Coil End Part Design Procedure

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Abstract

This paper provides a procedure for the design of coil end parts using the computer programs BEND and DELCOR created by Joe Cook and program PART created by Jeff Brandt at Fermi National Accelerator Laboratory. The superconducting cable paths are determined from both magnetic and mechanical considerations. The coil end parts used to shape and constrain the conductors in the coil ends are designed using the developable surface, grouped end approach. This procedure outlines the design steps, discusses the use of the computer programs for group and part creation, suggests standards for data management, and details the required CADD processes.

Obtain a coil **cross-section** - this will define the group's X-Y plane geometry requirements. All angles and point coordinates should be measured where the insulated conductor edges intersect the inner and outer coil radii.

For each group, determine the conductor **average keystone angle** by subtracting the group side angles, and dividing by the number of conductors. Unless this average keystone angle is used, getting an exact match of CADD geometry will be impossible, and mid-thickness adjustment will be much more complicated.

The **average conductor mid-thickness** for each group must be iterated by using program BEND to create a group with the nominal mid-thickness, comparing BEND geometry with CADD geometry, and adjusting the mid-thickness until a match with the cross-section is obtained. This iteration is made much easier if 0 conductors inside the guiding strip are used, because the inside group side and starting angles will already match the cross-section exactly. The conductor mid-thickness can then be adjusted to make the outside group side and starting angles match the cross-section.

The **guiding strip** may be placed at any conductor surface within the group. Once the conductor keystone angle and mid-thickness have been refined for a group, these values should be used for every guiding strip position. Program BEND defines the guiding as the least-strain surface in the group, and stacks conductors on either side of it as specified by the user.

If the guiding strip has conductors inside, the guiding strip **initial edge angle** and **starting angle** must be iterated by using BEND to create a group using the measured CADD angles, comparing BEND geometry with the CADD geometry, and adjusting until a match with the cross-section is obtained. First adjust the guiding strip initial edge angle to make the BEND side angles match the CADD side angles. Then adjust the guiding strip starting angle to position the group correctly in the X-Y plane. The BEND X and Y coordinates should be made to match the CADD coordinates at the inside and outside of the group. If the BEND input file has 8 decimal place accuracy, this match can usually be made to 6 or 7 decimal place accuracy.

With the magnet physicist, determine the **A-Length** and relative position for each group. A group's A-length must be proven to survive mechanically. An A-length can be specified that is too short to allow the twist in the group to be smoothly distributed. An A-length that is too long can cause the free edge to bulge excessively. These errors can sometimes be seen in BEND output, but all group surfaces should be viewed in a CADD package before being accepted. A starting point for determining a group's A-length would be to make it at least as big as the part inside the group is wide. On troublesome groups, several different A-lengths should be tried to find the one which optimizes the best.

An **origin difference** is a Z-axis translation used to shift the group into the proper relative position defined by magnetic analysis. An origin difference can be added to any group to locate the group where desired in the Y-Z plane. All surfaces of a group will have the same origin difference, but surfaces of a particular coil end part may have several different origin differences, depending on how many groups are required to define the part. The origin differences may have to be adjusted when a final magnetic optimization is complete.

It is preferred to design **lead end** and **return end** groups together so that A-lengths and origin differences specified for the return end will also work for the lead end. The A-lengths specified for a return end group are sometimes too short for the matching lead end groups to survive when they transition over to the other side of the wedge.

Before running program BEND, several sketches should be made which show the relative position of the groups in the coil end, and the orientation of the coil end parts that must be created. The first is a **developed top view sketch** of the coil **return** end, and is like looking down the positive Y axis with the paper being the X – Z plane. This sketch should show estimated A-lengths and origin differences, and will help the user to keep track of return end group creation and assist in establishing a naming convention.

The second is a **developed top view sketch** of the coil **lead** end. This sketch will help the user to keep track of lead end group creation, show which lead end groups must be created to transition to the other side of wedges, and show which surfaces and final edge angles must be matched to existing return end groups. The need for fillers and for parts with feather edges will be shown, and the method of handling the pole splice and power leads can be considered.

The third is a **Y – Z plane sketch** of the coil return end. This sketch will show the relative group positions, A-lengths and origin differences. Using a rough estimate of final edge angles, the user can verify that there is enough length in the coil end parts to allow the hole required for part manufacture and inspection.

Create a BEND **input file** with all the appropriate information included, and update the descriptive header at the top of the file. Separate input files may be created for each of the different A-length options being considered. The input file should be given the same naming convention as the group files which will be saved, and should have a **.xin** file type. The following file is provided for example (~brandt/lhc/irq/q1i/q2ir29.xin):

```
Input file for IRQ It.#1 Inner Coil R.E. group 2 (2/9 35mm A-length)
1.9922520         outer radius
1.3779528         inner radius
26.9594787        outer starting angle of the guiding strip
36.2058496        initial edge angle of the guiding strip
0.0632217937      mid-thickness of the cable
0.977125849       keystone angle of the cable
0.0               rounding of corners of the cable
2 9               numbers of cables on each side
1                 choose INside group A-length ( 2 for OUTside)
1.377952756       A-length
N                 do not choose the final edge angle of the guiding strip
20                estimated final edge angle of the guiding strip
```

The **naming convention** shown in the above file name is as follows: the **q** stands for quad, but is more of a means of grouping files together in a directory, and for keeping track of magnet projects and revisions. If a second revision of the IR quad end parts was started, the q would be changed to another letter. The **2** stands for the second-wound group in the coil specified. The **i** stands for inner coil. The **r** stands for return end. The **29** stands for 2 conductors inside and 9 conductors outside the guiding strip. The **.xin** stands for external input file.

Several **cable shape change parameters** are hard coded into **Program BEND**. The parameter FAT1 adjusts the mid-thickness of the cable at the group midpoint. FAT2 adjusts mid-thickness at the group termination, or nose. KEY1 adjusts the keystone angle of the cable at the group midpoint. KEY2 adjusts keystone angle at the group termination, or nose. The cable shape at the start of the group, where it meets the cross-section in the X-Y plane, is unchanged. All cable shape change parameters are applied smoothly along all cables in the group. Keep in mind that very small changes in these parameters can result in large changes in a group with many conductors.

