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Generating Coils in BRL-CAD

by Clifford Yapp

ARL-CR-691 April 2012

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14. ABSTRACT

Springs, shock absorbers, and other parts found in many modern mechanical systems can be described geometrically using a cylindrical coil. BRL-CAD is able to produce coils using the Constructive Solid Geometry (CSG) pipe primitive, but manually inserting enough pipe control points needed to create specific individual coils is a time-consuming process. The coil procedural tool automates most of this process by procedurally generating pipe primitives to describe coil shapes defined by high-level dimensional specifications.

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1. Overview

The *pipe* primitive is one of BRL-CAD's most flexible and powerful primitives. It consists of segments of cylindrical and toroidal volumes, each aligned with its neighbor(s) to form a continuous solid. Rather than requiring individual definition of each of these segments, the *pipe* primitive automatically deduces them from a series of control points defined by a modeler. While the result is a very flexible primitive, *pipe* input can require large numbers of manually specified control points to define a single shape. Coils represent a particularly glaring example of a shape representable using the *pipe* primitive but requiring a large number of control points. (Manual creation of coils using the *pipe* primitive is outlined in appendix A of the *BRL-CAD Tutorial Series Volume III - Principles of Effective Modeling*.[1])

Coil shapes are a good candidate for procedural geometry generation since the control points needed to define a coil are well defined and can be deduced for particular dimensions from high-level structural properties common to all coils. To achieve this automation, the coil tool accepts a variety of parameters describing the overall properties of the desired coil and calculates the required pipe control points from them.

1.1 Coil-Level Characteristics

When designing a coil, the termination or "capping" style of the coil must be considered. A simple coiled pipe is often insufficient. Smaller springs, such as those found in a pen, are describable using a coiled pipe alone, but many larger springs are made for uses requiring the end of the spring to be flush with some flat surface. Because this is a common real-world situation, the coil tool supports a number of capping styles.

The number of "sections" in the coil, regions exhibiting the same dimensional characteristics, is another important real-world variable that must be considered. Oftentimes, a spring will have several turns wound tightly together at the ends of the spring and a different, more open spacing between the middle coils. A case like this would be said to have three "sections"—the first end section, the middle section, and the second end section. To provide a general solution to the problem of modeling multiple sections, the coil tool supports the explicit definition of a sequence of two or more sections, each of which may have their own distinct properties. These properties are defined over a number of "turns" during which the properties hold.

Within each section (or over the whole of the coil if there is only one section), there are five properties that need to be defined and several ways these properties can be defined by the modeler. There is a degree of interdependency between these options. Each individual option may be specified, but there is a potential for incompatible definitions (particularly, in the case

[1] BRL-CAD Tutorial Series Volume III - Principles of Effective Modeling. http://www.arl.army.mil/www/default.cfm?page=515&id=795.

where overall length is specified). The coil tool will select options in order of priority. The options are (in order of decreasing priority) as follows:

- Right-handed vs. left-handed coiling
- Length
- Wire diameter
- Number of turns
- Outer coil diameter
- Pitch
- Helix angle

Many of these settings are independent of each other; however, in cases where they conflict, values of properties higher on the list will be preserved at the expense of those lower on the list.

1.1.1 Number of Turns

Turns on a coil (figure 1) are defined as the path from a given point on the coil to the point where, following the path of the coil, the path makes a 360° rotation about the center axis of the spring. Boundaries between turns are important because they define areas where sections may change. It is important for the modeler to be aware of the significance of turns in coil design and what a turn refers to geometrically.

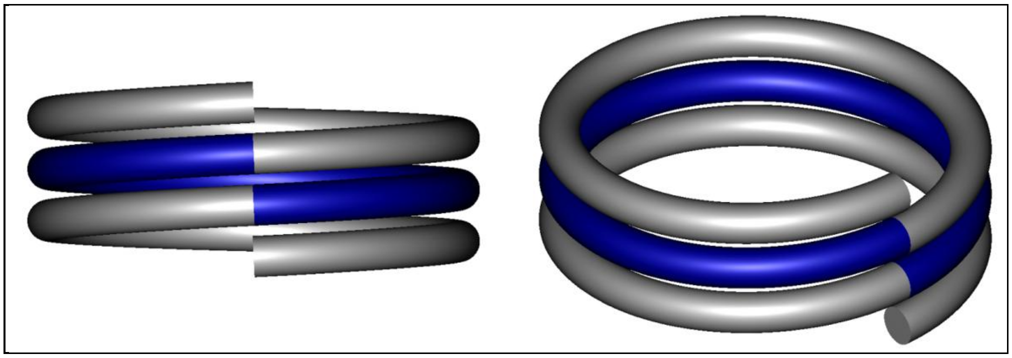

Figure 1. Illustration of a single turn within a coil; the blue section in the two views constitutes one full turn.

