A quick and dirty magnet design for the magnetized beam LDRD proposal

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Abstract

I describe a realizable Helmholtz pair design which provides 500 ppm Bz uniformity over a 1 cm cylinder 14 cm long for possible use in the LDRD magnetized beam experiment. The assembly has a 2 cm steel return to partially contain stray field and enhance the bore field about 20%. Other options suggested include a Halbach cylinder and an "open" MRI magnet. Both would require much less facility modification than would an electromagnet.

Electromagnet

Coils are Z-symmetrically placed extending from Z=13-23 cm and R = 28.5 – 43.5 cm, 10 cm Z by 15 cm R cross-section. A 9 mm square conductor with 6 mm hole is assumed, half-lapped with 0.002" mylar and then single-lapped with 0.01" B-staged S or E glass. The mylar provides insulation and the fiberglass-epoxy structural strength. With tolerances, the insulated conductor is 1 cm square. Coil will be fabricated of five double pancakes, each with 30 turns, for a total of 150 turns. Water pathlength 68m per double pancake, use 70 m for convenience. Copper cross-section 0.496 cm^2, use 0.5 for convenience. If I assume a 40C temperature rise, copper resistivity 2.09 μohm – cm. Resistance about 30 milli-ohm per double pancake or 0.3 ohm per pair of coils. At 420A, yielding ~2 kG, ~5300 W/double pancake aka water circuit. Water volume in 68 m of 6 mm hole is 1920 cc, so 2.76 W/cc. Since I don't know what the heat transfer efficiency is from the copper to water, I'm going to assume 1 calorie/s (4.2W) per cc. Round the 1920 cc to 2 liters. At 2 l/s, 1C conductor rise. At 2 l/min, 60C rise (too much given 35C entry), but only 2.8 bar pressure drop per http://www.pressure-drop.com/Online-Calculator/ for straight 70 m of 6mm tube with 0.005 mm internal roughness. For 3 l/min, 40C rise (so 75C exit), 5.8 bar. Unfortunately, building 18 (LERF) has only 80 psi (~5.5 bar) LCW pressure per G. Biallas. Power supply: 450A, 150V would be nice, but 425A by 140V would probably do, including lead losses. 60 kW. Ten double pancakes each requiring 3 l/min is 30 l/min, plus power supply coiling. Say 10 gpm at 35C and 8 bar at entry to be comfortable. But since I equated 2.76 to 4.2 above, this is a crude estimate. Tommy Hiatt confirmed that ~7 bar differential pressure is needed.
http://www.luvata.com/en/Products/Special-Products/Hollow-Conductors/Tool-List/Square-with-round-hole/

