The final? DS/DB/DJ replacement design

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Abstract

This design has evolved from a simple replacement for the DS in the injector, usable on 3” beam pipe, to one which can replace most of the DB/DJ magnets in the C100 zones with higher capacity and much higher radiation resistance. Two vendors who saw preliminary drawings suggested a change to square wire. One provided enough clues to jog my memory of MWS Wire Industries, www.mwswire.com, which makes Microsquare™ Magnet wire in sizes 15-35 AWG. This design changes from #17 round to #18 square, keeping resistance and therefore power supply interface constant. Turns count increases to 80, 10 turns by 8 layers, to keep coil section roughly the same. Power dissipation drops a little at fixed energy as a result.

Coil models

HELICALEND WIDTH=0.9 THICKNESS=1.12 H1=5 H2=5 R1=4.1 R2=1.12 ALPHA=23.1 BETA=90

HELICALEND WIDTH=0.9 THICKNESS=1.12 H1=5 H2=5 R1=5 R2=1.12 ALPHA=44 BETA=90

Steel (air) tube 6.35 cm OR, 0.2 cm wall aka 5” OD, 0.125” wall raw stock, bored to 0.080” wall

Discussion

In the injector, replacing the DS magnet, it is desired to use this design as a combined function magnet by rotating both coils slightly with respect to the Z access. An exaggerated rotation is shown in figure 1. The coils are each rotated by 0.1 radian, much more than is necessary for the function as shown below. For the DB/DJ replacements, no rotation: pure dipole.

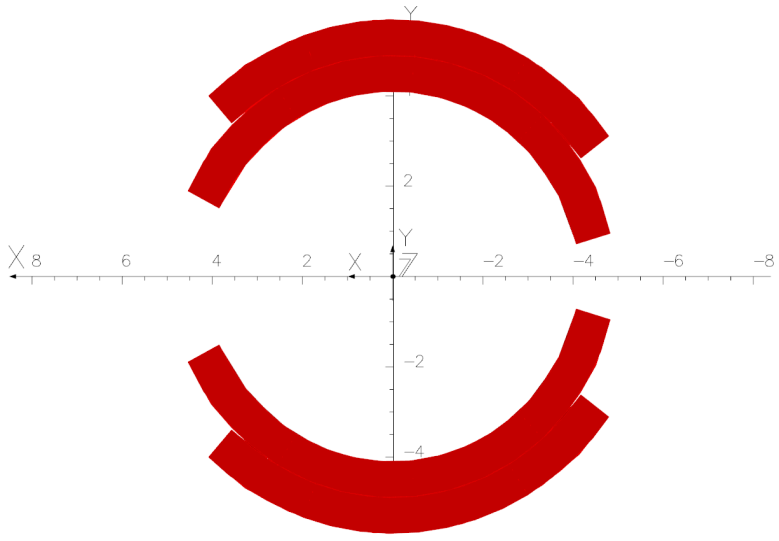

Figure 1. View from -Z, aka looking downstream, with +0.1 radian psi rotation applied to the coils. This is much larger than optimum. It is included to orient the author and reader.

The FEM model was constructed with the steel tube. For the air return case the steel BH properties were set to air. This ensures that the meshes are the same for both cases so that variable is removed. Five simulations at different angles for air and steel return. Lines were fit to the results and the optimal angle for combined function was computed. A sixth simulation was then run at this angle. Results are shown in Figures 2 and 3 for air and steel return with 3A in 80 turns.