1.1.2 Outer Coil Diameter

Outer diameter (OD) is defined as the maximum width occupied by the spring from the outer surface of one point of the wire to the outer surface of the wire 180° around the turn starting at the original point (figure 2). This is the maximum width of the coil section. This diameter is always centered relative to the central axis of the coil direction.

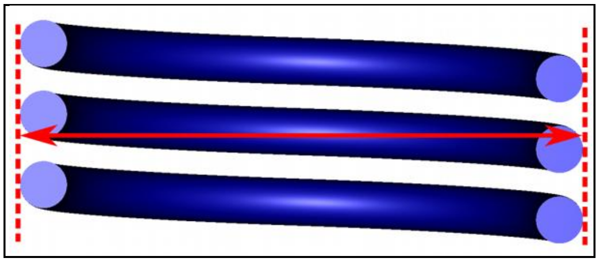

Figure 2. Outer diameter of a coil.

1.1.3 Wire Diameter

Wire diameter (figure 3) is simply the diameter of the circular cross section of the wire being wound into the coil shape.

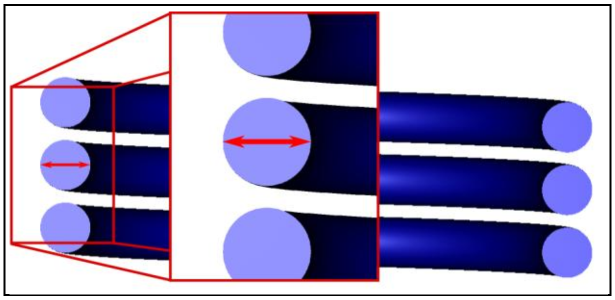

Figure 3. Diameter of the wire wound into the coil shape.

From the coil's standpoint, this dimension is the wire diameter; but in the pipe primitive used to form the coil, this dimension is referred to as "outer diameter." The distinction is not particularly important when using **coil**, but when working with the resulting geometry in MGED, the modeler should bear in mind that the OD parameter on a pipe configured as a coil refers to the OD of the pipe primitive, NOT the coil OD.

1.1.4 Helix Angle

The helix angle (figure 4) is the angle between the line described by the point at the top of the wire at the start of a turn and the bottom point of the wire 180° around the turn and the plane normal to the vector describing the overall coil direction. Note that increasing the helix angle does not tilt the "direction" in which the coil is wound—if a coil with helix angle of 0 is winding in the positive Z direction, the same winding direction will be used with a nonzero helix angle. For large helix angles, this may result in two "sides" of the coil looking longer than the other two.

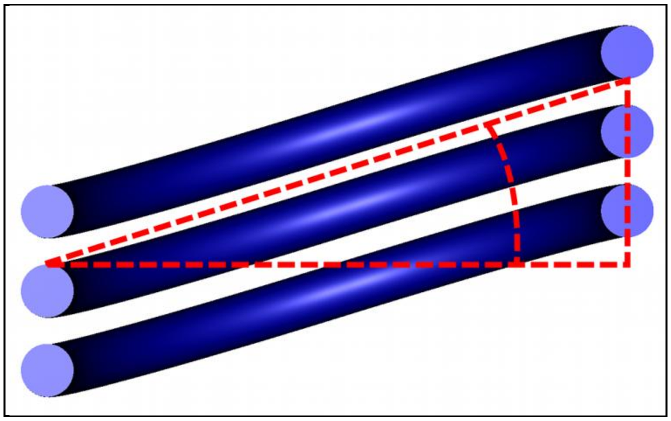

Figure 4. Helix angle of a coil.

1.1.5 Pitch

Pitch is the distance along the vector parallel to the coil direction vector that the center of the wire is displaced upon completing one full turn (figure 5). A pitch of 0 results in a torus, and the minimum pitch for a coil that is not self intersecting is the wire diameter. Pitch is one of the most common properties to change when defining multisegment coils.

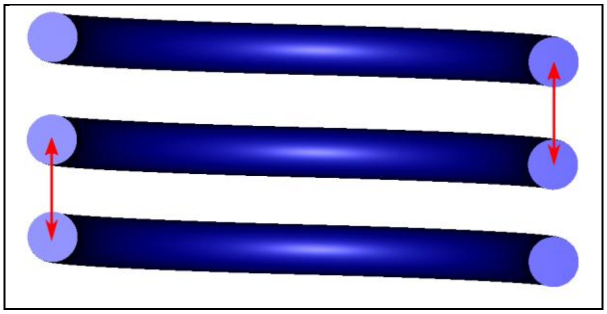

Figure 5. Distance between a turn's starting point and its ending point.

