First attempt at a conductively-cooled superconducting septum magnet for the FFA upgrade
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Abstract

The water-cooled copper technology used in the existing CEBAF septum magnets cannot be extended to higher energy. (1) MgB2 conductor is commercially available and can do 200 A/mm$^{2.}$ at 2T/20 K. (2) At the FFA working group meeting 29 July Ryan Bodenstein showed a concept for the NE spreader which included two 3 m dipoles at 8.83 kG nominal field, separated by 5 m. Scott Berg, in the subsequent discussion, suggested making one 6 m dipole. Only after I built the model described below did I realize that there have to be two 3 m dipoles with TBD drift between them because the lowest energy beam has to pass by the second dipole to continue in its purely electromagnetic magnet pass. The other six beams end up in the FFA after being brought back down to linac height. N evertheless, the exercise was instructive. Current density of 180 A/mm$^{2.}$ is required. Field at the conductor is 1.1T. The pole has to be widened about 3 cm from that shown below to accommodate the cryostat. Conductive cooling via copper sheet on either side of the SC has not been evaluated; that will be done after the next iteration since the distance to cryocoolers will be halved. Pole gap of 8 cm may be insufficient given 17 turns of 3.5 mm cable = 5.95 cm stack. It's worth documenting this work before the next iteration. Magnet modeled as horizontal bend, vertical is actually required.

Discussion

Five variations on septum design, including hybrid ones with both iron and current sheets, were tried before the one shown here was settled on for deeper exploration. Figure 1 shows an end view of the model with the field at the midplane displayed; this model has 185 A/mm$^{2.}$ Two bedstead coils are used in the model, reflected about the horizontal axis. It is expected that only one will be fabricated, extending ±3 cm about y=0, but the use of symmetry cuts computation time.

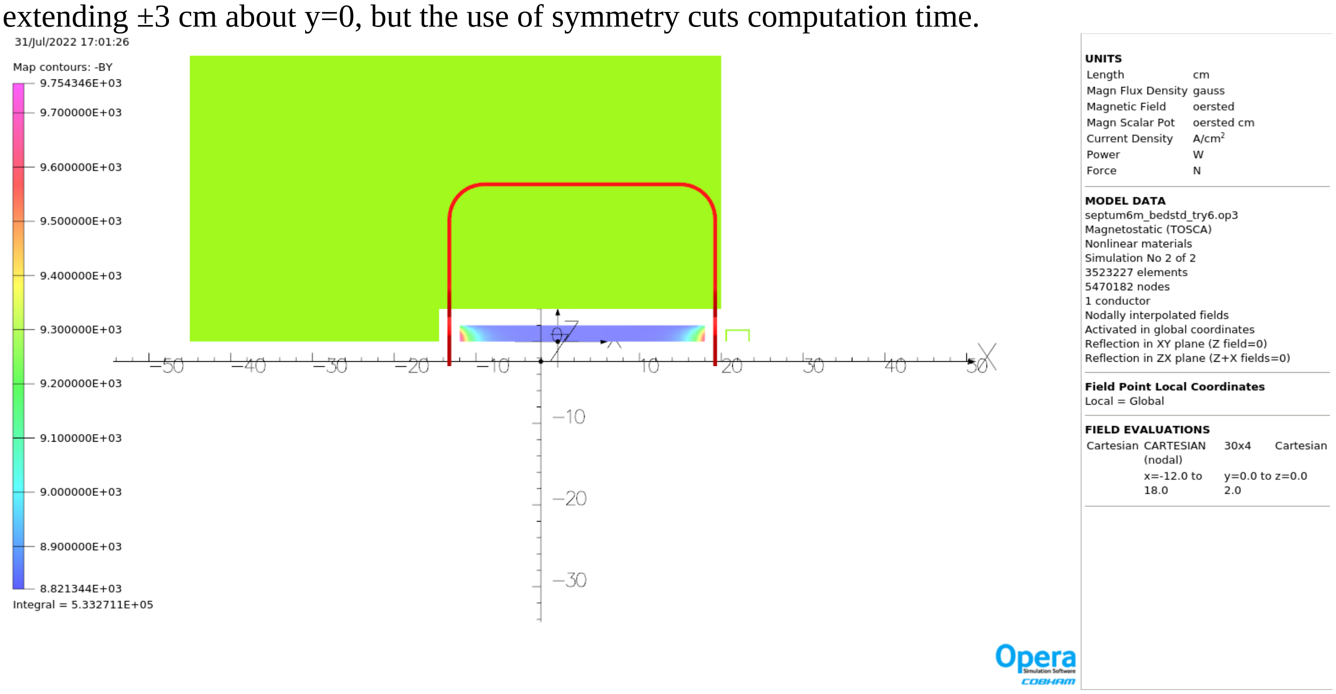

Figure 1. End view of model. Note the small green feature just to the right of x=20. This is a rectangular carbon steel beam tube for the “passing” beam.

