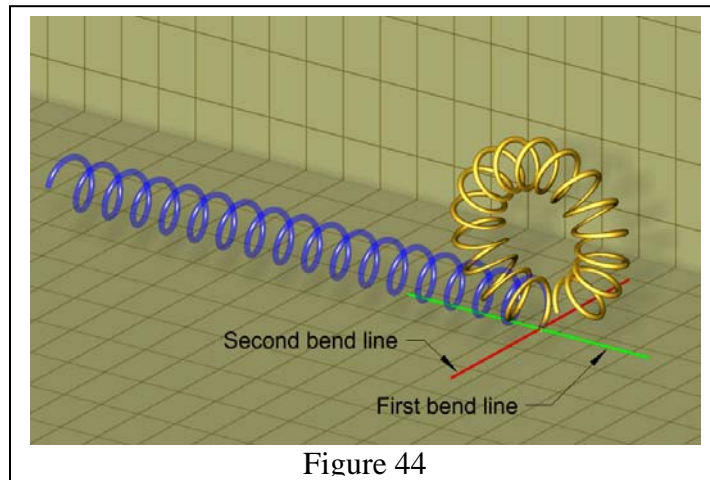


Figure 44

#### E.5.2. Pitch options.

The foregoing discussions of various envelope shapes have noted that axial pitch depends upon the slope of the preform as seen in the World Plan view and that radial pitch is a function of the slope as seen in Front view. It is therefore evident that either kind of pitch can be made nonuniform by using a preform whose slope is nonuniform in the appropriate view.

##### E.5.2.1. Progressive pitch with closed ends.

In this exercise, we create a spring with one closed coil at each end and eight open coils in the middle, their pitch varying from 0.6875 inch (11/16") at the bottom to 0.25 inch

(1/4”) at the top, with each coil space being .0625 inch (1/16”) smaller than the one below it. Mean radius of the spring is 0.75 inch and the wire diameter is 0.125 inch.

The sweep path for the preform will be a 2D Spline by Fit Points, with its nodes designated by snapping to the corners of an array of rectangles drawn and positioned in accordance with the following instructions...

Ten of these construction rectangles are required, one for each coil of the spring, drawn in the World Plan view and the World Workplane. The X dimensions of the rectangles are all the same, being equal to  $2\pi$  times the mean radius of the spring, which works out to 3.1416 inches in this example. The Y dimension of each rectangle is equal to the axial pitch of the corresponding coil—0.130 inch for each of the two end coils (thus allowing .005” clearance); 0.6875 inch for the bottom open coil; 0.625 inch for the next; and so on to 0.25 inch for the topmost open coil.

To draw these objects in the correct positions, begin by drawing one 0.130 inch-high rectangle. Snap to its upper right corner and draw a 0.6875 inch-high rectangle. Draw a 0.625 inch-high rectangle starting from the upper right of the previous one, and continue this procedure, finishing with the second 0.130 inch-high rectangle. These ten rectangles are the black objects in Figure 45.

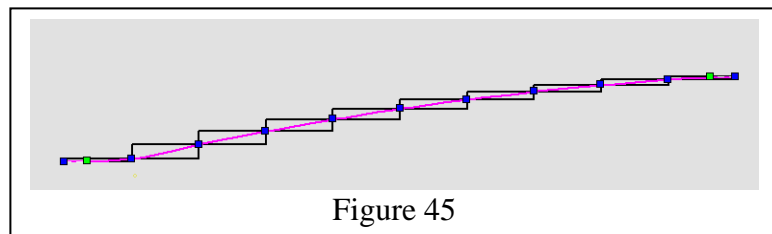


Figure 45

*Tip:* Here’s a way to avoid having to type “3.1416” in the *Size A* field each time you draw a new rectangle. After drawing the first rectangle, select it and highlight the *Size X* field of the Inspector Bar. Press Ctrl+C on the keyboard to copy this value to the Clipboard. Then, each time you start a new rectangle, TAB to the *Size A* field and press Ctrl+V to paste the copied value.

Make the sweep path with a 2D Spline by Fit Points, vertex-snapping to the lower left corner of each rectangle in turn, starting with the leftmost rectangle. Snap to the upper right corner of the rightmost rectangle to set the final node of the Spline. (In Figure 45, the Spline has been selected with the Edit tool with “Edit Fit Points” enabled.)

