A new 15 degree bend
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Introduction

A new vacuum section for introducing the laser beam to the photocathode and deflecting the resulting electron beam into the main section of the injector was designed with 7.5° entrance and exit angles and a 3” tube. The existing 15 degree bend dipole fits over a 2.5” tube and so cannot be used. See drawing 32709-C-0358. Several variations on the theme were described in TN-19-026. The author prefers the control provided by having separate nested dipole and quadrupole as described there. This TN describes a dipole with coils rotated about the Z axis to give equal focusing to the beams in both planes. This approach is preferred by R. Kazimi. The angles by which the coils are rotated are small (0.56° or 0.75°) so the coil form may be machined (or 3-D printed) to allow either the tilted-coil or nested approach.

Coil models

HELICALEND WIDTH=0.79 THICKNESS=1.06 H1=5 H2=5 R1=4.1 R2=1.06 ALPHA=23.1 BETA=90

HELICALEND WIDTH=0.79 THICKNESS=1.06 H1=5 H2=5 R1=4.9 R2=1.06 ALPHA=44 BETA=90

Here width is the cross-section in the radial dimension (cm). Thickness is the cross-section in the azimuthal direction. H1 is the half length of the straight. H2 is the half length to the end of the coil, so with H1=H2 the coil end is square to the length rather than tilte. R1 is the radius of the forming cylinder; the coil is round-bottomed, not flat-bottomed as in the drawing. R2 is the thickness of the end, generally the same as the azimuthal width as the conductor area is conserved. Alpha is the angle to the central filament of the coil from the X axis. For a single filament dipole this would be 30°. Beta is the angle to the top of the coil, 90° here because we want a vertical field. The alphas used are the same as those in the existing magnet. The radial and azimuthal widths have been changed somewhat rather than simply scaled by a factor of 1.2 (=3/2.5). The coils are assumed to be wound using #18 heavy film insulated magnet wire in a hexagonal close pack. At maximum material condition the aximuthal width allows nine turns plus the half-diameter offset from layer to layer. The radial width allows for eight layers in hexagonal close pack. If the coils are random-wound a 35 year old Phelps Dodge handbook estimates 63 turns would be accommodated.

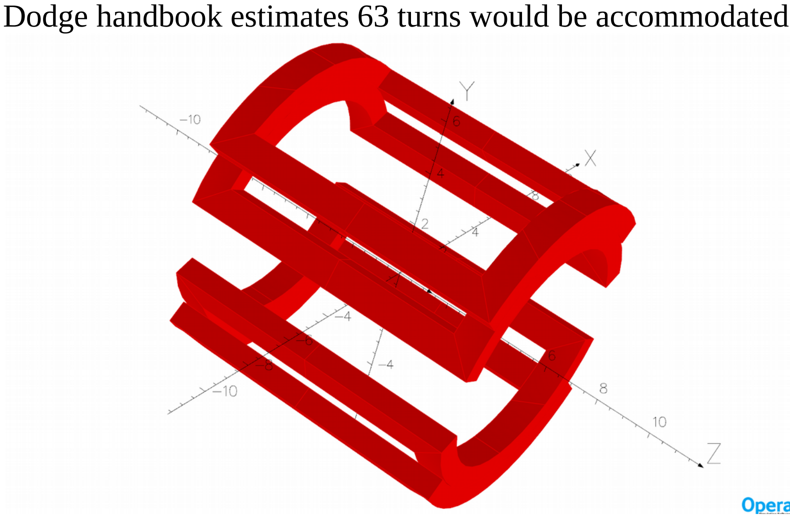

Figure 1. Basic coils, zero rotation.