1.2 Length

The coil tool supports the specification of length but only for the entire coil as a whole (figure 6). Length represents a particular problem when describing coil properties since most of the other properties used to specify a coil impact the length. Helix angle, in particular, complicates this calculation. Currently, a length specification will work only for uncapped coils with a helix angle of 0.

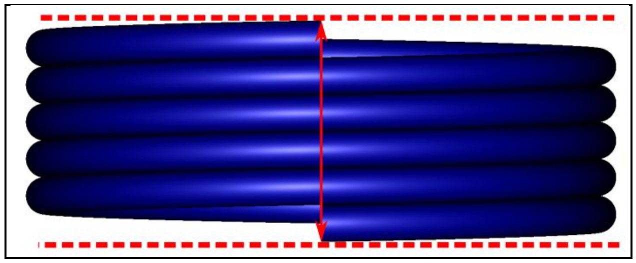

Figure 6. Length of a coil.

1.3 Inner Diameter (ID)

Unlike the other dimensional properties listed here, ID (figure 7) is not directly configurable in the coil command. Mathematically, ID is defined as the minimum width occupied by the spring from the inner surface of one side of the wire to the inner surface of the wire 180° around the turn starting at the original point. This is the maximum width of the empty interior of the coil section, and it is changed indirectly by setting either the OD, wire diameter, or both.

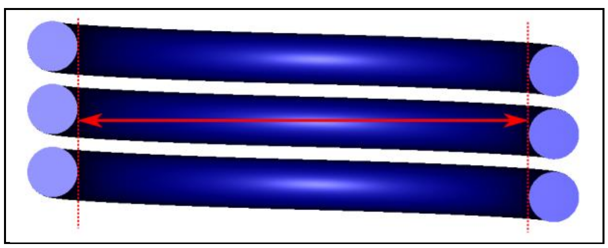

Figure 7. Inner diameter of a coil.

1.4 Summary

In some sense, the coil shape may be regarded as a “special-case” primitive built on top of the pipe primitive, imposing additional constraints and adding custom settings for defining shapes according to those constraints. Interdependencies between the coil shape’s custom settings are summarized in table 1. The pipe primitive is not sufficiently general to encompass all possible coil shapes. In particular, continuously varying wire diameter or OD sections are beyond the capabilities of the pipe primitive.

Table 1. Summaries of the various controllable properties of coils and which properties may (singly or in combination) constrain them.

	Turning Direction	Length	Wire Diameter	Number of Turns	Outer Coil Diameter	Pitch	Helix Angle
Turning Direction	—	—	—	—	—	—	—
Length	—	—	x	x	—	x	x
Wire Diameter	—	x	—	x	x	x	—
Number of Turns	—	x	x	—	—	—	—
Outer Coil Diameter	—	—	x	—	—	—	—
Pitch	—	x	x	—	—	—	—
Helix Angle	—	x	—	—	—	—	—

It is worth illustrating the fact that pitch and helix angle are independent of each other. Raising the helix angle does not require changing the pitch, and vice versa. Figure 8 illustrates a case where helix angle has been changed but the pitch has remained constant.

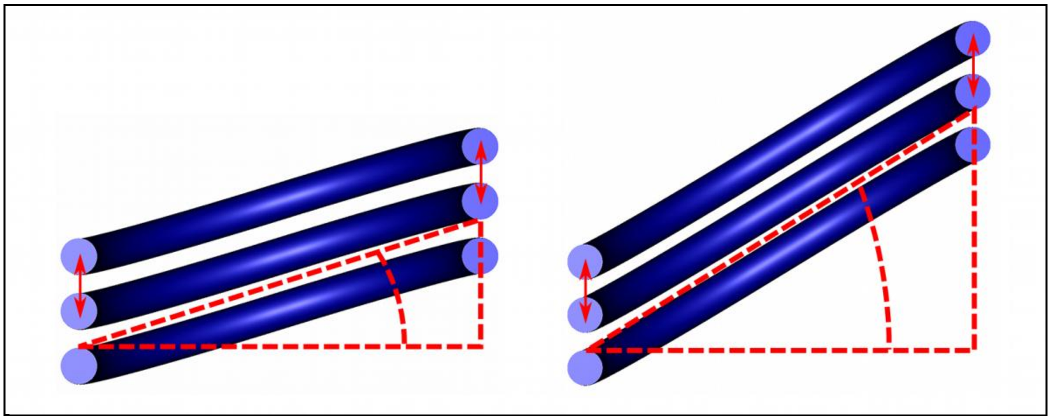

Figure 8. A pair of example coils with identical pitch and different helix angles.