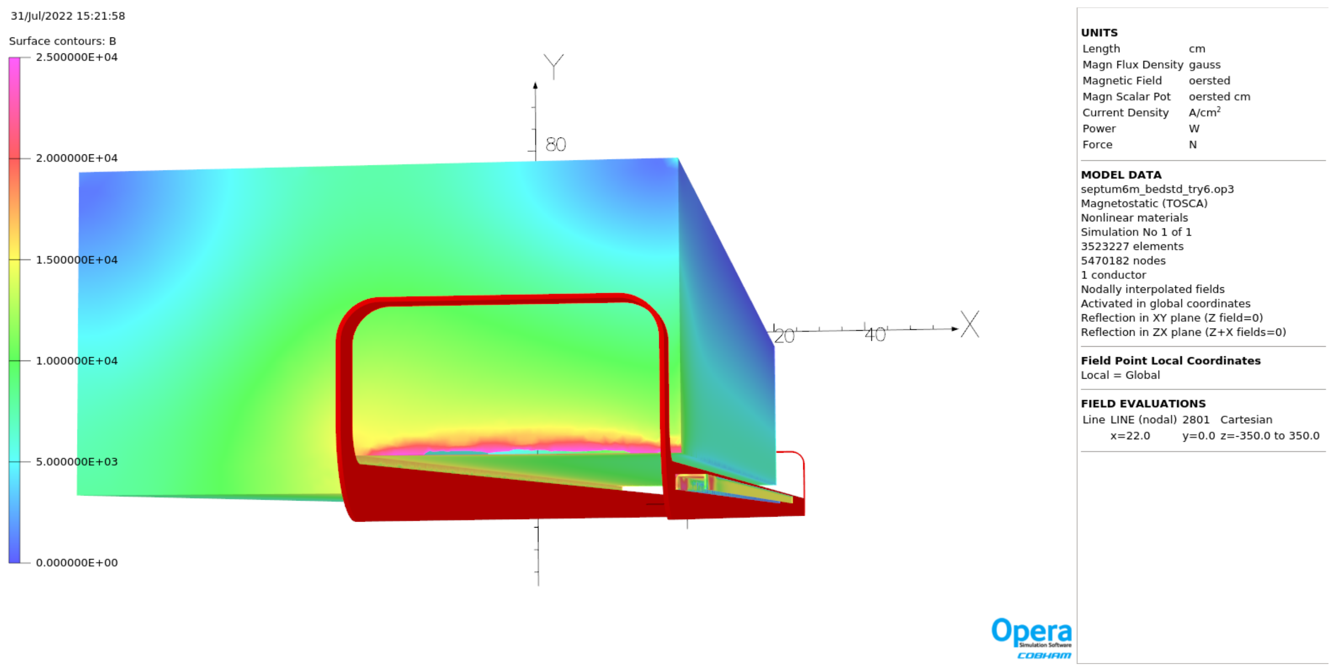

Figure 2. |B| on the surface of the steel. Again, 185 A/mm^{2}. The field on the tube at the right indicates that most of the stray flux is blocked except at the ends.