When running BEND, several run-time options are available. **Option 1** is almost always chosen to allow the use of an external input file. **Option 7** is used for optimizing a group, and allows the user to define sweeps through a range of the variables shift and blunt. Refer to one of the referenced papers on end part design for descriptions of shift and blunt.

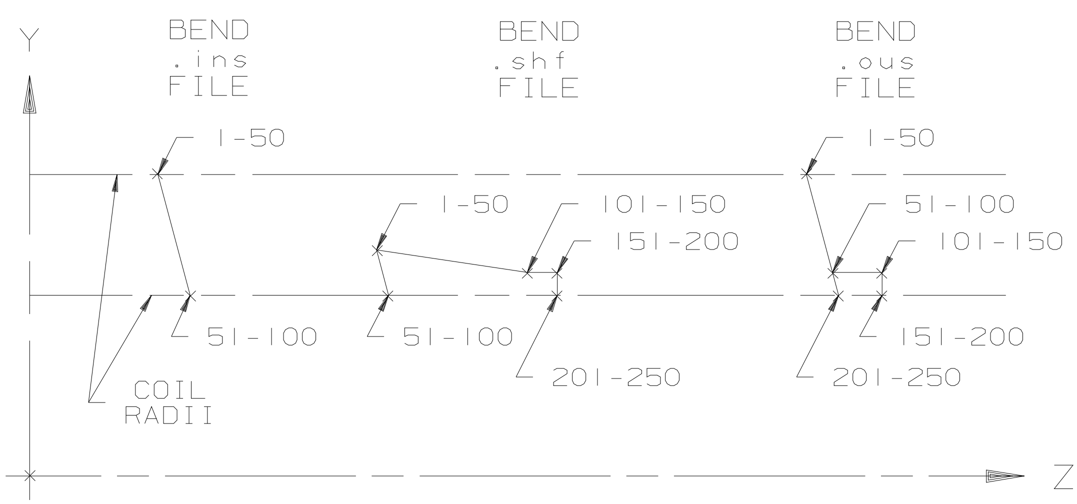
Shift should be optimized first, by sweeping through a range from –2 to 2 while holding blunt fixed at 0. Having found one or more local delta L / L minimums within the shift range, **Blunt** can then be swept through a range of 0.0 to 0.5, while holding shift fixed at the values of the local minimums. For troublesome groups, negative shifts are not recommended, because much of the twist is distributed late in the group. Blunt values can usually be found that improve the minimum curve radius in a group, sometimes at the expense of delta L / L's. Again, all group surfaces should be viewed in a CADD package before being accepted.

When satisfied with a group, all pertinent information and group geometry should be listed on a group data sheet. All six BEND files, **.cen**, **.cor**, **.fra**, **.ins**, **.ous**, and **.shf**, should be given a meaningful naming convention and saved. The **.cen** file contains the centroids of current density for all conductor trapezoids at each ruling, and is used for magnetic analysis. The **.cor** file contains the four corner points for all conductor trapezoid at each ruling, and is used for mechanical and magnetic analysis. The **.fra** file contains the Frenet frame for all conductor trapezoids at each ruling, and can be used to specify automated winding positions.

The last three BEND files represent geometry of the group and are used to define the coil end parts needed for a magnet: The **.ins** file contains points defining the inside surface of the group, where the rulings intersect the tube radii. The .ins file contains 100 lines: lines 1 – 50 define the outer radius spline, and lines 51 – 100 define the inner radius spline.

The **.ous** file contains points defining the outside surface of the group, where the rulings intersect the tube radii. This file also contains points defining the shelf undercut, which is required in the group outside surface if the group's shelf uses a shelf extension. The .ous file contains 250 lines: lines 1 – 50 define the outer radius spline, lines 51 – 100 define the intersection of the shelf with the group outside surface, lines 101 – 150 define the end of the undercut required for a shelf extension, lines 151 – 200 define the end of the undercut on the inner tube radius, and lines 201 – 250 define the inner radius spline, used when a shelf extension and undercut are not required or desired.

The **.shf** file contains points defining the group's shelf and shelf extension. The .shf file contains 250 lines: lines 1 – 50 define the intersection of the shelf top surface with the group inside surface, lines 51 – 100 repeat the points defined by the .ins file inner radius spline, lines 101 – 150 define the intersection of the shelf with the group outside surface, lines 151 – 200 define the end of the shelf extension, and lines 201 – 250 define the end of the shelf extension on the inner tube radius.



BEND File Point Labels

Based on experience with the LHC Dipole magnet ends, another program, DELCOR, was created by Joe Cook. This program uses the .cor file of a group to compute the delta L / L's of each cable edge at each ruling. Typical hard-way bend around the mandrel produces a stretching of the cable top edges and a compression of the cable bottom edges, resulting in a **negative delta L / L**. This results in the cable becoming more rectangular, which requires the BEND variables KEY1 or KEY2 to be made smaller. In the LHC Dipole program, one group appeared to have gaps near the midpoint of the group. After running DELCOR, it was found that a section of **positive delta L / L**'s existed, which would have been better compensated for by making KEY1 larger.

Program DELCOR was updated to **DELCORD**, which contains double precision variables. The Unix command sequence for producing an output file from program DELCORD for the q2ir29 group mentioned above is as follows, each line followed by a carriage return except where two carriage returns are indicated:

delcord.exe > q2ir29.txt		will write DELCORD output to **q2ir29.txt** file
q2ir29		will use q2ir29.cor as input file
-2	(2C/R)	analyze cable –2 from GS, and yes for next cable
-1	(2C/R)	analyze cable –1 from GS, and yes for next cable
1	(2C/R)	analyze cable 1 from GS, and yes for next cable
2	(2C/R)	analyze cable 2 from GS, and yes for next cable
3	(2C/R)	analyze cable 3 from GS, and yes for next cable
4	(2C/R)	analyze cable 4 from GS, and yes for next cable
5	(2C/R)	analyze cable 5 from GS, and yes for next cable
6	(2C/R)	analyze cable 6 from GS, and yes for next cable
7	(2C/R)	analyze cable 7 from GS, and yes for next cable
8	(2C/R)	analyze cable 8 from GS, and yes for next cable
9		analyze cable 9 from GS
n		terminate program