Rail Sweep a 0.125 inch diameter circle along this path. Create a bend face and a bend line in the plane of the sweep path. Finish the spring model by applying the Bend Sheet tool, using a *Radius* of 0.50 inch and an *Angle* of at least 3600 degrees, and being sure that the *Neutral depth* is zero. The result of this exercise is shown in Figure 46.

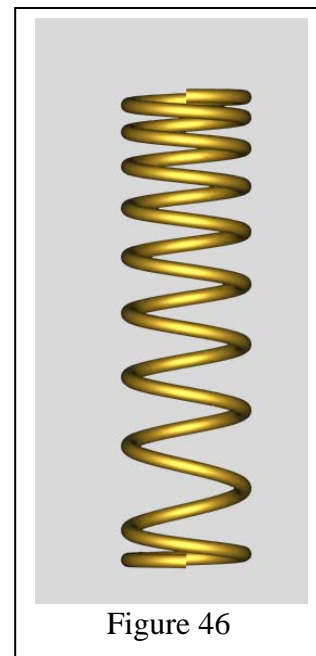


Figure 46

E.5.2.2. Nonuniform radial pitch. Spiral springs with nonuniform radial pitch are made with preforms that are curved in the Front view. Examples are shown in Figure 47.

**E.5.3. Wire shapes.** The Bend Sheet tool can handle all reasonable wire shapes, including those which taper, twist, or even morph from one shape to another along the length of the wire. (Create a preform with a “morphed” cross section by Lofting between profiles of different shapes.) Be aware that an envelope significantly different from cylindrical might result in noticeable distortion of the cross section.

### **F. Special ends.**

Helical *torsion* springs almost always need off-axis ends—i.e., extensions of the wire that protrude beyond the basic envelope, more or less perpendicular to the axis of the spring. Such extensions sometimes are left straight but more often are bent or shaped into hooks or loops.

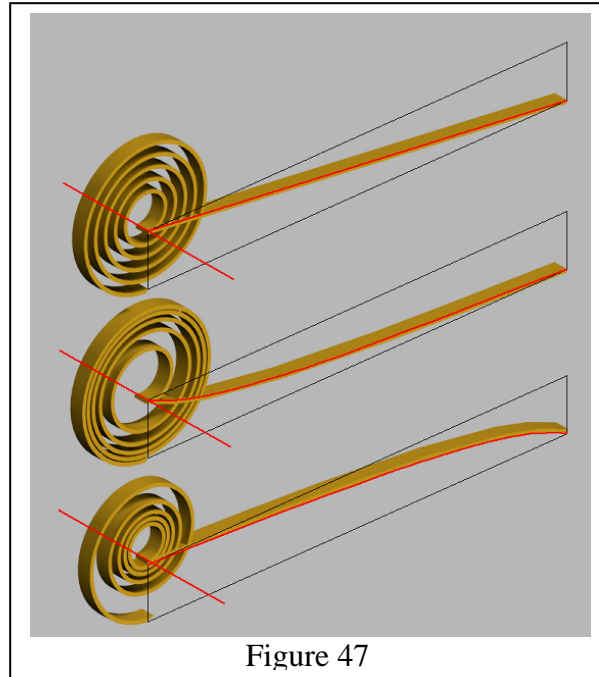


Figure 47

Flat *spiral* springs, being functionally similar to helical torsion springs, likewise often need some kind of special end treatment so they can be attached to a mechanism.

Every *extension* spring needs some means for attachment, and this usually takes the form of an extension of the wire, more or less parallel to the axis of the spring, and generally bent into a hook or loop.

Most *compression* springs do not need any supplementary end treatment, although closed end coils—perhaps ground flat after winding the spring—are commonplace.

In TurboCAD it is sometimes fairly easy to incorporate certain kinds of ends in a spring during the modeling of the basic spring itself. (For example, if a spring is to be created by Rail-Sweeping a profile along a helical path, hook ends can be included by editing the path.) In most cases, though, a better approach is to draw the end fittings as separate objects and then attach them to the basic spring. Both of these techniques are discussed in the following sections.