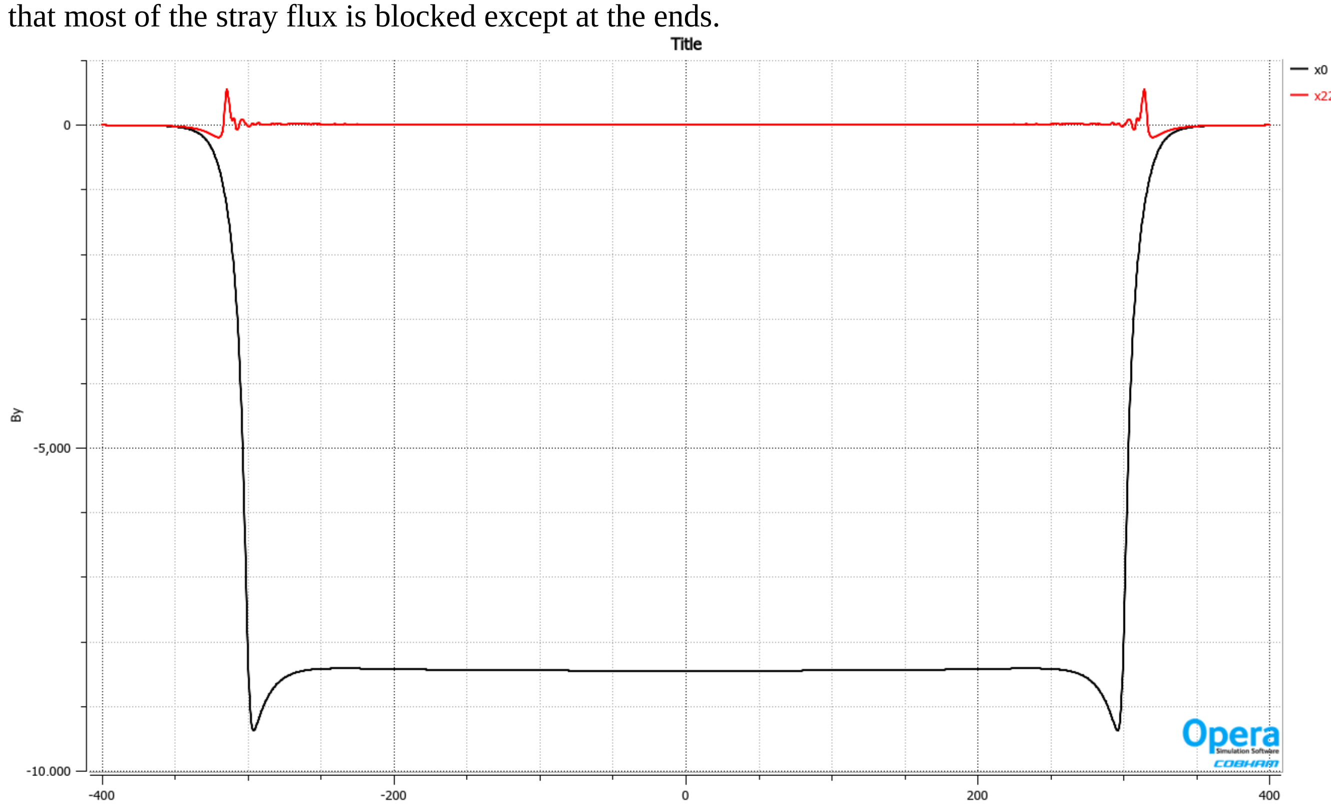

Figure 3. By(z) at X=0 (x0, black) and X=22 (x22, red) cm; the latter is within the steel beam tube noted above. This plot was done in the simulation with 180 A/mm^{2}. Field integral along the black line -5.213E6 G-cm. Field integral along the red line 1312 G-cm.

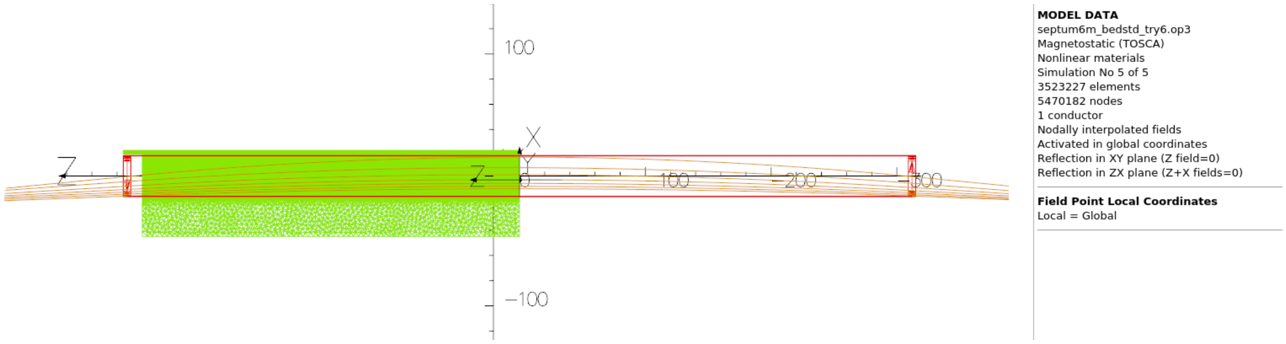

Figure 4. Seven orbits, energies 8350 -21550 MeV at 2200 MeV intervals with starting locations and angles taken from Ryan's NE spreader design.

