SoLID with 6.5° nose angle and 6” endcap steel corrected

Jay Benesch

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Summary

Physics Division Mechanical Engineering was recently able to devote some time to comparing the Opera model I exported to their CAD model. Two typos were found and corrected in the Modeller primatives (Appendix A). There are still some discrepancies at the hundred micron level; since there's no cost effective way to machine such large stock to that tolerance I have not put effort into resolving them. See appendix for notes.

In the meeting to discuss the differences on 26 April, Robin Wines suggested that it might not be possible to obtain steel with the assumed chemistry for the large cone casting. I show force results with 1010 steel BH curve for the cone and plug in what follows.

Results

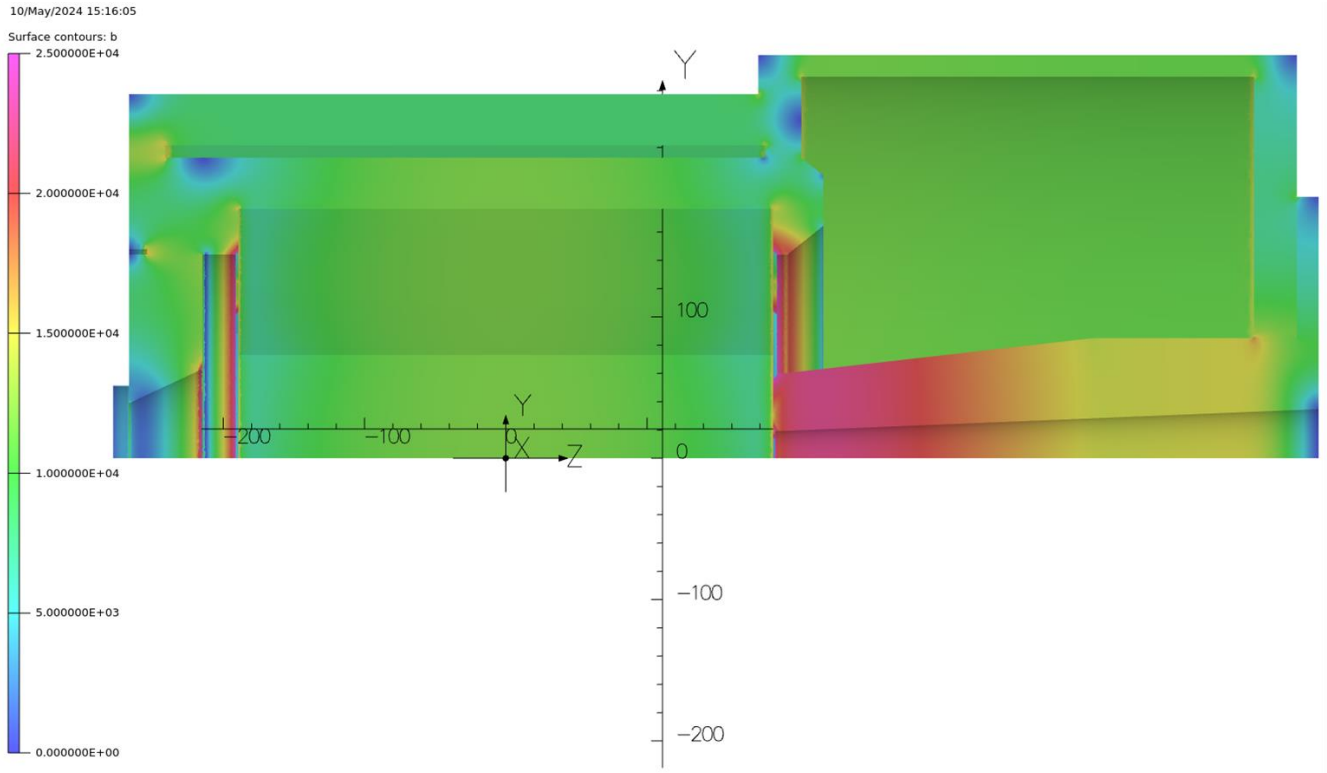

Figure 1. Field on surface of model L as defined in table which follows Appendix. Existing notch in coil collar is at left in blue with enhanced field just after it in Z. Esthetically I'd like to have it filled with 1.5” by 5” bar stock, any carbon steel alloy, but that isn't necessary magnetically. Plug and cone are 1010 steel in this model.

I couldn't make LibreOffice put the table on the next page.