### **F.1. Off-axis end treatment**

#### **F.1.1. Straight**

TurboCAD’s Quick Pull tool offers the quickest and easiest way to create straight extensions. Be aware that the face selected for that operation will extend in the direction perpendicular to that face. If the spring was drawn by sweeping a profile along a path, the extension will be a smooth continuation of the path. But if the Revolve tool was used to make the spring without tilting the profile as prescribed in Section E.1.1.1.2, the extension will be normal to the spring axis and there will be a sharp kink where the extension begins. These two conditions are illustrated in Figure 48.



### F.1.2. Shaped ends with various envelope shapes

#### F.1.2.1. Flat spiral spring.

A 2D spiral (a flattened Helix or 3D spline), used either as a sweep path or an object to be extruded and shelled, can often be edited to incorporate special ends as integral parts of the basic spring.

Alternatively, the spiral can easily be extended and reshaped by

tacking on a 2D Spline or Polyline. If an endpoint of this additional object coincides with an endpoint of the spiral, the sweep or extrude operation will include both objects when “Use compound path” or “Use compound profile” is enabled. Figure 49 shows an example in which a Polyline extension (red) has been attached to a 2D spiral.

If the spring-end modification needs extra treatment, such as a hole punched in it, a better approach would be to draw the end fitting as a separate object and add it to the spring later. This method is also preferred for a spiral spring made with the Bend Sheet tool.

Section F.1.2.2.2 discusses the technique in greater detail.

#### F.1.2.2. Other envelope shapes.

If the spring wire cross section is a circle, the user may be tempted to create a specially shaped off-axis fitting by exercising Quick Pull to make a straight extension and then applying Tube Bend to the result. One should be aware, however, that the straight extension in this case is an integral part of the original spring and that Tube Bend has to include the whole thing in the operation. The job might take a long time to complete, and there is a good chance the result won't be correct anyway. A better alternative is to draw the fitting as a separate object and add it to the spring later. The following paragraphs outline two different ways to do this.

##### F.1.2.2.1. Extrude in place.

This technique works nicely if the wire is round and the intended shape is fairly simple. It creates a straight extension that looks exactly like one made with Quick Pull, except that the result is a cylindrical object that is not a part of the basic spring. Tube Bend will therefore work quickly and with no danger of distorting the spring itself.

To make an extension by this method, just place a copy of the profile directly on an end face and Simple Extrude it. (To put the profile in position, create a Workplane by Facet

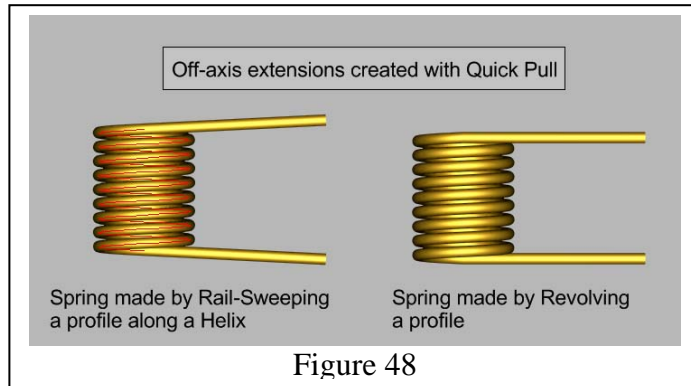


Figure 48

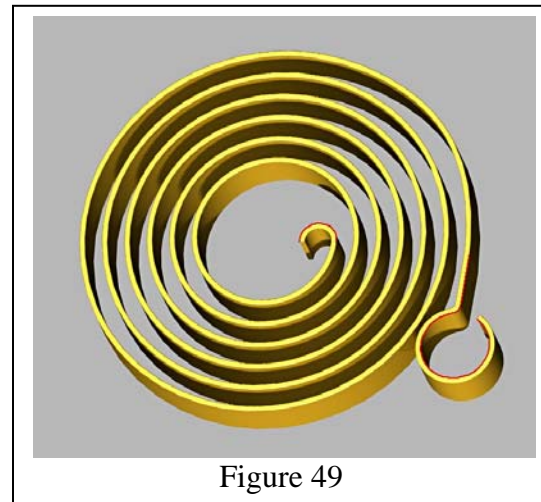


Figure 49

on the end face. Select the profile and apply Place on Workplane. Then enable Degenerative Faceting and snap the profile to the Center of the end face.)

The Tube Bend tool is a bit tricky, mainly because the *Axial distance* parameter doesn't always respond smoothly and the *Azimuth* parameter is hard to understand. To circumvent these problems, turn on the Part Tree before using the tool

(Options>ACIS>Create Editing History).