2. Creating Coils

The coil command allows very direct control over each of the parameters specified earlier. The default coil created is right handed, has 1000-mm OD, wire diameter of 100 mm, 0 helix angle, pitch of 100 mm, and 30 turns. Since this will seldom be what is needed by a modeler, the coil command provides the options specified in table 2 for convenient adjustment of these parameters.

Table 2. Available coil options and what they mean.

Option	Description
-n <integer>	Number of turns
-h <float>	Helix angle
-p <float>	Pitch
-d <float>	Outer diameter
-w <float>	Wire diameter
-s <integer> -e <integer>	Starting (s) and ending (e) cap styles. Options are 1 (squared), 2 (ground), and 3 (both)
-l <float>	Overall coil length
-L	Wind coil in left-handed direction (default is right handed)
-S	Define one section of a multisection coil (use 0/1 to set left/right handed winding.)
	Number of turns, outer diameter, wire diameter, helix angle, pitch, winding direction
	<integer>, <float>, <float>, <float>, <float>, <integer>

The following sections will illustrate each option in more detail.

2.1 Setting the Number of Turns

Number of turns is set using the “-n” followed by an integer number of turns that is greater than or equal to 1 (figure 9).

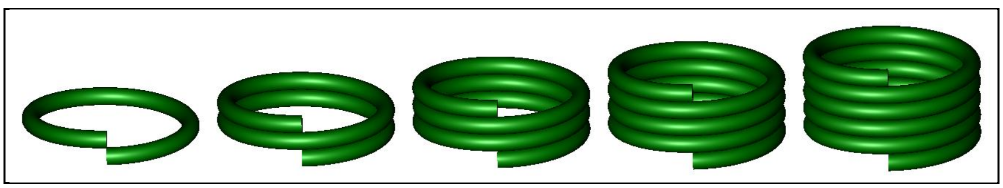

Figure 9. Example coils with (left to right) turn counts of one, two, three, four, and five turns. All other control parameters are identical.

2.2 Setting the Helix Angle

Helix angle is set using the “-h” followed by an angle in degrees (figure 10).

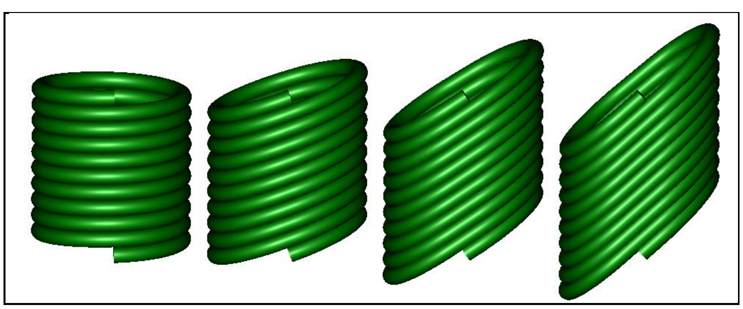

Figure 10. Example coils with (left to right) helix angles of 0, 20°, 40°, and 60°.

2.3 Setting the Pitch

If less than the wire diameter pitch will be increased to the wire diameter, pitch is set using the "-p" followed by the desired pitch in millimeters (figure 11).

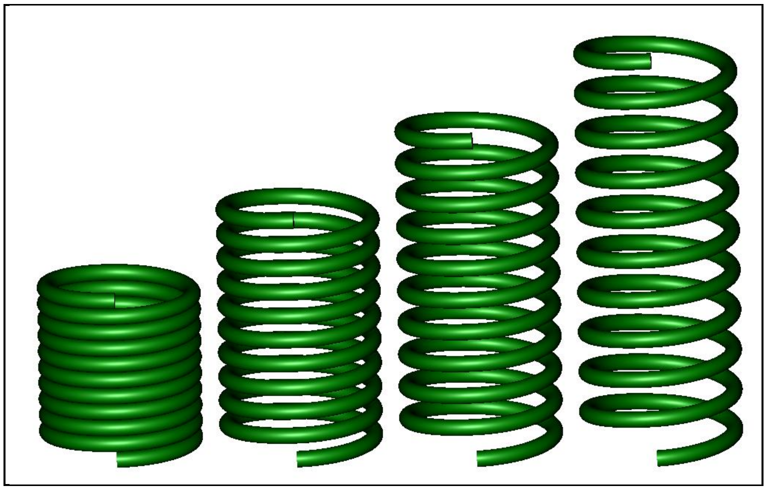

Figure 11. Example coils with pitch of (left to right) 100, 150, 200, and 250 mm.