The file q2ir29.txt should then be edited, and the appropriate file names and cable numbers added. Printing out this file will help to see the areas of positive delta L / L which may occur, and trends in size and position of these areas. For the LHC IR quad program, the BEND executable b02l1.exe (KEY1 = 0.1) was used for groups which did not show a significant area of positive delta L / L's at mid-group, and b02q1.exe (KEY1 = 0.5) was used for groups which did. **The files and programs used for creation and analysis of any accepted group should be dated and well documented. Any file created in the design process should be saved using a consistent and meaningful naming convention.**

Program BEND produces files that represent groups of conductors. Coil end parts must be created with files that represent the spaces between and under conductors. These files can be produced with **Program PART**. This program prompts the user to enter the appropriate BEND files needed for part creation, prompts for key and saddle extension lengths and origin differences, adds negative signs to point coordinates where required, checks group final edge matching, adds required Anvil program creation data, and produces part files in three different formats:

The **.50p** file contains all 50 points for each spline needed to define the part. This is the file that should be used in Anvil for part creation. Three lines are added to the bottom of this file which identify the part type, whether it is lead or return end, and define the necessary straight section extensions and origin differences.
The **.20p** file contains only a select 20 points for each spline, and was once used for creating parts within I-DEAS. This file is no longer necessary to be saved.
The **.dap** file contains the same 20 points, in a format with general part information, and curve and point labels. This file can be used when producing the part drawings to identify curves and verify angles and other part features.

For any part created, at least the .50p and .dap files should be saved under a meaningful **naming convention**. For example, the spacer (5520-MD-344181) inside the q2ir29 group mentioned above was saved in the following files:

181_irspa.50p and .dap
181_irsshf.dap
181_shffrt.50p
181_shftop.50p

The "**181**" are the last three digits of the Fermi drawing number this part was given. The "**irspa**" stands for inner return end spacer. The "**irsshf**" stands for inner return end spacer shelf. Only the .dap file was created for the shelf because the default shelf part has an extension added to it, and the extension was not desired for this part. The 180_irsshf.dap file was created by Program part as a shelf in the default way, and then edited to remove the curve 5A and 5B points that define the extension, and add the curve 2 points from the **182_irsad.50p** file that were necessary to define the lower spline of the shelf front (renamed to curve 4B).

The **181_shffrt.50p** and **181_shftop.50p** files were actually created in Program PART as **keys**, using a key extension of 0.0 and an origin difference of 0.0. Entering 0's here will avoid the creation of un-needed Anvil geometry later. The Anvil programs do not have an option to create a shelf without an extension, so the shelf front and top surfaces have to be created in Anvil separately as keys. This requires two additional "BEND" files to be created by the user:

To produce the 181_shffrt.50p file, the "BEND" file **q2ir29frt.shf** file was created by copying from the q2ir29.shf file and removing the 1st, 2nd, 4th, and 5th splines, represented by lines 1 – 100, and 151 – 250. This leaves only the 3rd spline (50 lines) representing the top edge spline of the shelf front. The other 50 lines needed are lines 201 – 250 of the q2ir29.ous file, which must be appended to the q2ir29frt.shf file. This adds the 5th spline of the group's outside file which provides the lower edge spline of the shelf front. Here are the Unix and vi editor commands to do this:

cp q2ir29.shf q2ir29frt.shf	create copy of shelf file
vi q2ir29frt.shf	edit using vi editor
151G	go to line 151
100dd	delete 100 lines – the shelf's 4th and 5th splines
1G	go to line 1
100dd	delete 100 lines – the shelf's 1st and 2nd splines
:wq	write file and quit
cat q2ir29.ous >> q2ir29frt.shf	append group.ous file to shelf front file
vi q2ir29frt.shf	edit using vi editor
51G	go to line 51
200dd	delete 200 lines – the outside's first 4 splines
:wq	write file and quit vi editor

To produce the 181_shftop.50p file, the "BEND" file **q2ir29top.shf** file was created by copying from the q2ir29.shf file and removing the 2nd, 4th, and 5th splines, represented by lines 51 – 100, and 151 – 250. This leaves only the 1st and 3rd splines (100 lines) of the group's shelf file which represent the shelf top with no extension. Here are the Unix and vi editor commands to do this:

cp q2ir29.shf q2ir29top.shf	create copy of shelf file
vi q2ir29top.shf	edit using vi editor
151G	go to line 151
100dd	delete 100 lines – the shelf's 4th and 5th splines
51G	go to line 51
50dd	delete 50 lines – the shelf's 2nd spline
:wq	write file and quit vi editor

This method of producing shelves without extensions is tedious and somewhat confusing, but is all that is available at this time. To automate this process, Program PART would need to be revised to provide a "no extension" option in shelf creation, and the Anvil programs would have to be revised to produce the shelf using this new part option. If a shelf with a **shelf extensions** is desired, program PART and the Anvil programs can be used to create the shelf in the regular, default way. If a shelf extension is used, then the part in front of it must be created with the undercut option.

Before running program PART, the sketches that were made should be updated to show the names of the accepted groups in the coil end, and the accepted group A-lengths and origin differences as measured from the 0,0,0 origin of the end. The **updated sketches** will help the user to enter the correct group surfaces and origin differences when running program PART, will define the location of the wedge terminations, and will identify straight section extensions which must be added to part surfaces. For example, a key will need a straight section extension if the first wound group has an origin difference. A spacer is created from surfaces of two different groups. If these groups have different origin differences, then straight sections will need to be added to the spacer surface with the longest origin difference.

All group surfaces created with BEND should be **examined** in Anvil before being accepted for use in a magnet. The splines should be smooth with no kinks or discontinuities. The free edge of the inside group surface should be examined to ensure that the optimum blunt values have been used - too little blunt can make the nose appear too pointy, too much blunt can make the nose appear square. Any bulging of the free edge can be seen and its magnitude measured. Rulings should not cross each other, particularly at the free edge near the nose. Feather edges can be visually inspected by making the two surfaces a different color and viewing them in the shaded image mode. If the inside surface color protrudes too early into the outside surface, the groups may have to be redesigned.