Then, after bending the object, select it and open the Selection Info palette. Click on

“Part” in the lower panel and edit any of the bend parameters that need to be changed, and the object itself will update accordingly.

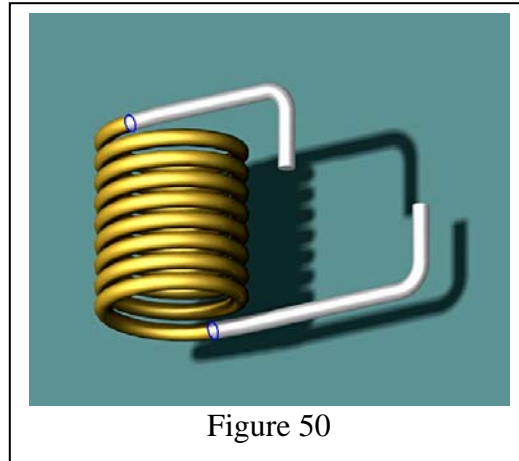


Figure 50

Figure 50 shows two simple ends that were created by this method but not yet 3D-Added to the basic spring.

#### F.1.2.2.2. Create elsewhere.

The most versatile approach is of course to create the special end fitting all by itself and attach it to the spring later. Use the same profile (or a copy) for the fitting as for the spring. If the profile has well defined vertices, Assemble by Three Points is an easy way to attach the fitting. If it does not have such vertices—if it's a circle, for instance—three steps are generally necessary to put the fitting in the right place:

1. Use the Assemble by Facet tool to orient the fitting so its end face lies in the plane of the spring's own end face.
2. To make the center of the fitting's end face coincide with the center of the spring's end face, start by enabling “Degenerative Faceting.” Activate the Assemble by Three Points tool. Click on the fitting to select it; “Center” snap to the end face of the fitting; “Center” snap to the end face of the spring; click the “Finish” icon to complete the move.
3. If the fitting needs to be rotated around the axis of the end face profile, establish a new Workplane by Facet on the end face. Move the Reference Point of the fitting to the center of that face and use either the mouse or the *Rot Z* field on the Inspector Bar to orient the fitting as required.

#### F.2. Short hook or loop end

A “short” hook—formed by sharply bending the final one-half of a coil—is one of the most common end configurations for extension springs. If the spring is created by sweeping a profile along a 3D spline path, the curve can be edited to make the hook an integral part. With a bit more work, a loop rather than a hook can be fashioned using a similar procedure. Sections F.2.1 and F.2.2, below, explain how to do the editing. The short hook and short loop in Figure 51 were made from an edited 3D spline.

If the spring is modeled with a technique other than sweeping a profile, a hook or loop must be created separately and attached afterward.

F.2.1. Adding a short hook by editing a spline.

If the spline is a result of exploding a TCad Helix, be sure to delete the two troublesome nodes near the ends, as explained in the *Note* in Section E.2.2.2.1.

Switch to Left Side view and select the spline with the Edit tool. If the spline is not oriented as in Figure 52, rotate it to the correct orientation before proceeding. Then, with “Edit Control points” and “Selector Mode” both enabled, draw a selection

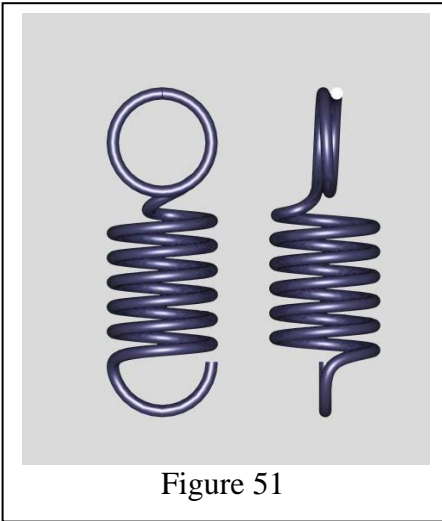


Figure 51

rectangle around the set of nodes that define the top half of the top coil, as in Step “A” in the figure. Set the *Size Z* of the selection to zero. Click the “Edit Reference Point” icon (the “D” hotkey doesn’t work here) and relocate the Reference Point of the