2.4 Setting the Outer Diameter and Wire Diameter

OD and wire diameter can be set independently (figures 12 and 13). Unless both are specified, the default behavior is to maintain a ratio of 10:1 between OD and wire diameter. OD is specified with the "-d" followed by the OD in millimeters, and wire diameter is specified with the "-w" followed by the wire diameter in millimeters.

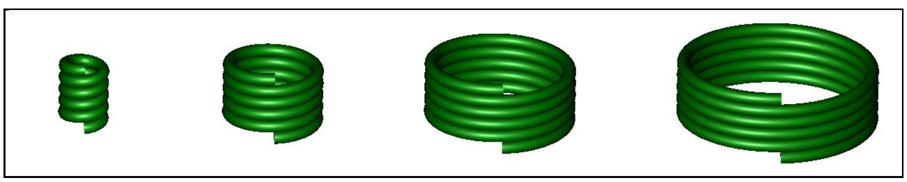

Figure 12. Increasing outer diameter with constant wire diameter (left to right).

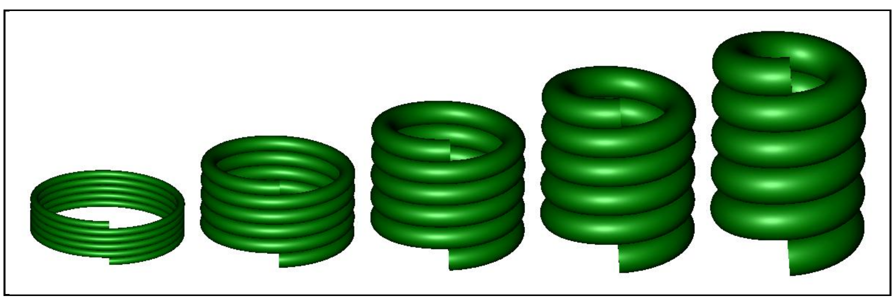

Figure 13. Increasing wire diameter with constant outer diameter (left to right).

2.5 Setting the Style of Coil Termination

It is possible to choose different terminations or "caps" for the start and end of a coil. The style chosen for the end is independent of the style chosen for the front. It is also possible to "mix and match" on a single coil (figures 14 and 15).

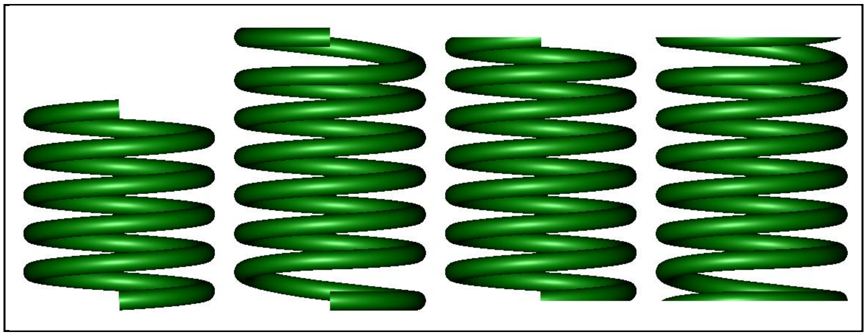

Figure 14. Example coils with (left to right) default (no) capping, capping style 1 (squared), capping style 2 (ground), and capping style 3 (squared and ground).

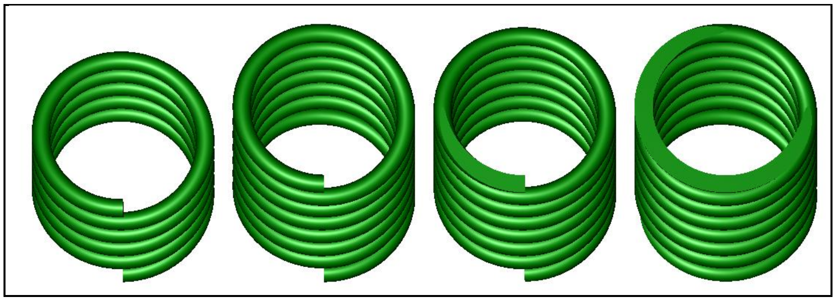

Figure 15. Slanted view of coils to better exhibit coil surfaces.