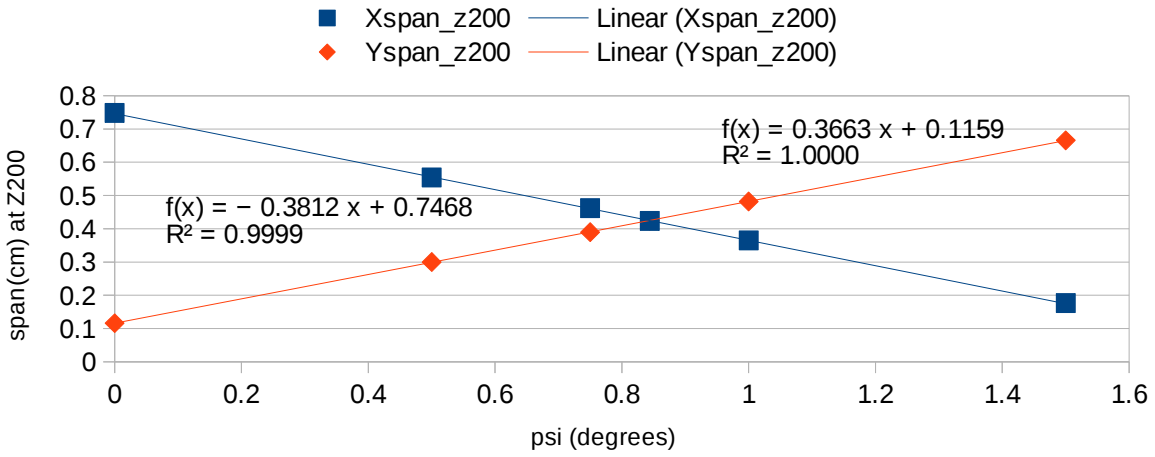

Figure 2. X and Y spans at Z=200 cm of an array initially (z=-40) 1 cm square. Air return. X span corrected for 7.5° input/output angles in injector. The lines intersect at 0.844° rotation of coils in same manner as figure 1. Trajectory start: x 4.622 y 0 z -40 "around new Y -7.5", 394 keV kinetic energy

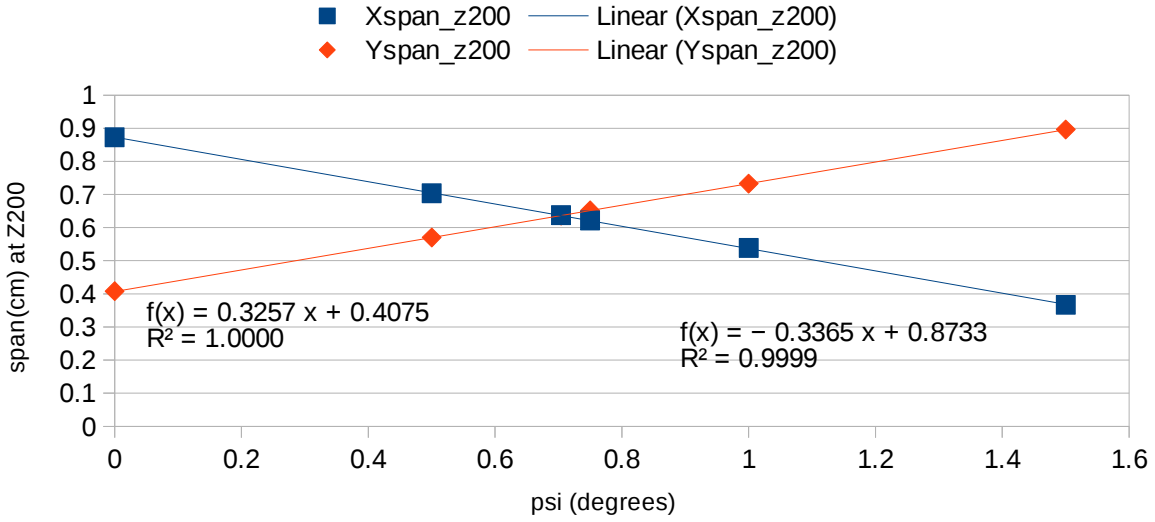

Figure 3. X and Y spans at Z=200 cm of an array initially (z=-40) 1 cm square. Steel return. X span corrected for 7.5° input/output angles in injector. The lines intersect at 0.703° rotation of coils in same manner as figure 1. Trajectory start: x 4.475 y 0 z -40 "around new Y -7.5", 827 keV kinetic energy