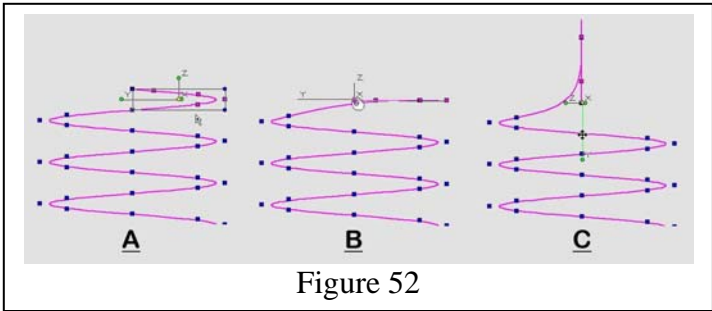


Figure 52

selected nodes as shown in Step “B.” Type “270” in the *Rot X* field and press Enter. Step “C” shows the spline after rotating the selection. Press the Esc key to exit the Edit mode.

F.2.2. Short loop by editing a Spline.

A short loop—similar to a short hook but incorporating at least one full turn—can be modeled using a procedure somewhat like the one outlined above. In this example we shall use one and a half turns.

Move to Front view, then select the spline with the Edit tool and enable the same options as in F.2.1, above. Snare the nodes that define the topmost one and a half turns and set *Size Z* to a little more than 1.5 times the wire diameter. Move the Reference Point of this set to the node at the bottom left, then type “270” in the *Rot Y* field and press Enter. Figure 53 shows the result of these operations.

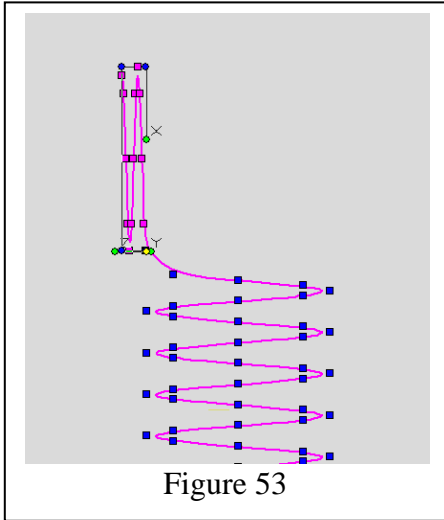
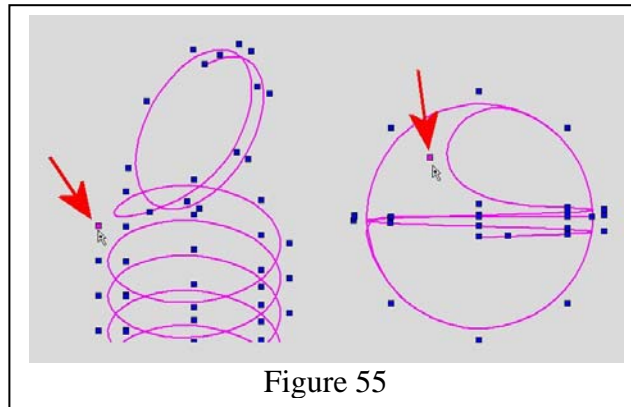
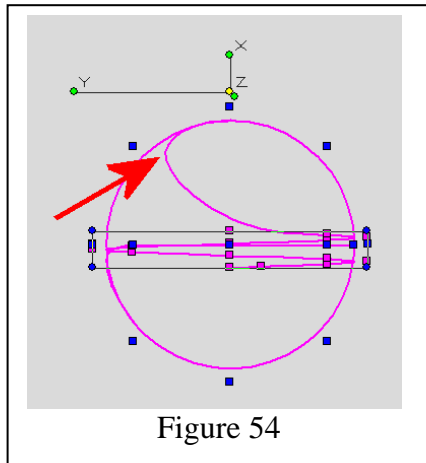


Figure 53

Without deselecting any nodes, switch to World Plan view and move the Reference Point of the set to the approximate center of the helical portion of the spline. Rotate the selection 90 degrees about the Z axis, then use the mouse to drag the selection until it appears centered on the helix. Your result should look like Figure 54 (except that you won’t see a red arrow).