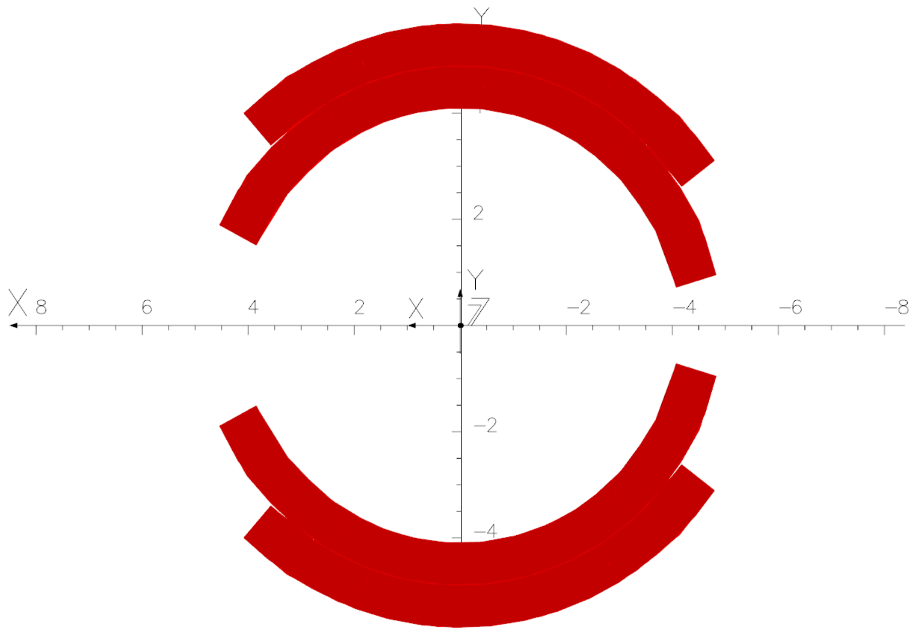

Figure 2. View from -Z, aka looking downstream, with +0.1 radian psi rotation applied to the coils. This is much larger than optimum. It is included to orient the author and reader.

Initially ±2° psi rotations were applied and the focusing in both planes evaluated. It soon became clear that only positive psi rotations were relevant. In the figure below the x and y widths of the beam at z=200 cm are plotted as a function of psi. The five half-degree steps were evaluated first, the linear equations solved, and the final points added.

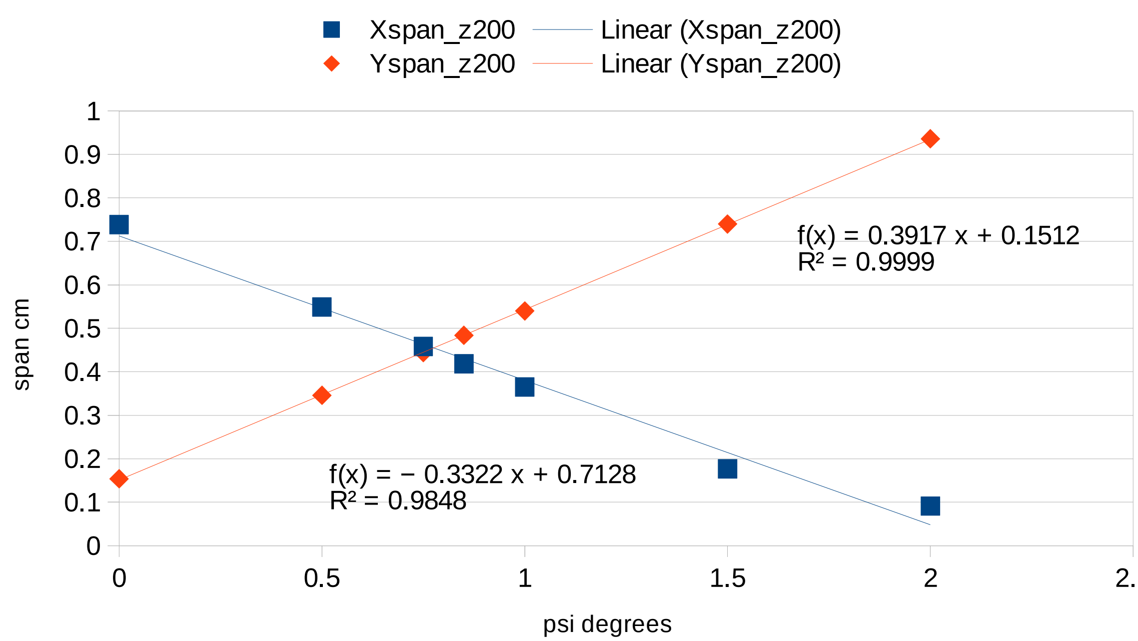

Figure 3. X and Y spans at Z=200 cm of an array initially (z=-40) 1 cm square. X span corrected, if imperfectly, for 7.5° angle. The lines intersect at 0.78° rotation of coils in same manner as figure 2.

The models above were evaluated with 167.48 AT, 225 keV electrons. For 275 keV electrons, 2.62 A in 72 T, no problem for potted #18 wire.