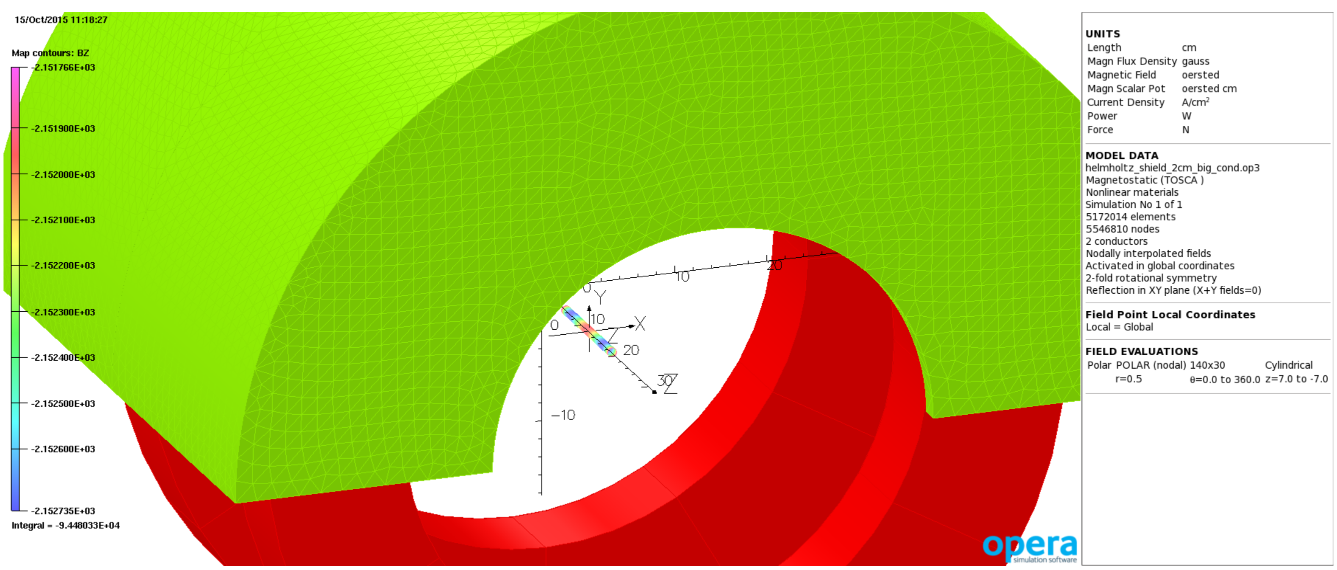

Figure 1. Coil pair with a 1 cm diameter, 14 cm long cylinder at the center showing field uniformity.

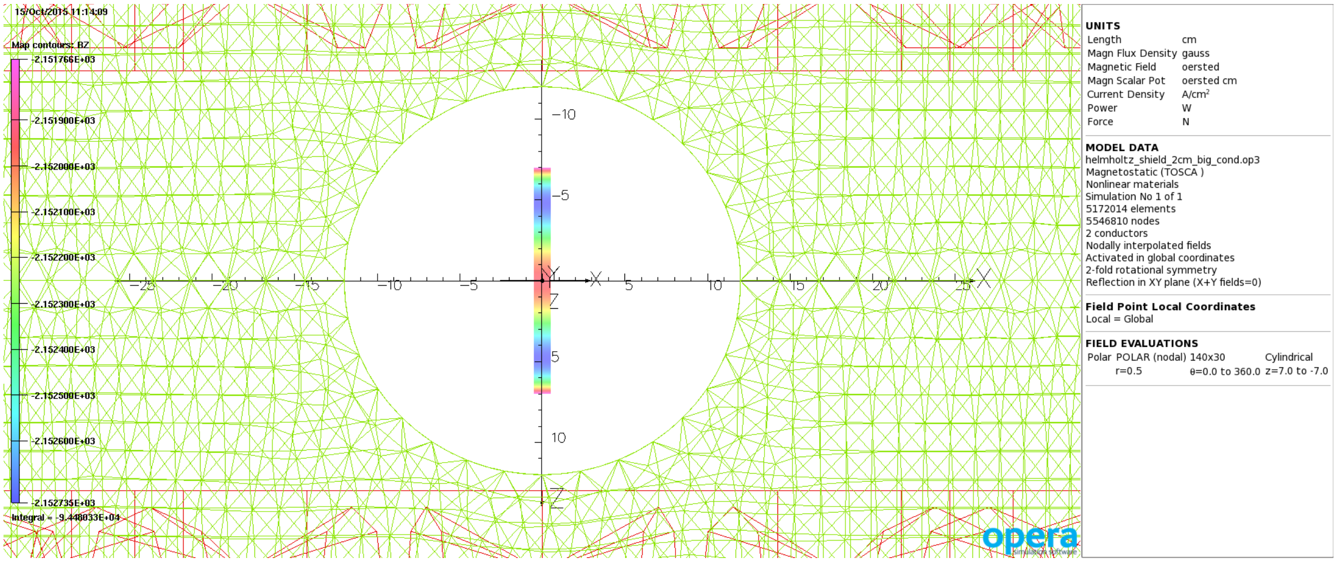

Figure 2. Top view of assembly showing the 24 cm diameter hole in the shield, the green steel mesh, the edges of the red coils, and the same 1 cm diameter by 14 cm long cylinder with Bz evaluated on its surface. Field homogeneity needed was not specified in the LDRD proposal. Laser spot was to be up to 6 mm in diameter, so a 1 cm cylinder ought to encompass the beam.