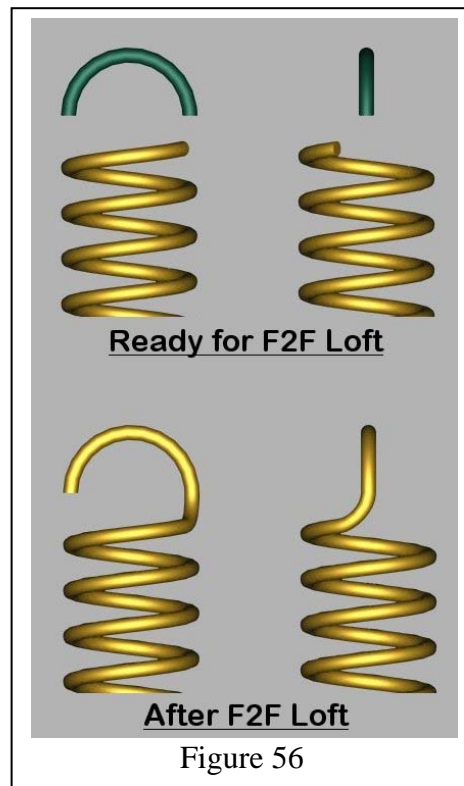
The arrow in Figure 54 indicates a bend that's too sharp for good spring design. To soften the bend, switch to the Southwest Isometric view and snag the single node shown the left hand side of Figure 55. Then go back to the World Plan view, lock the *Delta Z* field, and move the node to roughly the position shown in the right side of the figure.

Rail-Sweep a profile along the curve to make the spring.

#### F.2.3. Hook created elsewhere

A quick way to create a hook is to use a portion of a TurboCAD Torus for the basic hook and then apply Quick Pull to extend one or both ends if required. The Face to Face Loft tool can connect the fitting smoothly to the spring if the two objects are reasonably close together before joining. (If they're too close, the resulting bend in the wire will be too sharp for good spring design, and if they're not close enough, the bridge won't be smooth.) To use this method, maneuver the fitting into the position shown in the upper part of Figure 56. Activate Face to Face Lofting, click on the end face of the spring and wait until it becomes highlighted in green, then do the same with the end face of the fitting.

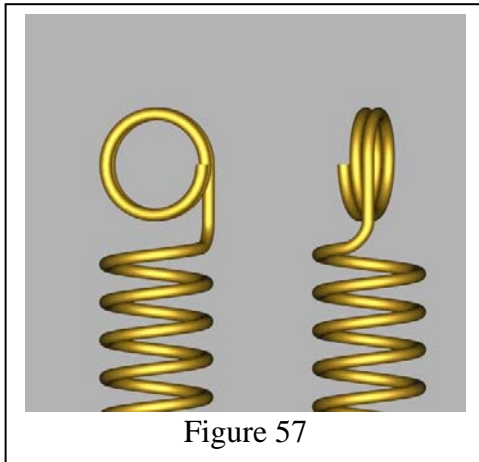
If you cannot make the Face to Face Lofting tool create a smooth enough transition between the spring and the hook, draw the transition as a separate piece using Bend Sheet as explained in F.2.4, below.



#### F.2.4. Loop created elsewhere

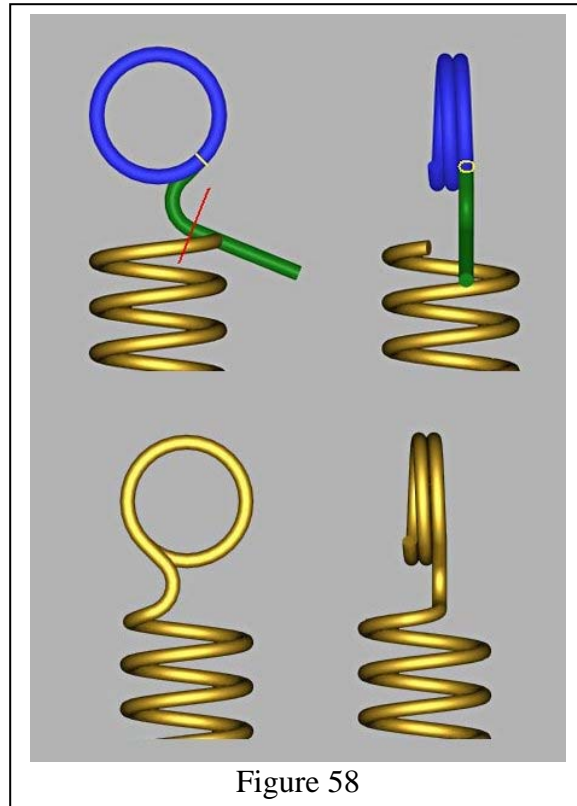
A similar technique can model a loop fitting that looks like Figure 57. In this example, the loop was made by Revolving a circular profile, and one end was extended with Quick

Pull. The fitting was carefully moved into position and then joined to the spring with Face to Face Lofting.