3. Multisection Coils

In many real-world cases, a coil does not have one unique pitch but combines two or more sections with distinct properties to form a single, relatively complex coil. The coil tool does support specifying such coils through an advanced option, "-S."

The -S option accepts a comma separated list of the five parameters needed to define a coil, and the coil accepts multiple instances of the -S option. To build a multisection coil, the modeler specifies in order the properties of each distinct geometric section to be added to the final pipe. Note that if the -S option is used, only the options for capping style will remain active—all other geometric options just discussed will be ignored.

To illustrate this ability, a coil is created with 3, 0-pitch turns followed by 15, 250-mm pitched turns and 3 more 0-pitch turns:

```
coil -S 3,1000,100,0,100,1 -S 15,1000,100,0,250,1 -S 3,1000,100,0,100,1
```

A real-world example of using multisection coils (figure 16) is the pen model pictured in figure 17. The spring is generated using the following coil command:

```
coil -S 3,4.8,0.381,0,0.381,0 -S 17,4.8,.381,0,1,0 -S 3,4.8,.381,0,.381,0
```

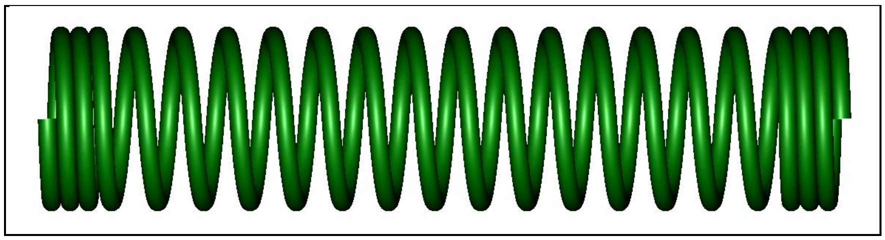

Figure 16. Example of a multisection coil.

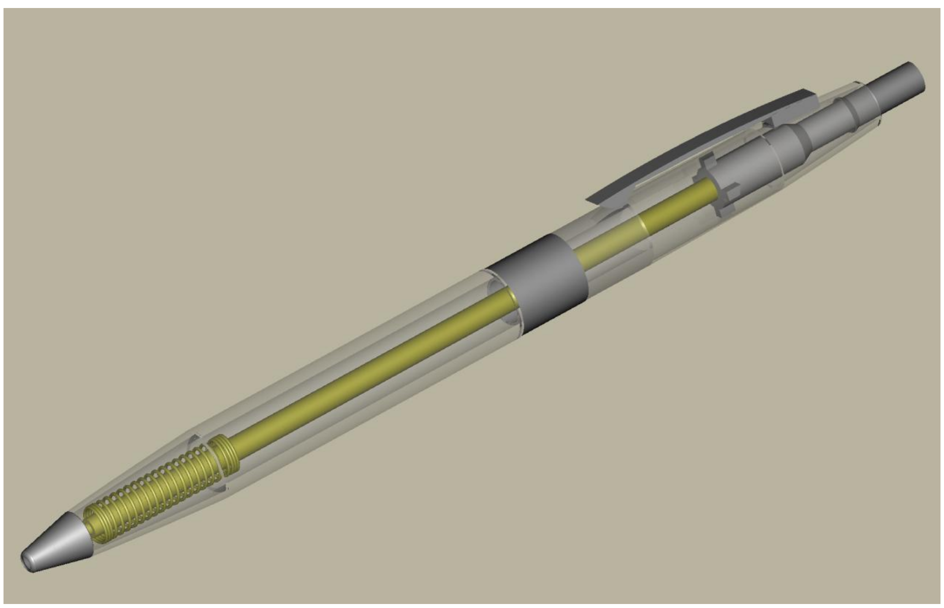

Figure 17. Pen model with a spring generated using the coil tool.

4. Manually Editing a Coil

There may be situations when modeling where the modeler wants to generate a coil as a starting point and edit that coil in a few places manually (e.g., fractional turns on the ends of a coil). When doing so, it is important to remember that the modeler will be interacting with the control points of the pipe primitive and *not* the dimensional parameters presented to the user by the coil command.

To illustrate this process, a default coil with five turns is edited to only do three-quarters of its final turn. When editing a coil in MGED, it is important to draw *only* the coil primitive itself and not the combination that includes it. This is done with the following command on the MGED command prompt:

B coil_core.s

When editing pipes in MGED, it is helpful to activate the Faceplate and Faceplate graphical user interface options under the Misc menu. It is also a good idea to shift the view slightly so the coil is not obscured by editing information. Once this is done, enter the following:

sed coil_core.s

The display should now show something similar to the view in figure 18.