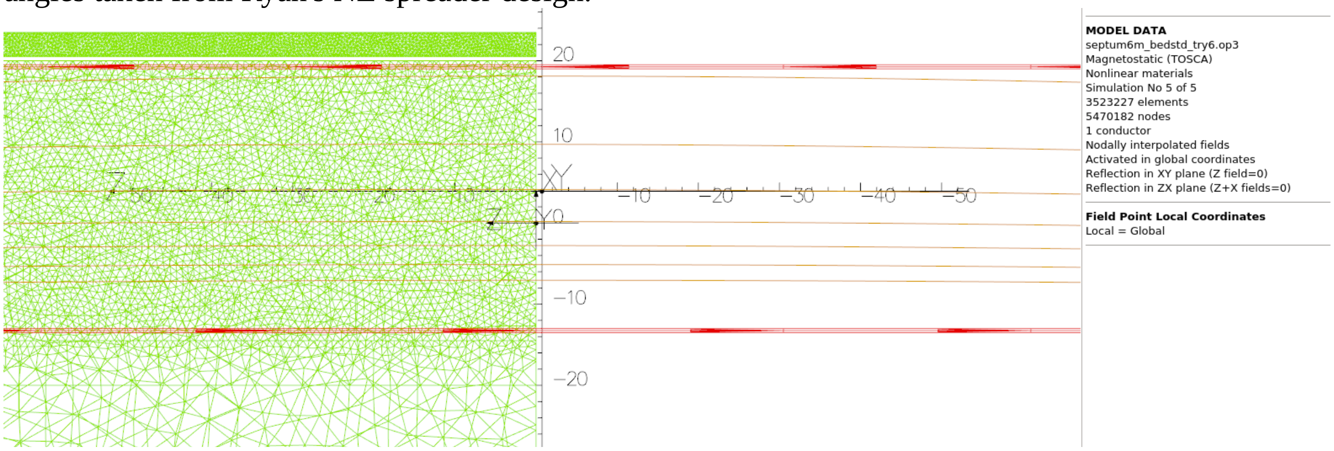

Figure 5. Central region of Figure 4. The lowest energy beam (topmost) is too close to the conductor for a functional cryostat so the pole will have to be widened and the conductors separated by ~3 cm.

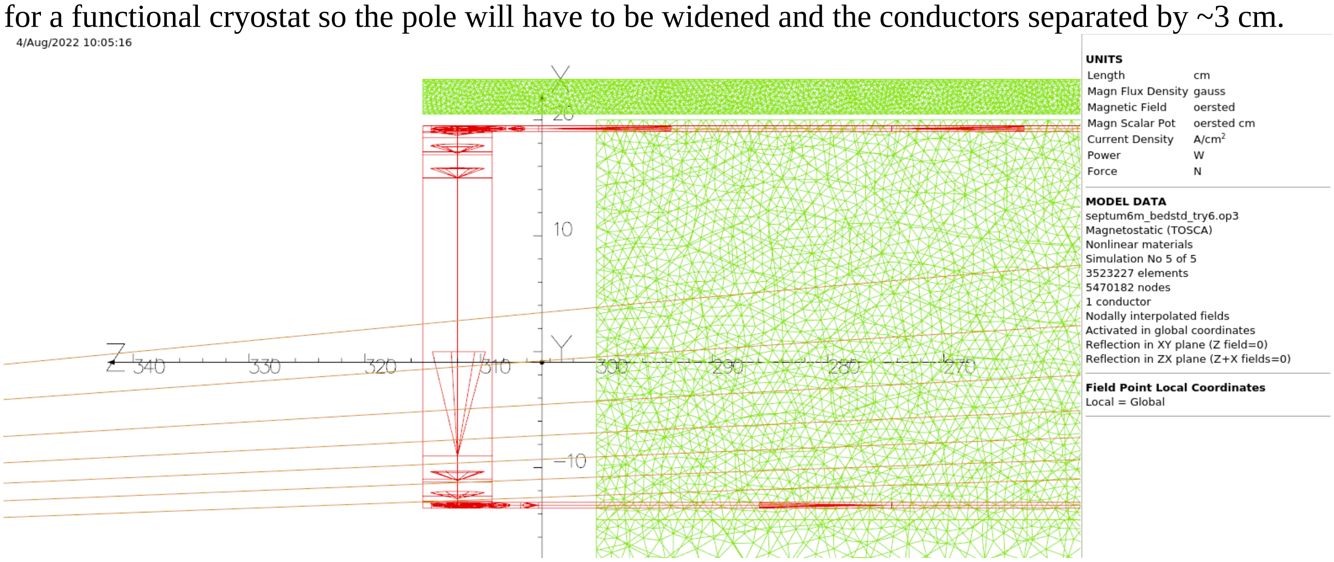

Figure 6. Seven orbits at left end of figure 4, exiting the magnet. Again the beam is too close to the conductor for a functional cryostat.