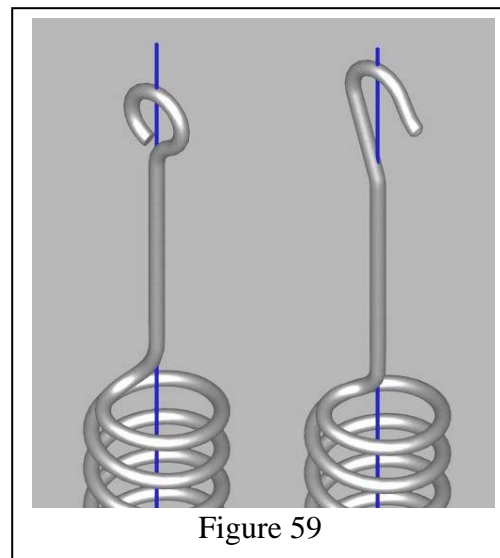
A more complex procedure is necessary to make a spring-to-fitting transition that looks like the bottom object in Figure 58. Here's how that one was drawn:

The loop was made as in the previous example, by Revolving a circular profile. The Spin and the profile were Grouped for safe handling, then relocated and rotated as depicted by the blue object in the top part of the figure. After exploding the Group, the circular profile was extruded to create a new object that was in effect a straight extension of the loop. This was shaped with the Tube Bend tool, and then tweaked by adjusting various parameters in the Part Tree, to make the green transition object in the figure. That was sliced along the red line visible at the upper left, and the right-hand part was deleted. Face to Face Lofting connected the transition to the spring.



An end fitting with a shank that lies on the axis of the spring, as in Figure 59, is easy to create by Tube Bending a cylinder or by sweeping a profile along a path. The tricky part is joining it smoothly to the spring, a task that Face to Face Loft seems unable to handle gracefully. The Bend Sheet tool, fortunately, does offer a reasonably simple way to create a smooth transition. The procedure is explained in the next couple of paragraphs.

The first step is creating sweep path for the Bend Sheet preform. To begin, move to a view that shows a side view of the spring and establish a Workplane by View. Draw a line along the axis of the spring, and then draw a



parallel line to the right of that one, at a distance equal to the mean radius of the spring multiplied by  $\pi/2$  (1.57089). Draw a new line starting at the spring axis and extending upward and to the right, at an angle equal to the helix angle of the spring, and extending somewhat beyond the second vertical line. (The angle can be established accurately enough just by eyeballing it.) Insert a 2D Fillet between the angled line and the one parallel to the axis, using a *Radius* equal to the spring mean radius for a rather long transition or about half of that for a short transition. If “To Polyline” was active when inserting the fillet, select the result with the Edit tool and delete the node at the upper end of the vertical leg. The correct sweep path is shown in red in Figure 60.

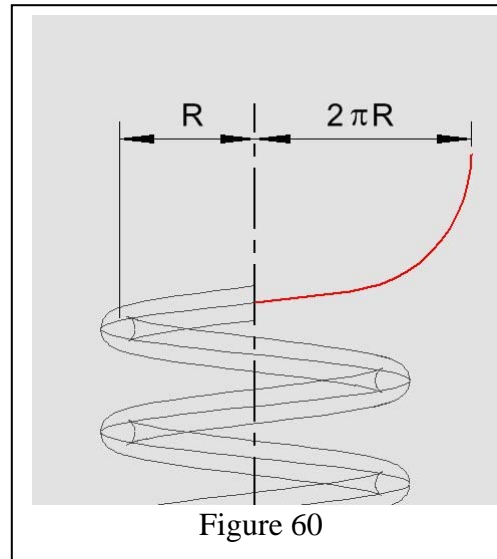


Figure 60

Draw a circle of the same diameter as the spring wire and Rail-Sweep it along the path. Make a bend face in the Sweep by drawing a tiny 3D Box that barely intrudes into the Sweep, like the blue object in the closeup in Figure 61. (Be sure to use a small positive number for the Height of the Box so its bottom face will lie in the same Workplane as the sweep path.)