Examining the splines near the **feather edge** will show if they cross each other, and the part thickness can be found by measuring the distance between them. The **shelf thickness** can also be studied in this way. In manufacturing, parts usually break up when they are around .005 to .008 thick. Shelves thinner than .020 thick at the nose will also cause manufacturing and assembly problems, particularly when there are large numbers of conductors in the group.

Once the program PART files necessary for the coil end parts have been created, an **Anvil object** of the part must be created for use by inspection and the machine shops by following the procedure below. The **part drawing** may also be created in Anvil if desired, or can be created in I-DEAS using the procedure contained later in this document.

Anvil 6.0 Model Space construction of a return end spacer with a shelf:

The following procedure will create the spacer (5520-MD-344181) with shelf inside the q2ir29 group mentioned above. The shelf has no extension, and the following files are required for Anvil model space construction:

181_irspa.50p	Contains points for four splines to make the spacer inside and outside surfaces.
181_shffrt.50p	Contains points for two splines to make the shelf front surface.
181_shftop.50p	Contains points for two splines to make the shelf top surface

Get into the proper Unix directory and create a new Anvil.prt file with the following Unix command:

cp ~simmonsa/LHC/q2i/template.prt 181_irspa.prt

This template.prt file has all the desired defaults and auxiliary views already set up.

Start Anvil and open 181_irspa.prt.

Create **shelf front**:
In Unix, rm E*

Click front view (1)
Click user icon
Click user customized #2
Click READ PNTS
Click 1, KEY
Enter "./181_shffrt.50p" followed by an O/C or two returns
Click blank and unblank icon
Click unblank all, yes
Click delete and trim icon
Click delete, click delete L=, FROM LEVEL = 600, O/C, O/C, yes
Click left view (7)
4-manipulation, 3-simple move, 5-all displayed, yes, 3-delta, X=1.8110, O/C, O/C
2-entity control, 3-entity modify, 3-N entities/1 change, 5-all displayed, yes, 2-offset level, displace=400, O/C
Click blank and unblank icon, click blank menu, 4-blank all, yes
8-file control, 1-file, yes

Create **shelf top**:
In Unix, rm E*

Click front view (1)
Click user icon
Click user customized #2
Click READ PNTS

Click 1, KEY
Enter "./181_shftop.50p" followed by an O/C or two returns
Click blank and unblank icon, click unblank all, yes
Click blank L=, FROM LEVEL = 500, TO LEVEL = 599, O/C, O/C, yes, O/C
Click delete and trim icon
Click delete, click delete L=, FROM LEVEL = 600, O/C, O/C, yes
Click left view (7)
4-manipulation, 3-simple move, 5-all displayed, yes, 3-delta, X=1.8110, O/C, O/C
2-entity control, 3-entity modify, 3-N entities/1 change, 5-all displayed, yes, 2-offset level, displace=300, O/C
Click blank and unblank icon, click blank menu, 4-blank all, yes
8-file control, 1-file, yes

Create **spacer body**:
In Unix, rm E*
Click front view (1)
Click user icon
Click user customized #2
Click READ PNTS
Click 3, SPACER
Enter "./181_irspa.50p" followed by an O/C or two returns
Click blank icon, click unblank all, yes
8-file control, 1-file, yes
In Unix, rm E*

Create **centerlines**:
Switch to level 0
Click color red#1
Click left view (7)
Click point, 2-coordinates, X=0, Y=0, Z=0, O/C, X=1.8110, O/C, click REJECT
Click font=centerline
Click line, 5-horiz/vertical/axis, 1-horizontal line, 3-point, click 0-0-0 point, O/C
Click delete and trim icon
Click trim 2 ends, click p at the 0,0,0 point and x at far right, click tube c-line, O/C
Click line, 2-coordinates, X1=2.625, Y1=1.125, ZI=0, X2=2.625, Y2=2.250, Z2=0, O/C, click REJECT
8-file control, 1-file, yes

Create **straight section lines**:
Switch to level 1
Click color green#1
Click font=solid
Click ISO 2 view (8)
Click blank and unblank icon
Click blank L=, FROM LEVEL = 400, TO LEVEL = 599, O/C, O/C, yes, O/C
Click line, 6-parallel/perp, 1-par to line thru pt, click tube c-line, click 4 pts at ends of spacer ous surface, O/C
Click left view (7)
Click delete and trim icon
Click trim 2 ends, click 0-0-0 point and 0-0-1.8110 point, click all 4 previous lines, O/C
8-file control, 1-file, yes

Create **arcs and wedge lines**:
Click front view (1)
Click arc, 3-center point and radius, click 0-0-0 pt, RAD=1.3779528, SA=45, EA=135, O/C
Click arc, 3-center point and radius, click 0-0-0 pt, RAD=1.9922520, O/C, O/C
Click ISO 2 view (8)
Click line, 3-join, click i and i at ends of each pair of trimmed lines in X-Y plane, create 2 lines, O/C

Click line, 3-join, click p and p at ends of each pair of ins surface splines in X-Y plane, create 2 lines, O/C
Click delete and trim icon
Click trim 2 ends, click 2 outside wedge lines in X-Y plane, click 2 arcs to trim, O/C
Click trim middle, click 2 inside wedge lines in X-Y plane, click 2 arcs to trim, O/C
8-file control, 1-file, yes

Create **cylindrical surfaces**:
Switch to level 2
Click color green#3
Click extended geometry (surface) icon
Click analytic surfaces (cylinder) icon
Click cylinder - axis at existing line icon, click tube c-line, RAD=1.3779528, O/C
Click cylinder - axis at existing line icon, click tube c-line, RAD=1.9922520, O/C
Click cylinder - axis at existing line icon, click hole c-line, RAD=.254/2, O/C
8-file control, 1-file, yes