Following the insights demonstrated in TN-19-027 a 5” OD, 0.06” wall, 14 cm long steel tube was added to the model above. The same process was then used to determine optimal coil rotation angle. 14 cm = 5.5” length chosen as that was the span of 3” tube measured by R. Kazimi in the new part.

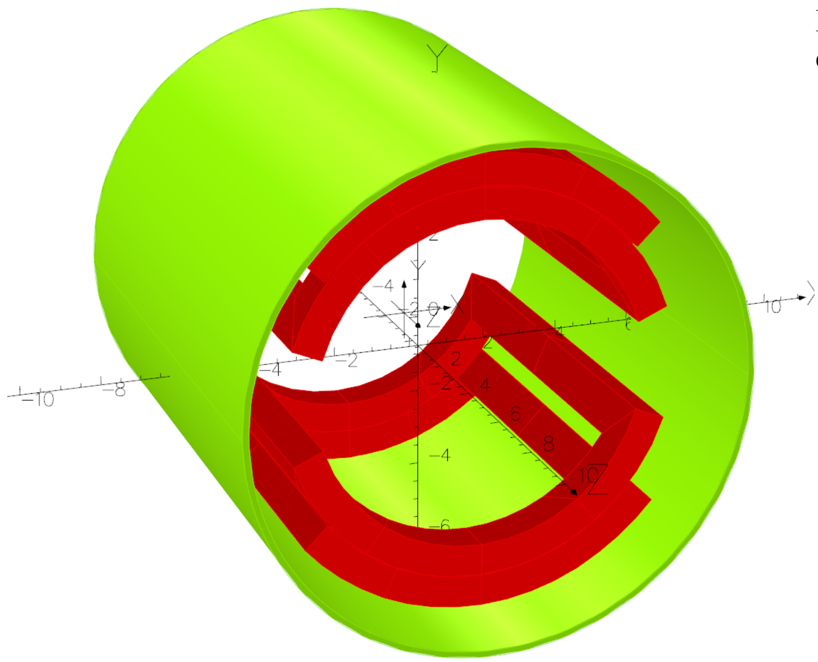

Figure 4. Steel tube added to basic coils, no rotation.

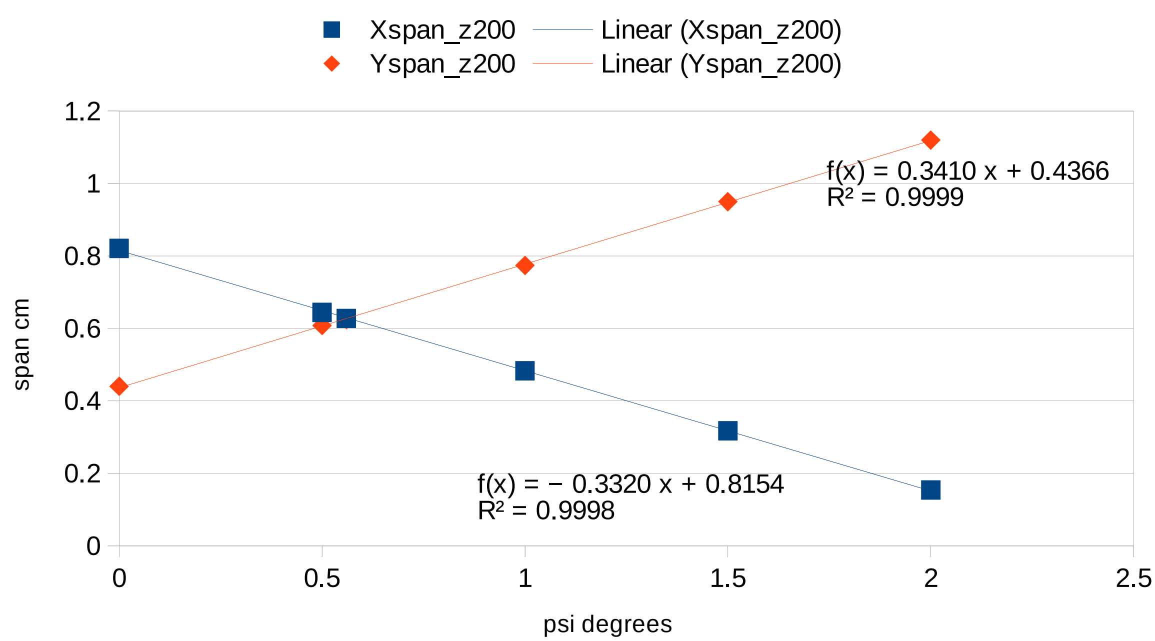

Figure 5. X and Y spans at Z=200 cm of an array initially (z=-40) 1 cm square. X span corrected for 7.5° angle. The lines intersect at 0.56° rotation of coils in same manner as figure 2.