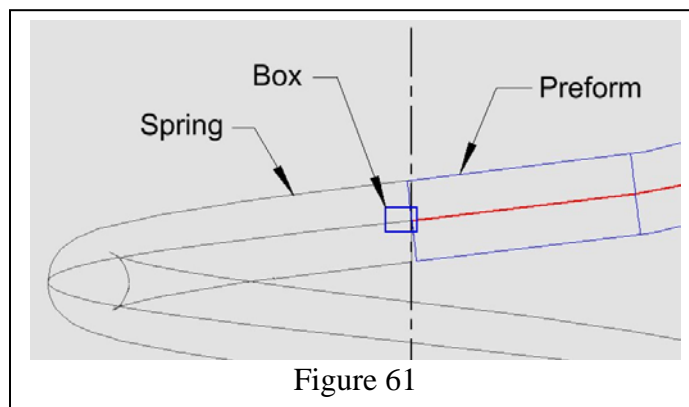


Figure 61

Subtract the Box from the Sweep to finish making the preform.

The final step in creating the transition is to bend the preform, using the Bend Sheet tool. Highlight the bend face (the one that lies in the Workplane) and then select the vertical line that lies on the spring axis. (Zoom in and rotate the view a little if necessary so you can see what’s happening. You might also want to put the spring on a hidden layer for the time being.) Use a *Radius* equal to one-half the mean radius of the spring; an *Angle* of 180 degrees for a spring with left-hand wind, or negative 180 degrees for a right-handed spring; and a *Neutral Depth* of zero.

If you’re using this method to create a transition piece for a hook—as mentioned in 2.3, above—*Radius* should be the full mean radius of the spring and *Angle* should be 90 degrees for a left-handed spring or negative 90 degrees for a right-handed spring.

*Note:* The bending operation causes a bit of distortion in the cross section. It probably won’t be noticeable, but if you apply Quick Pull to extend the transition piece, the extension will not be perfectly cylindrical. Consequently, neither the Tube Bend tool nor the Thread tool will recognize it.

Make the spring visible if you've hidden it and then switch to an isometric view. You'll probably see that the new object is not correctly positioned with respect to the spring. Use the procedure outlined in F.1.2.2.2 to put it where it belongs.

Depending upon how the spring was created, it's quite possible that the end faces of the spring and the transition won't exactly match. In that case, welding them together with 3D Add is likely either to make an unattractive joint or to fail altogether. If you encounter this problem, the solution is to nip a small piece from the ends of the two objects—by subtracting a small Box from each, for example—and then apply Face to Face Lofting. Figure 62 shows the steps in this procedure. Similarly, when connecting the end fitting to the transition piece, be sure there's a gap between them and then apply Face to Face Lofting.

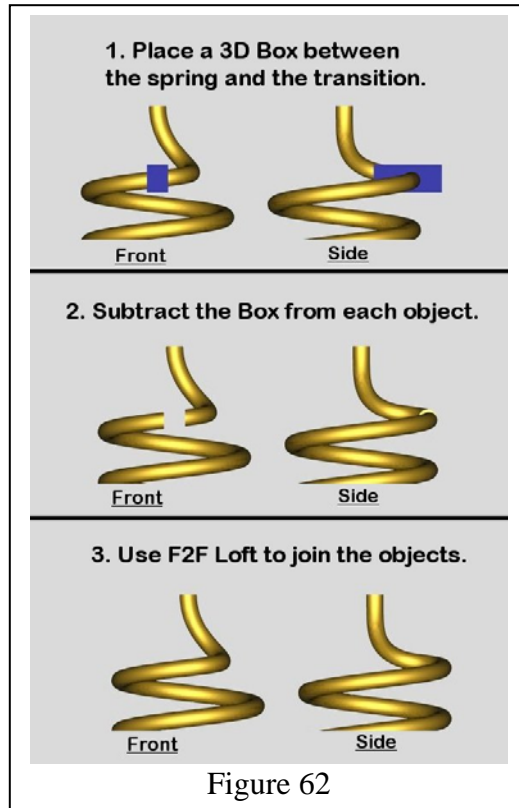


Figure 62