Appendix A: Modeller primitives used to build Opera models revised 5/10/24 (changes in red)

Inner octagon steel1 level 92 4cm

inside Y 69.5" = 176.53 cm * (1/cos 22.5)= 191.075 IR
outside Y 83.71" =212.62 cm * (1/cos 22.5) = 230.142 OR
radial thickness 39.069 cm.
Z -266.7 to 224.79

Opera has a operation: make n-sided polygon. Using 230.142 OR and thickness 39.069 one arrives at an octagon with the inside and outside heights on the Cornell drawing 6052-303 sheet 3.

Chamfer at Z 224.79 OR 15.56 in Z by 12.45 in R

Notch construction air at end of inner octagon

Whit has a 1.5" notch running Z=189.23 to 224.79 which is 1.5" deep to match hexagonal OD of new coil collar. But coil collar has round ID. So I have to make a hexagonal notch in inner octagon and then trim overlap. As above, the OR 71" = 180.34*(1/cos 22.5) = 195.2,
IR 69.5" =176.53*(1/cos 22.5) = 191.075 but use deltaR 4.25 and Z 225 max to grab it.

Outer octagon steel2 level 91 4cm (so I can make it air BH later)

outside Y 101.42" = 257.61*(1/cos 22.5) = 278.832 OR
radial thickness 39.069 cm
Z -266.7 to 209.23
Again, make n=8 polygon of this Opera "tube"

Spacer bars steel2 level 91 4cm (so I can make them air BH later)
Between octagons: I figured out the volume of the bars and determined that cutting the Z extent to 25.5 cm would maintain the steel volume. Z extent: -266.7 to -241.2, 183.73 to 209.23. This simplifies the model a lot. These end annuli are merged with the outer octagons in the model and trimmed by inner - no air gaps.

Coils used cold dimensions from OMT manual, including Z shrinkage, and warm Z lengths of outer segment from winding drawing.

IR 151.7 OR 154.9
Z1 -173.75 to -85.45 3814.273 A/cm^2
Z2 -85.45 to 85.45 3708.32 A/cm^2
Z3 85.35 to 173.75 3814.273 A/cm^2

Current densities were derived by looking at total turns, 1281, and conductor sizes from IEEE paper and estimating winding pattern. Only later did I see the winding drawing. I can't find turns count on it. I did learn that the 4.9 mm conductor is used only on the outer winding outer layer, not both layers. More recently I've multiplied the current densities above by -1.0072 (ends) and -0.9961 (center) to get the ratio closer to 1.04 quoted in the paper. Correction solenoid 9 cm square, -1.2

Upstream coil collar steel1 93 4cm
OR 194.145 cm, 113.50" ID => 144.145 cm IR, deltaR 50, Z -266.7 to -189.23 cm (30.5" extent). Trim overlap with inner octagon. At the IR there is a step, Z 12.7, δR 3.81 cm. An annulus of air Z -270 to -254, R147.955 cm with δR 3.81 cm was trimmed from the coil collar steel. Z -270 start so it could be selected easily. I would prefer the annular gap be filled with 1.5" by 5" bar stock, any carbon steel alloy, but it's not required.

Coil air: level 100 2cm
OR 156 cm, thickness 5 cm, Z -175 to 175 cm

Upstream plug steel1 93 4cm
Z -266.7 to **-214.25** cm (20.65”Δ) with 6.5° taper on steel cone. Plug OR 144.145 cm. Solid to start. Create a cone with 1 mm R tip at Z=-350 and base 74.61 cm R at Z=-190, aka 25 degree angle. Trim overlap of steel with air, then delete air leaving conical hole. *Bold value varied to null force on coils.* See table in body for the forces resulting from variations in the BH curve and -214.25 dimension. The 1 mm radius cone tip is needed in Opera and causes a tiny discrepancy with the trigonometric calculation used for the cone steel and cylinder A. I

Downstream collar steel1 94 4cm
Z 189.23 to 224.79
tube OR 195.20 deltaR 51.2
at IR 144, Z 224.79 chamfer R 20.447 Z 25.56
trim overlap to inner octagon notch made on previous page

Cone steel1 95 4cm
R59.16 cm at Z 189.23 from 6.5° constraint
R85 at Z 416.04 from 6.5° constraint and 85 cm OR maximum
trim cone started 1 mm radius at Z= -330 per Michael Paolone email, 6.5°