The two inner coils total approximately 40.5 m of wire. The two outer coils approximately 42.2 m. Resistance of #18 square from MWS literature is 5.546 Ω/1000'. Resistance of four coils is then 1.6 Ω at 35 C, typical tunnel temperature. For air return coil, 1.99 A needed for 200 keV KE beam so 6.03 W. For steel return, 1.2 A needed for 200 keV KE so 2.32 W. JLab has 28 V power supplies with 1 A, 3A and 10 A ratings. Either 3 A or 10 A would work with this design. ∫Bdl at 3A with air return is 653 G-cm. With steel return, 1077 G-cm. The DB/DJ magnets do under 980 G-cm at 10 A and have seen thermal damage at 6 A so this magnet would be a superior replacement.

Radiation resistance

In addition to the thermal failure just mentioned, the DB/DJ magnets near the C100s have failed due to radiation damage. These are magnets made by etching printed circuit copper on G10 board. Radiation damage to the G10 has necessitated the replacement of several units. There are forty sets in the old FEL so units of this design will not be purchased soon. Budgetary cost information is desired, however, for lots of ten. This design will fit over BPM body but not over SMA connectors.

For radiation resistance and low activation potential, the coil former is to be made of aluminum. For radiation resistance the wire insulation is specificed as polyimide, aka ML, as this is resistant to 5E6 grays per CERN Yellow Report 96-05. Since upwards of 10 Gy/hour has been measured in the vicinity of the C100 cryomodules, polyimide insulation provides assurance that the new design will last longer than CEBAF.

The grooves in the coil former are dimensioned for maximum material condition on width. If the wire is smaller, Kapton or equivalent polyimide tape should be used on the sides of the groove to center the conductor pack around the specified central angle of the coil. Kapton tape 0.001" nominal, actually 0.001" polymide plus 0.0005" adhesive, may be used on the bottom of the groove at vendors choice.

Wire: MWS M181281 or equivalent aka 18 gauge, copper, heavy film, ML, natural color. Ten turns by eight layers in each of four coils.

Steel tubes: Danny Machie found two sources for 5" OD 0.125" wall steel tube. Since the tolerance on round tube is relatively loose, Danny recommends that the 0.125" tube be purchased and bored out to the tolerance on the accompanying drawing. Sources he found for inch tubes:

https://www.metalsdepot.com/steel-products/steel-round-tube-dom
https://www.speedymetals.com/c-8242-round-tube.aspx?thickness=5

Three additional figures for JLab personnel:

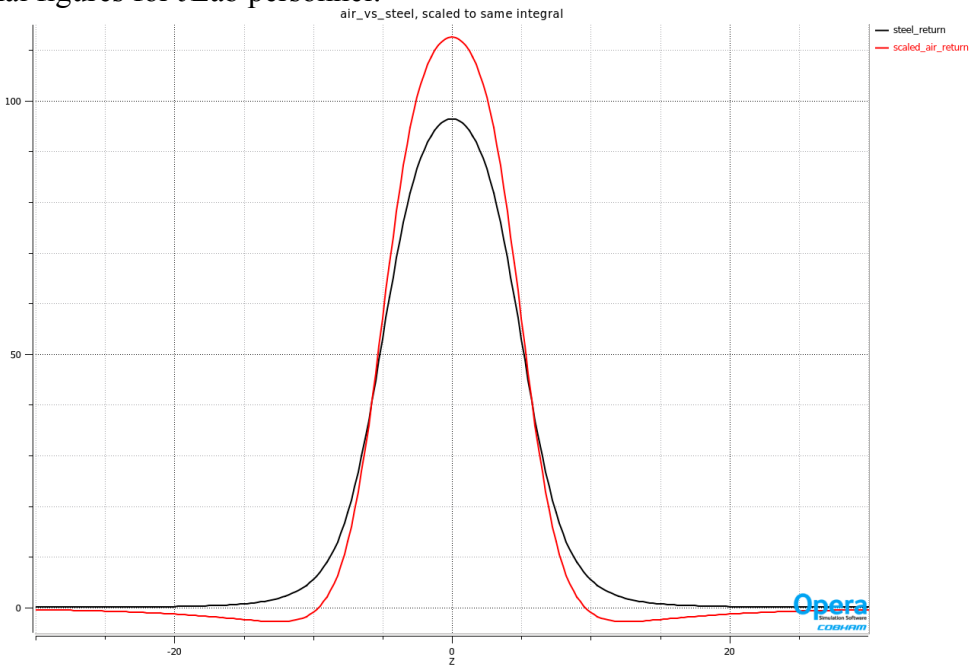

Figure 4. By(z) for steel (black) and air return (red). The latter is scaled to the same ∫Bdl as the former so one can better appreciate the field differences outside the coil proper, 11.2 cm long.

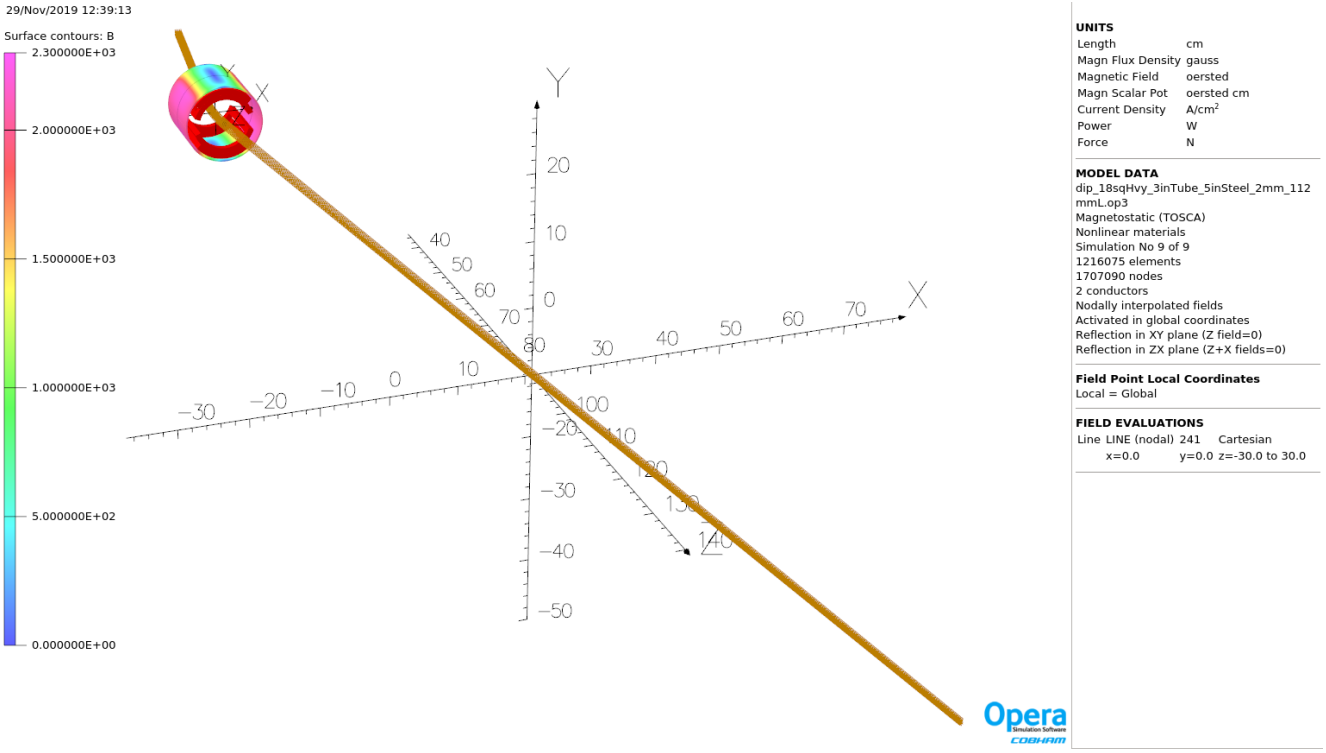

Figure 5. Magnet with steel return, 827 keV bundle of rays as described on page 2 including caption of Fig. 3. Field in steel is low enough (2.3 kG max) that the 3A can be doubled (57 W) or tripled (130 W) while remaining linear. The higher current may be limited thermally if convection is the only cooling. No such application is anticipated, but it merits mention.