Create **surface intersections**:
Switch to level 1
Click color green#1
Click blank and unblank icon, click blank menu, 4-blank all, yes
Click unblank all surfaces
3-geometric const, 5-3D constructs, 7-surface intersection,
1-surface/surface, click hole cyl, and outer tube, chordal tol=.0001,
1-surface/surface, click hole cyl, and inner tube, chordal tol=.0001,
1-surface/surface, click shelf top, and inner tube, chordal tol=.0001, O/C
8-file control, 1-file, yes

Prepare part for release:
Click blank and unblank icon, click blank menu, 4-blank all, yes
Click unblank L=, FROM LEVEL = 0, TO LEVEL = 1, O/C, O/C
Click unblank menu, 1-unblank all of a type, 4-other curves, 7-3D splines, O/C
Click blank L=, FROM LEVEL = 540, O/C, O/C, yes, O/C
8-file control, 1-file, control-w, 3-part filing format, 2-IEEE generic, O/C, yes

At this point the **Anvil Model Space** construction is complete. If the part drawing is to be made in Anvil, another procedure is required to produce a four-view **Anvil Drawing Layout**. At this time, it is envisioned that the part drawing will be done in **I-DEAS Drafting**, brought down from an **I-DEAS Solid Model**. If this procedure is followed, the Anvil portion of the part design is complete, and the Anvil.gen file is ready for release into XDCS.

I-DEAS Master Series 5 construction of a return end spacer with a shelf:

The following procedure will create the inner coil return end spacer #2 with shelf inside the LHC IR Quad Iteration #2 r3ir05 group. The shelf has no extension, and the part number for this spacer is 5520-MD-369021.

Creating the I-DEAS Program Files:

To produce the I-DEAS Program Files, several surface.50k files must first be created. These .50k files will represent one surface of the part being created, and will have the necessary "K : " string inserted at the start of each line.

The **05ins.50K** file was created by first copying from the r3ir05.ins file. Here are the Unix and vi editor commands:

```
cp   r3ir05.ins   05ins.50k        create copy of inside surface file
vi   05ins.50k                     edit using vi editor
:g/  /s//K  :   /                  globally substitute "K  :   " for first two spaces in each line
   ^^     ^ ^^                                               ^ ^^
:wq                                write file and quit vi editor
```

The **05ous.50k** file was created by first copying from the r3ir05.ous file and removing the 2nd, 3rd, and 4th splines, represented by lines 51 – 200. This leaves only the 1st and 5th splines (100 lines) of the group's outside file which represent the outside surface with no undercut. Here are the Unix and vi editor commands:

cp r3ir05.ous 05ous.50k	create copy of outside surface file
vi 05ous.50k	edit using vi editor
51G	go to line 51
150dd	delete 150 lines – the shelf's 2nd, 3rd, and 4th splines
1G	go to line 1
:g/ /s//K : /	globally substitute "K : " for first two spaces in each line
^ ^ ^ ^ ^	^ ^ ^
:wq	write file and quit vi editor

The **05top.50k** file was first created by copying from the r3ir05.shf file and removing the 2nd, 4th, and 5th splines, represented by lines 51 – 100, and 151 – 250. This leaves only the 1st and 3rd splines (100 lines) of the group's shelf file which represent the shelf top with no extension. Here are the Unix and vi editor commands:

cp r3ir05.shf 05top.50k	create copy of shelf file
vi 05top.50k	edit using vi editor
151G	go to line 151
100dd	delete 100 lines – the shelf's 4th and 5th splines
51G	go to line 51
50dd	delete 50 lines – the shelf's 2nd spline
1G	go to line 1
:g/ /s//K : /	globally substitute "K : " for first two spaces in each line
^ ^ ^ ^ ^	^ ^ ^
:wq	write file and quit vi editor

The three surface.50k files described above represent the surfaces of any group which are needed to create coil end parts in I-DEAS. Once a surface.50K file is complete, it must be inserted into the surface.prg file before it can be read by the I-DEAS modeler. This can be accomplished with the following Unix and vi commands. The example below is for creating the shelf top under the r3ir05 group, but this procedure can be used with any of three different surface.50k file types by substituting the appropriate file name.

cp ~simmonsa/LHC/q2i/blank.prg 05top.prg	
cat 05top.50k >> 05top.prg	append 05top.50k file to 05top.prg file
vi 05top.prg	edit using vi editor
1467G	go to line 1467
100yy	yank 100 lines
100dd	delete 100 lines
3G	go to line 3
p	put 100 lines back into file
3G	go to line 3
dd	delete blank line
:wq	write file and quit vi editor

Setting up the new I-DEAS Model File:

Start I-DEAS Solid Modeler

Open Model File Form

Give unique name for new Model File

Make sure you're in the following application task:

MASTER MODELER

Set units to inch (pound f)

Create Bins in new Model File.

MANAGE BINS/CREATE BIN... (create "PARTS" and "SURFACES" bins)

Warning!
If, during the creation of this part, you are prompted by I-DEAS to save your model file, respond: **No.**
Save only when this procedure instructs you to – not when I-DEAS prompts for a save. If you make a mistake at any time between saves and can't recover, you can re-start your model file at the point of the previous save by pressing: **Control-Z**

Create the surfaces:
Each of the following program files was created as described above, contains the point data coordinates of (2) 50 point splines, and will create one surface of the part:

05ins.prg	(inside surface of "third-wound, inner layer, 5 conductor group")
05ous.prg	(outside surface of "third-wound, inner layer, 5 conductor group")
05top.prg	(top shelf surface of "third-wound, inner layer, 5 conductor group")
06ous.prg	(outside surface of "second-wound, inner layer, 6 conductor group")

For program files to work properly there must NOT be any other parts or entities on the workbench.
Before running the program files, verify that there is nothing on the workbench.
INFO/RIGHT CLICK-**WORKBENCH** - (List window region should list 0 entities)

Run one program file to create a surface.
FILE/PROGRAM FILES/RUN/SELECT (example) 05ins.prg

Delete points.
DELETE/FILTER/POINTS/ALL

Reflect surface.
REFLECT/RIGHT CLICK**/AXIS PLANES/YZ PLANE/**0.0 **DISTANCE/KEEP BOTH**

Name the surface, and store in the SURFACES bin.
PUT AWAY/part name (example) 05ins/**BIN** – "SURFACES"

Save model file.
FILE/SAVE

Repeat for all four surfaces.