The steel shield is 2 cm thick. The cylinder has an IR of 50 cm and an inside half-length of 35 cm, so it's 12 cm from the coils. Each end has a 24 cm radius hole. Top and bottom have 12 cm radius holes. Homogeneity would improve modestly if steel collars were put around the top and bottom holes to replace the steel lost to the holes. Peak field in the 2 cm steel is 1.58 T with 420A, 2013 G Bz. I haven't modeled 0.75” (1.9 cm) or 1” (2.54 cm) plate. Either would work; thinner is easier to roll. Steel is about half a tonne net of holes at 2 cm. Conductor brings it to about 0.8 tonne. Can the floor in the gun test stand take the load? 150 #/sq.ft. before the gun's weight and all support structures. 200#/sq.ft. indicated.

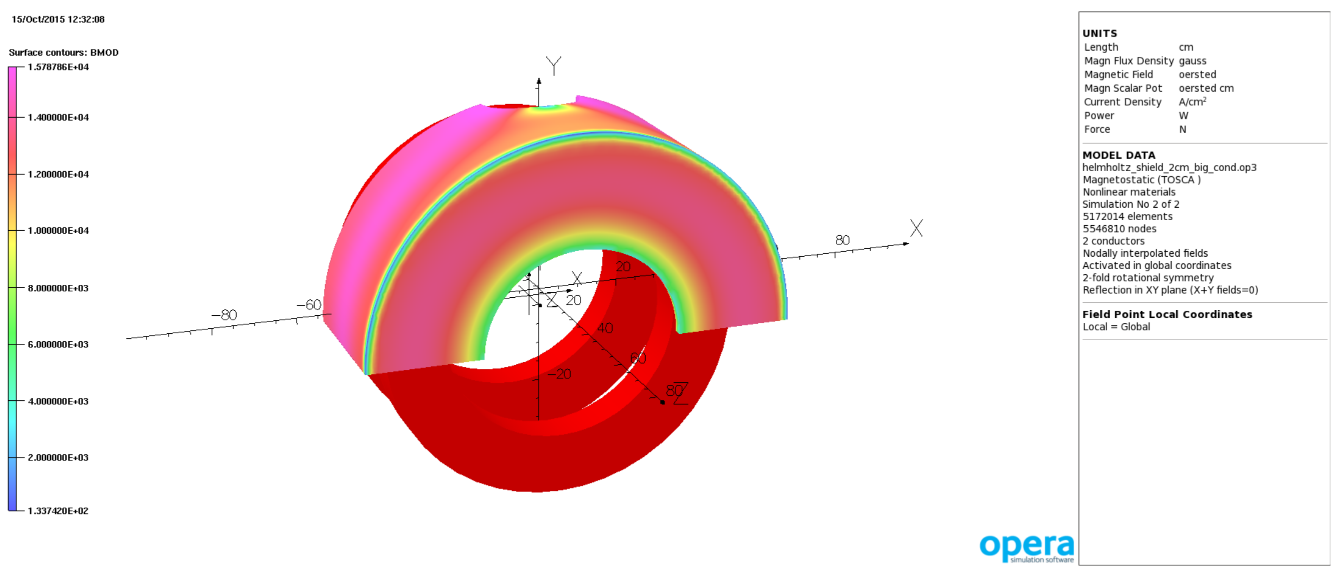

Figure 3. Field in steel with 420 A in coil.

The sizes shown here were my eyeball estimates of what would work if the shield were fabricated in pieces and the magnet assembled around the gun less cable. Cable plugged into top hole later. If it has to be larger – much more weight.

Alternatives

Halbach cylinder of permanent magnets. http://arxiv.org/abs/1510.02772 discusses the possibility of these for MRI systems in less developed countries and has references indicating some of the required size have been built.

Adapting an MRI magnet. http://paramedmedicalsystems.com/ is an Italian firm which makes “open” 0.3T MRI systems using MgB_2 wire and a closed-cycle refrigerator. The big names (GE, Phillips, Siemens) won't sell magnets, just full MRI systems. This smaller firm might, perhaps with intervention by one of JLab's Italian collaborators. This could cost less than the electromagnet when the changes necessary in facilities (LCW, power, HVAC, floor capacity) are properly accounted for.

Conclusion

A conventional electromagnet of the required size and access can be built. If better homogeneity is required, the 1968 paper by Milan Wayne Garrett has four and six coil solutions for the adapting. If an MRI magnet of appropriate size can be purchased off the shelf, that is likely the best solution.