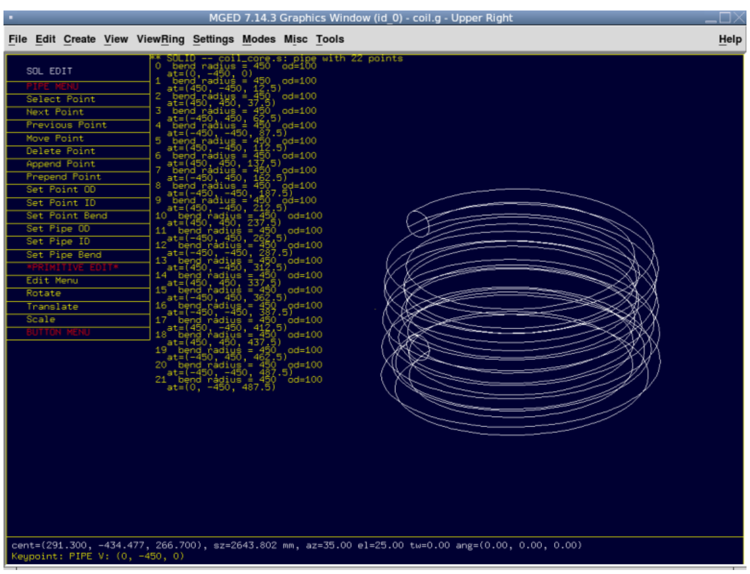

Figure 18. Coil in default solid edit mode state.

Next, click on “Select Point” in the “SOL EDIT” menu and select the final point in the pipe (figure 19).

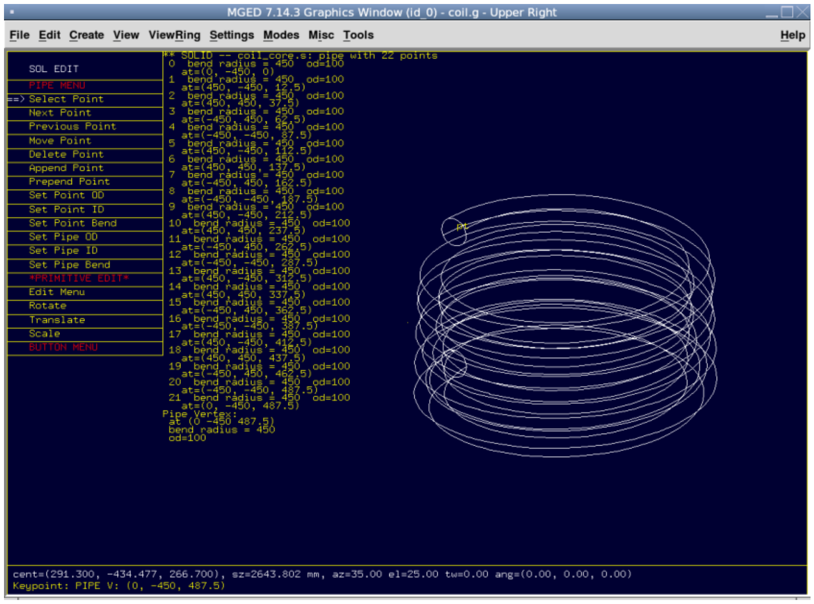

Figure 19. Selecting the final point on the coil.

Once this point is selected, click on “Delete Point” twice to eliminate the last point (which is what “pegs” the pipe to the ending point) and the point immediately before it. The coil should now look as shown in figure 20.