CylinderA steel1 95 4cm
OR 85 Z 416.04 to 575.31

Endcap_cyl steel3 90 4cm
OR 285.24 delta R 15.24 (6”) Z 209.23 to 529.59

End_plate1 steel1 90 4cm
OR 285.24 delta R 200.24 (leaving 85 cm for CylinderA), Z 529.59 to 544.83 *(3mm typo in previous model corrected)*

End_plate2 steel1 90 4cm
OR 285.24 delta R 200.24 (leaving 85 cm for CylinderA), Z 544.83 to 560.07

Cone_plate steel1 95 4cm
OR 185 delta R 100 (leaving 85 cm for CylinderA), Z 560.07 to 575.31, no chamfer as hard to cast

Hole in cone: IR 19 cm at Z 189.23, IR 35 at Z 581.85 from 2 and 3.5 degree constraints

Interface_endcap steel1 90 4cm
OR 285.24 delta R 30.73 Z 178.75 to 209.23 aka 12”: interface octagons to end cap cylinder. Trim overlap with outer octagon.

Inner_air level 80 4cm
R310 Z -300 to 600. R100 Z -450 to -300
And in gap between octagons: Z -240 to 184 overlaps bars a bit OR 240 deltaR 10 should cover gap.
Use cut plane at Z=0 to see gap and trim overlap sequentially.

Detector air, level 82 2cm
part 1: R132 Z [-188,188] *part 2*: OR 258, dR 173 Z [224.79,508.79] shorter OK per Xiaochao
Outer air 70 32cm
R500 Z -500 to 800. level 70.

Background cylinder has multipliers applied to stuff I defined. Z 9 R 8 240 cm max mesh. Meshes out to 5000 cm both directions.

corrector_ring steel1 97 2cm
OR 51.435 deltaR 0.635 so IR 50.8 (20")
Z -266.7 to -278

Correction_coil IR 40 cm vs end plug hole 38.84 IR. Cross section 9 cm square. J 100 A/cm^2 is base current density in model; multipliers used are shown in Figures 5 and 6. Offset -277 cm from Z=0 so downstream end is at -268, 1.3 cm from plug face. #8 square conductor is 0.1298+0.005 = 0.1348" maximum dimension. 0.3424 cm. Assume conductor is butted within layers and there is 0.010" glass between layers to wick epoxy. 25 turns/layer +1 for transition, 24 layers, 600 turns total. More layers are possible within the 68 V stable maximum of the 1500 W trim supply if more field capability at He3 target is desired. Steel OD will have to be adjusted if 28 or more layers are desired.

Not done for model: Service turret steel removal. I built a rectangular parallelopiped of air inclined at 22.5 degrees with 13.2" X width and 14" Z width. I made it substantially longer than the chord of the paired octagons. I moved it to 30.75" from -Z end at the edge of the top plate. I trimmed the overlap of the steel and air, then deleted the air. "Inner air" above fills the gap created.

Table detailing model variations

model	plug_downstream_Z	plug_material	plug_Z_extent_cm	cone_material	coil_collar_step(Y/N)	coil_force_N	coil_force_lbf	plug_Z_inch
A	-214.25	JLab_spec	52.45	JLab_spec	N	-2520	-566	20.65
B	-214.25	JLab_spec	52.45	1010	N	-26553	-5969	20.65
C	-214.3	JLab_spec	52.4	JLab_spec	N	6504	1462	20.63
D	-214.4	JLab_spec	52.3	JLab_spec	N	9695	2179	20.591
E	-214.25	JLab_spec	52.45	1010	Y	-27373	-6153	20.65
F	-214.25	JLab_spec	52.45	JLab_spec	Y	-3340	-751	20.65
G	-214.25	1010	52.45	1010	N	-26070	-5861	20.65
H	-214.63	1010	52.07	1010	N	-6431	-1446	20.5
I	-214.25	1010	52.45	1010	Y	-26843	-6034	20.65
J	-214.7	1010	52	1010	Y	-3978	-894	20.472
K	-214.75	1010	51.95	1010	Y	-2287	-514	20.453
L	-214.8	1010	51.9	1010	Y	-758	-170	20.433

Comparing models A and C one sees that with the JLab steel BH curve plug extent 52.435 cm would approximately null the force on the coils, 0.015 cm or 0.006” from model A. Hard to hold that tolerance on a piece this size. With 1010, models K and L, 0.030” less than K gets close to null.