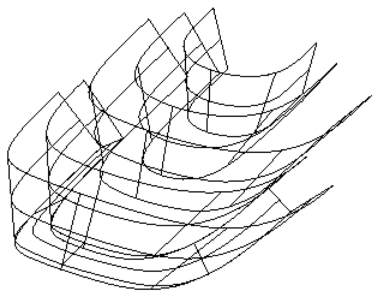
Copy and Orient the Surfaces:
Copy all surfaces into the PARTS bin. Always use these copied surfaces to create the part.
MANAGE BINS/COPY/ NAME PART-KEEP SAME NAME/**BIN** – "PARTS"

Put away all original surfaces in SURFACES bin, and get all copied surfaces from the PARTS bin.
GET/SELECT "PARTS" BIN/**OK**

Orient copied surfaces to match origin differences.
MOVE/PICK APPROPRIATE SURFACES/**TRANSLATE** in the positive Z direction (XX.mm/25.4)

Required surface translations for this part:

05ins, 05ous, and 05top	62mm
06ins, and 06ous	34mm



Put away all surfaces.
PUT AWAY/RIGHT CLICK-**ALL**

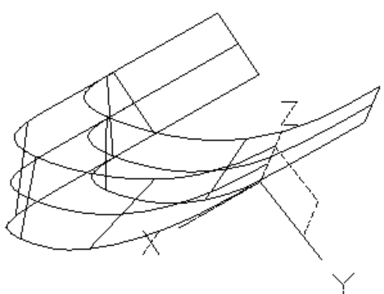
Save model file.
FILE/SAVE

Creating the Spacer Body:

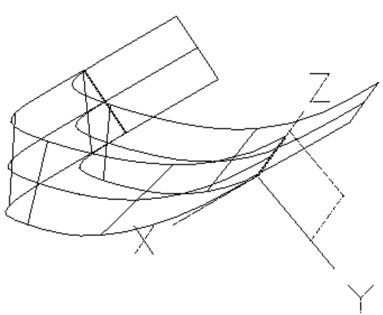
Get the copied surfaces 05ins, and 06ous from the PARTS bin.
MANAGE BINS/GET

Build coordinate system on the end of 05ins and create planar straight section extensions.
COORDINATE SYSTEMS/pick feather edge of 05ins/**DONE**

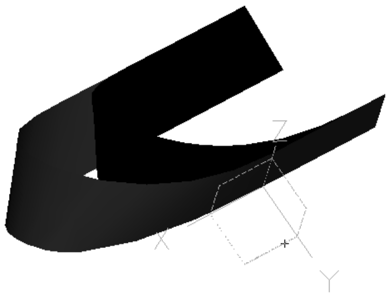
Sketch in place on plane of new coordinate system parallel to the Model File X-Y plane.
SKETCH IN PLACE/pick coordinate system plane



Sketch line focused onto plane.
LINES/RIGHT CLICK-**FOCUS/**SELECT LINE/ repeat for other side.



Extrude both lines to match feather edge of 06ous. (62mm - 34mm = 28mm)
EXTRUDE/SECTION OPTIONS/PLANER SECTIONS ONLY/
pick both focused lines/**DISTANCE** (28/25.4)

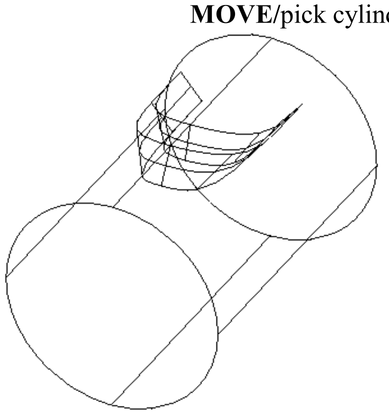


Stitch Edges of 06ous to 05ins.
STITCH SURFACE/RIGHT CLICK-**PICK SURFACES/**RIGHT CLICK-**ALL**

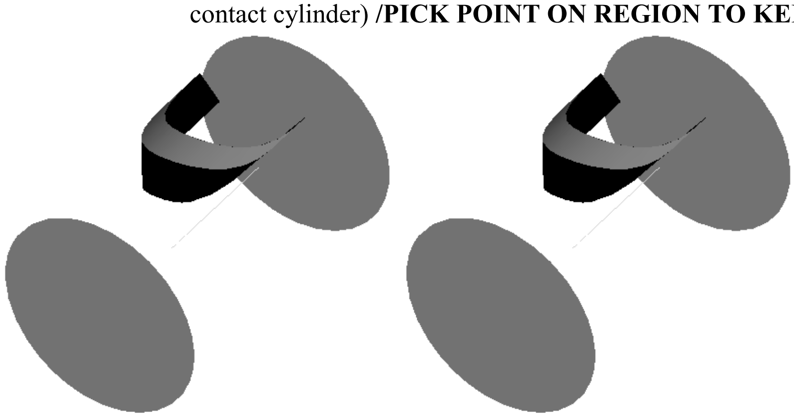
Confirm that feather edges have been stitched.
SHOW FREE EDGES/ALL/DONE (Feather edges should not show white dotted lines.)

Create cylinder with a radius equal to inner coil outside radius (1.9922520) and a height of 6 inches.
PARTS/CYLINDER/

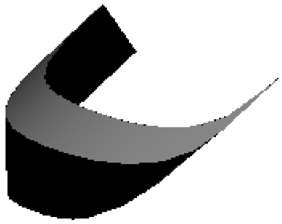
Rotate cylinder about the origin 90 degrees on the X axis, and translate in the positive Z direction.
ROTATE/pick cylinder/**ORIGIN/ABOUT X**/ "ENTER" TO ACCEPT 90 DEGREES
MOVE/pick cylinder/0,0,3 inch translation



Trim surface of cylinder.
TRIM SURFACE/pick cylindrical surface/pick trimming curves (use curves from 05ins & 06ous that contact cylinder) **/PICK POINT ON REGION TO KEEP**(cylinder within outline)**/DONE**