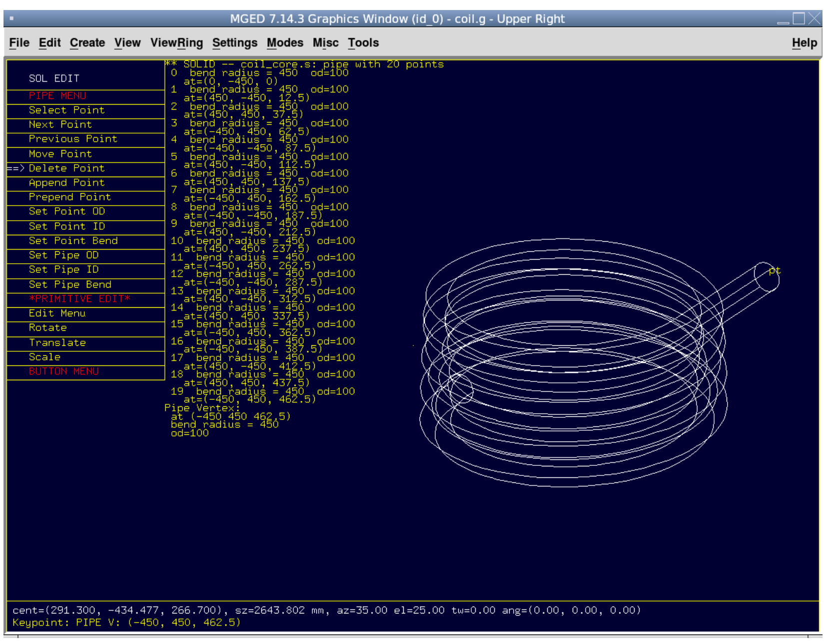

Figure 20. Coil after deleting control points.

To get information about the new final point, re-select “Select Point” and select the new final point. In this case, the following information should be displayed:

Pipe Vertex:
at (-450 450 462.5)
bend radius = 450
od=100

To re-terminate the pipe with the coil inward but one-quarter turn back from its previous termination, a new control point must be appended. The new height must be one-quarter of the pitch plus the height of the previous control point. In this case, that increments the height by 25 and puts z at 487.5. The final control point is on the coil at -450,0 in x and y. To insert such a point, select "Append Point" from the "SOL EDIT" menu and enter the following on the MGED command line:

p -450 0 487.5

The pipe should now display the correct geometry as shown in figure 21. To finalize the changes, enter "accept" on the command line.

The final before-and-after results of these steps can be seen in figure 22.

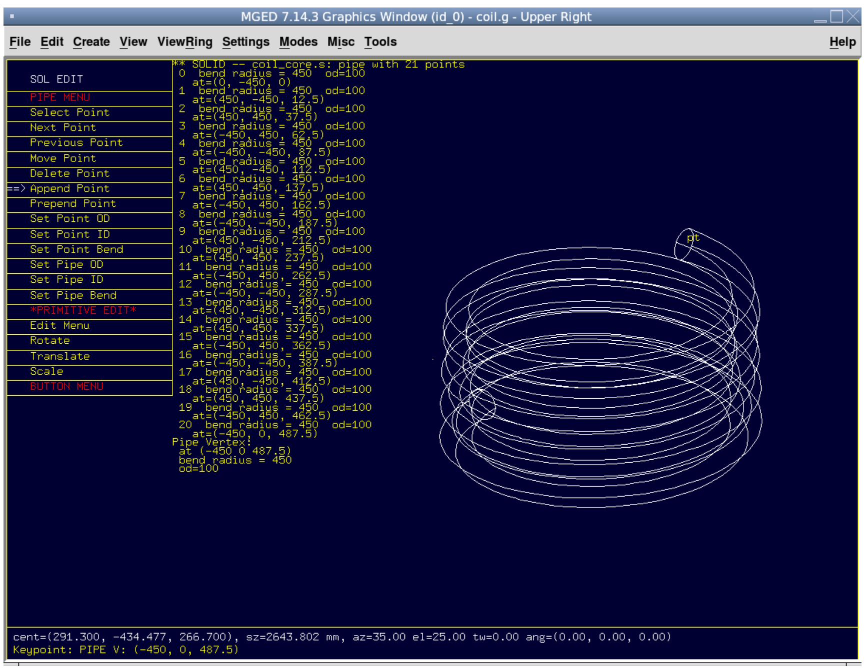

Figure 21. Coil with new three-quarters turn at top.

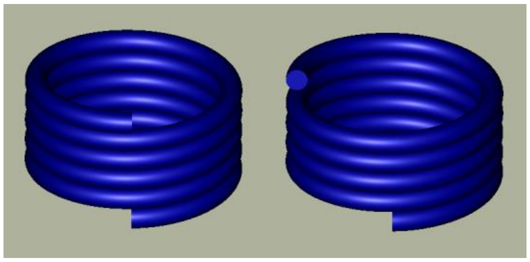

Figure 22. Comparisons of the coil before and after editing. The coil on the left is unedited, and the coil on the right is seen from the same view and is missing the last quarter turn of its top turn.

5. Summary

- The **coil** tool uses the *pipe* primitive to procedurally generate coil shapes.
- High-level parameters for controlling the properties of the coil shape automate what is otherwise a labor-intensive process in MGED.
- Currently, coil shapes are constrained to geometries representable using BRL-CAD's pipe primitive.
- Multiple sections in a single coil are achieved by manual definition of those sections using the -S option.
- Customization of a coil after generation is achieved through standard pipe editing in MGED.

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