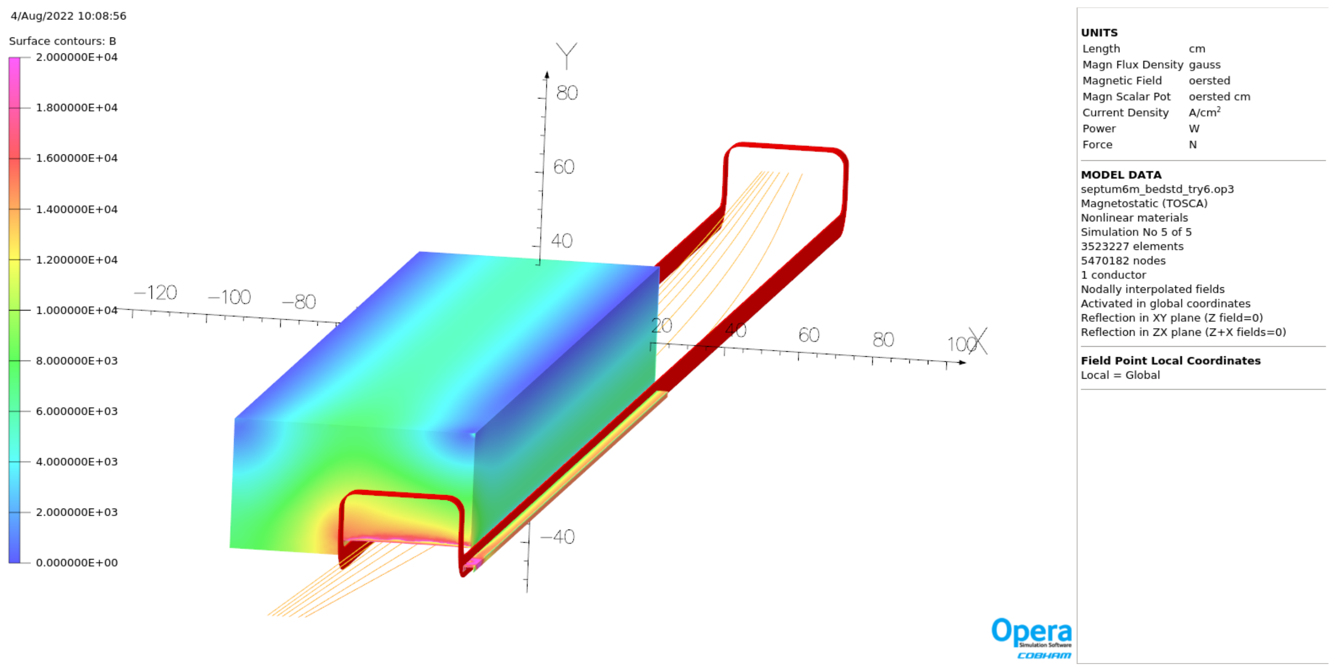

Figure 7. Perspective view of the model with the seven orbits. 180 A/mm^{2}.

Conclusions

This first look at a septum magnet for the CEBAF energy upgrade demonstrates:

1. Two three-meter magnets will be required so the fourth pass beam can be conveyed to its arc, drift at least one meter for cryocoolers, rather than one six-meter unit as shown above.
2. Superconductor is absolutely required: the existing ZA at 50 A/mm^2 in the copper already pushes conventional technology farther than any other DC septum magnet. Highest current pulsed septum the author has located is 80 A/mm^2 ; not relevant for CEBAF.
3. Clear width between the conductors in the next model should be 35 cm as compared to 32 cm here to allow 1.5 cm on either side of the conductor for the cryostat and ~1 cm beam halo allowance. There is only a 1 cm gap between the conductor and the pole top and bottom; I'm assuming we can live with greater heat leak there. If not, pole gap will have to increase to 9 cm. I will solicit input from out cryo group before starting the next iteration. [1.3 cm gap is roughly what the MRI magnets I worked on had between the OD of the helium vessel and the OD of the "patient" cylinder. This gap included a thermal shield connected to a cryocooler and superinsulation. In other words, I've seen an existence proof. Of course those were cylinders, not flat-sided, so deflection due to air pressure was less of a consideration.]
4. With the additional pole width this magnet will be 68 cm high. Bottom is getting close to the floor. Overall width 70 cm.
5. The author can provide Fourier components along the seven orbits if requested. Allow a few days for response.

References

1. https://jlabdoc.jlab.org/docushare/dsweb/Get/Document-254194/22-010.pdf
2. https://arxiv.org/abs/2201.09501 Advances in MgB_2 Superconductor Applications for Particle Accelerators, Akira Yamamoto