Delete end cap faces of cylinder.
DELETE/PICK 2 FACES/**YES**



Stitch edges of trimmed cylinder surface to spacer (after first stitch, the 05ins *surface* becomes the spacer *part*)
STITCH SURFACE/RIGHT CLICK**-PICK SURFACES**/RIGHT CLICK**-ALL**

Put away part.
PUT AWAY/Pick spacer (05ins)

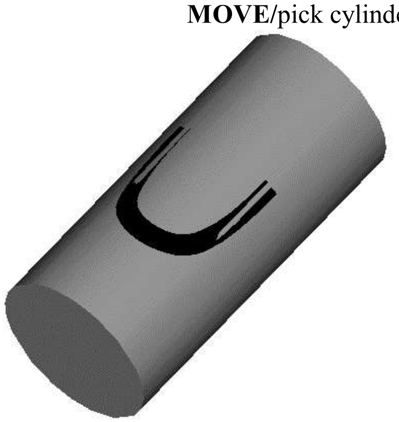
Save model file.
FILE/SAVE

Creating the Shelf Top:

Get copied surface that will define the top surface of shelf from the PARTS bin.
MANAGE BINS/GET/05top

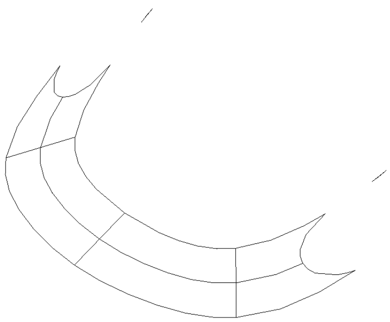
Create cylinder with a radius equal to inner coil inside radius (1.3779528) and a height of 6 inches.
PARTS/CYLINDER

Rotate cylinder about the origin 90 degrees on the X axis, and translate in the positive Z direction.
ROTATE/pick cylinder/**ORIGIN**/**ABOUT X**/ “ENTER” TO ACCEPT 90 DEGREES
MOVE/pick cylinder/0,0,3 inch translation



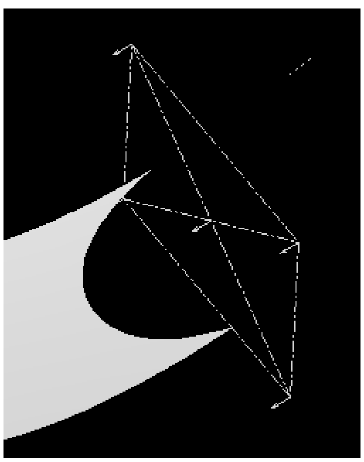
Name cylinder “MANDREL”, and specify the “PARTS” bin.
NAME PART/ “MANDREL”

Cut shelf top with MANDREL.
CUT/Pick cutter part (pick MANDREL)/ Pick part to cut (pick 05top)



*At this point it is possible that the cut has left small "islands" of surface area, outside of desired surface. These must be removed by the following technique:

PLANE CUT/(pick part**)/PICK CUTTING PLANE** (right click - Three Point)**PICK 1ST POINT** (pick vertex of "fish hook**")/PICK 2ND POINT** (pick other vertex of the "fish hook")/right click/ **TRANSLATED**/PICK POINT TO TRANSLATE FROM (pick either point)/**ENTER TRANSLATION** (0 .5 0)**/PICK SIDE TO KEEP** (arrows point to positive side)



Repeat for the other side.

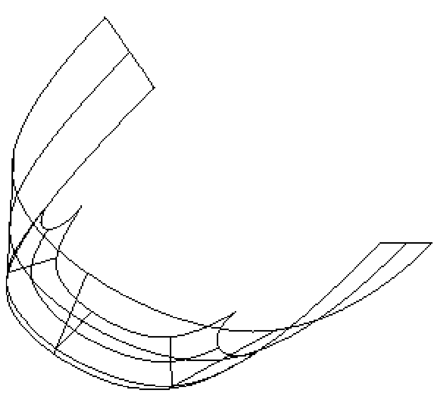
Save model file.

FILE/SAVE

Creating the Shelf Front:

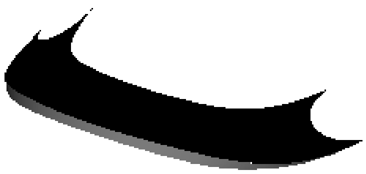
Get copied 05ous surface from the PARTS bin, this will become the shelf front.

MANAGE BINS/GET/05ous



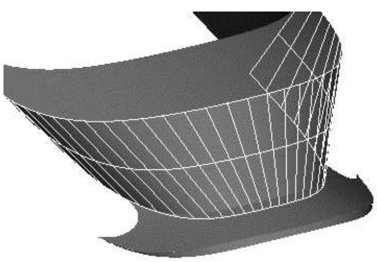
Trim surfaces of shelf front (05ous) with curves from trimmed shelf top (05top).
TRIM SURFACE/PICK SURFACE (pick 05ous)/PICK TRIMMING CURVES (use curve from 05top)**/DONE/PICK POINT ON REGION TO KEEP** (pick lower shelf front surface)**/DONE**

Repeat for other half of shelf front.

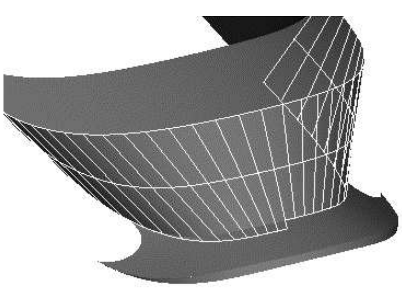


Save model file.
FILE/SAVE

Creating the Bottom Surface of the Part
Get the spacer (05ins) from the PARTS bin.
MANAGE BINS/GET/spacer (05ins)