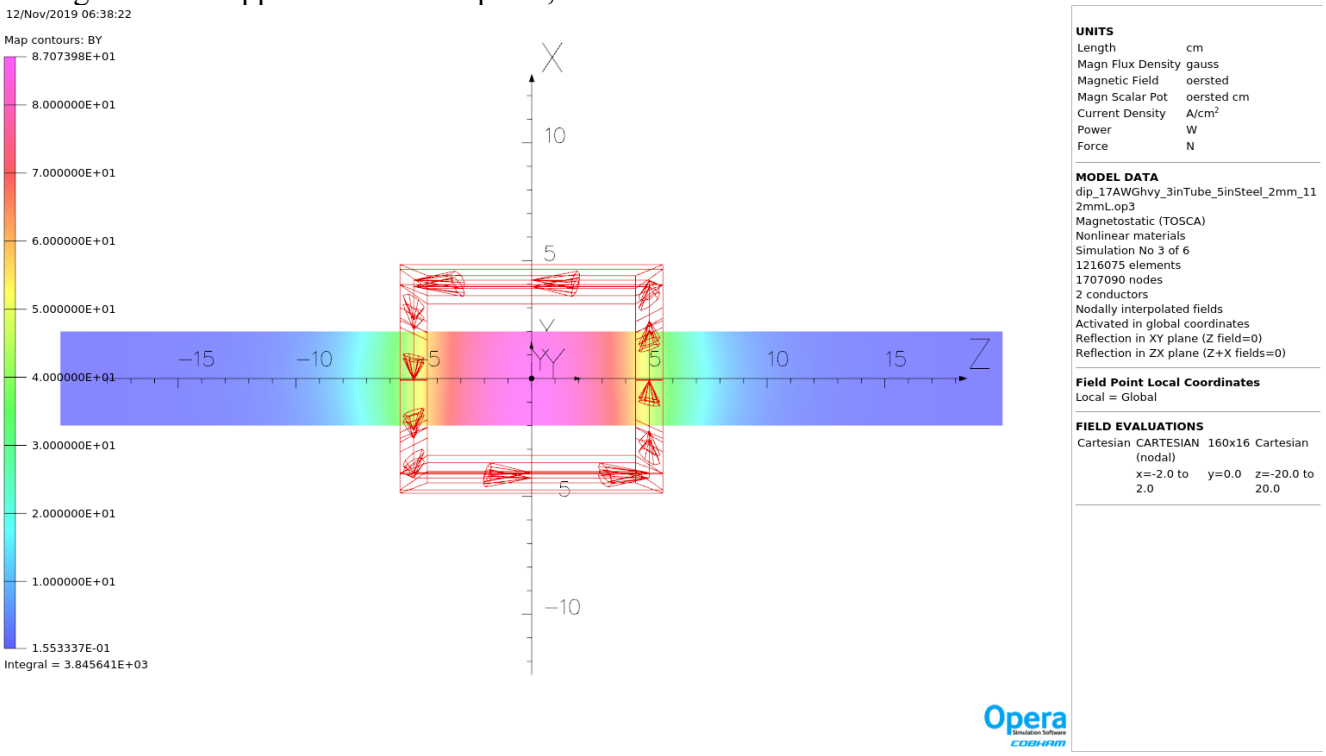

Figure 6. By in midplane of a similar but not identical model, with steel return hidden so field amplitude may be seen.

Accompanying drawings

Drawing title: CEBAF Injector 200 keV Gun Y Chamber Dipole Coil Fixture
Drawing number: JL0087295

Drawing title: COIL FIXTURE WIRE ASSEMBLY
Drawing number: JL0087835

Drawing title: SHIELD FOR COIL FIXTURE
Drawing number: JL0089687