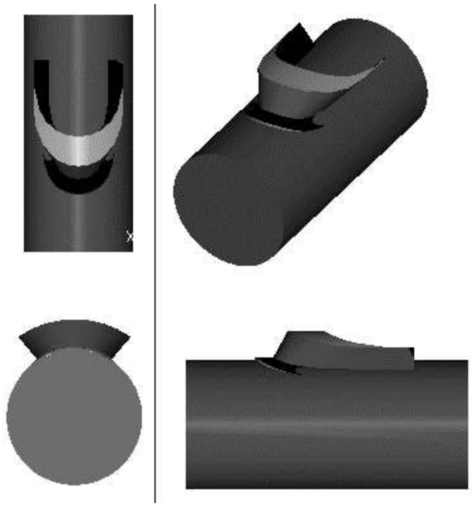


Trim spacer front surface with curves from the trimmed shelf top (05top).
TRIM SURFACE (pick spacer front surface)**/PICK TRIMMING CURVE**(pick 05top curve that intersects with spacer front surface**/DONE/PICK POINT ON REGION TO KEEP** (pick upper area of spacer front surface)**/DONE**

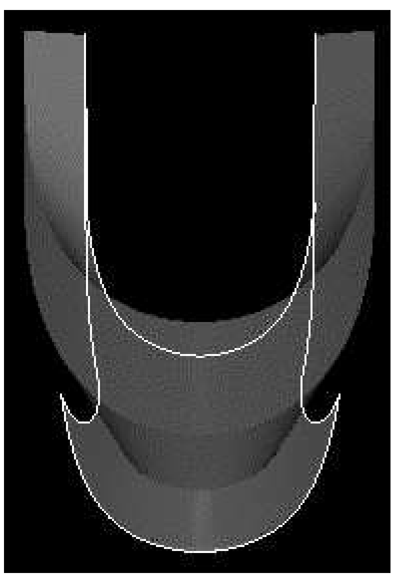


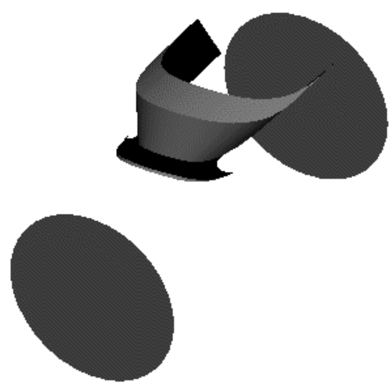
Repeat for other half of spacer front surface.

Get the part “Mandrel”, from the PARTS bin.
MANAGE BINS/GET/“MANDREL”

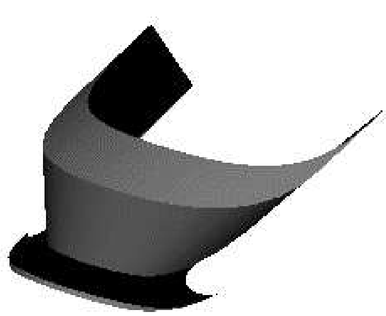


Trim surface of “MANDREL” cylinder.
TRIM SURFACE/pick cylindrical surface/pick trimming curves (use curves from 05ins, 05ous, and 05top that contact cylinder) **/PICK POINT ON REGION TO KEEP**(cylinder within outline)**/DONE**





Delete end cap faces of cylinder.
DELETE/PICK 2 FACES/YES



Stitch all edges of cylinder, shelf front, and shelf top to spacer (05ins).
STITCH SURFACE/PICK SURFACES/ALL/DONE

Confirm that all surfaces have been stitched together.
SHOW FREE EDGES/RIGHT CLICK-**ALL/DONE** (should show zero free edges found).

Confirm that only one part is on the workbench.
INFO/RIGHT CLICK-**WORKBENCH** - (List window region should list 1 Part)

Check that the part has Volume and Density
PROPERTIES/PICK PART/**MATERIAL/**Assign **8-GENERIC_ISOTROPIC_STEEL/ CALCULATE**. Physical Properties window should show Volume, Density, and Mass.

Rename the part.
RENAME/Pick spacer (05ins)/**PART NAME** - Inner RE Spacer #2 / 5520-MD-369021
All remaining copied surfaces in the PARTS bin can now be deleted.

Save model file.
FILE/SAVE

The **part drawing** can now be created from the solid model by using the I-DEAS Drafting Setup task, and exporting the multi-view Drafting Setup to Drafting. Hidden line removal, title block annotations, and dimensioning can be completed.

Once the I-DEAS modeling and drafting portions are complete, the drawings should be plotted, checked, and approved for release. The checking and approval information should be added to the I-DEAS drawings and the Ideas.dwg file saved. The Ideas.dwg file can be moved or copied into the XDCS produced drawing name, with a .dwg extension. The Anvil.gen file should be copied, not moved, into the XDCS produced drawing name with a .gen extension, so that a record of the Anvil part will remain in the user directory. When the XDCS check-in is done, both the **Ideas.dwg** and the **Anvil.gen** files with the XDCS name will exist in XDCS.

The **Anvil.gen** file will be used by the machine shops to produce tool-paths for part manufacture, and by inspection to produce probe-paths for part inspection. The Anvil.gen file contains all the curve mesh surfaces, based on the original BEND rulings, that are needed by the machine shops. The Anvil.gen file also contains all the surface inspection points needed for Material Control Cordax inspection. The **Ideas.dwg** file can be plotted as a hard copy for manufacturing, inspection, engineering, and design/drafting. The coil end parts produced by the I-DEAS Solid Modeler should be checked into the appropriate **I-DEAS library**, for use by other engineering and design/drafting personnel.

References

[1] J. M. Cook, "An Application of Differential Geometry to SSC Coil End Design," SSC Laboratory SSCL-N-720, FERMILAB-TM-1663, Fermi National Accelerator Laboratory, Batavia, IL, 1990.

[2] J. M. Cook, "Strain Energy Minimization in SSC Magnet Winding," in *IEEE Transactions on Magnetics*, vol. 27, pp.1976-1980, March 1991.

[3] J. S. Brandt, "Coil End Design for the SSC Collider Dipole Magnet," FERMILAB-TM-1735, FERMILAB-Conf-91/196, Fermi National Accelerator Laboratory, Batavia, IL, July 1991.

[4] J. S. Brandt, "Coil End Design for the LHC Dipole Magnet," FERMILAB-TM-1954, Fermi National Accelerator Laboratory, Batavia, IL, May 1996.

[5] J. S. Brandt, "Coil End Design for the LHC IR Quadrupole Magnet," Fermilab Technical Support Technical Note #TS-96-013, Fermi National Accelerator Laboratory, Batavia, IL, November 1996.