The steel reduces the drive current required for a given momentum. For the same 15° total deflection the 167.48 AT allows for a 472.5 keV beam, so 2.41A suffices for 500 keV and only 1.37A for 200 keV. The coil will remain cooler. The steel may be fabricated in two halves to allow for iterative adjustment of the rotation angles of the coils with beam. Once the angle is locked in, add steel and reduce current.

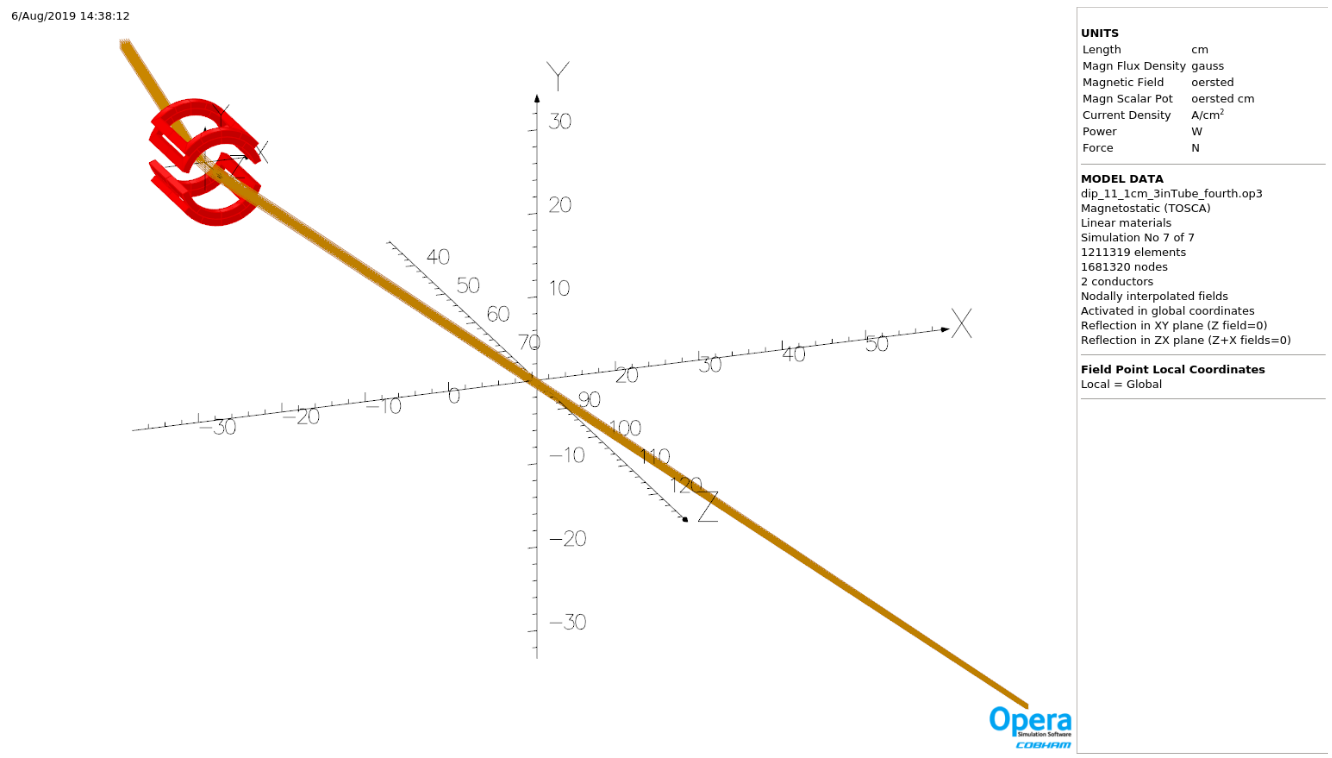

Figure 6. 225 keV array propagated through the air core assembly with 0.75° coil rotation.

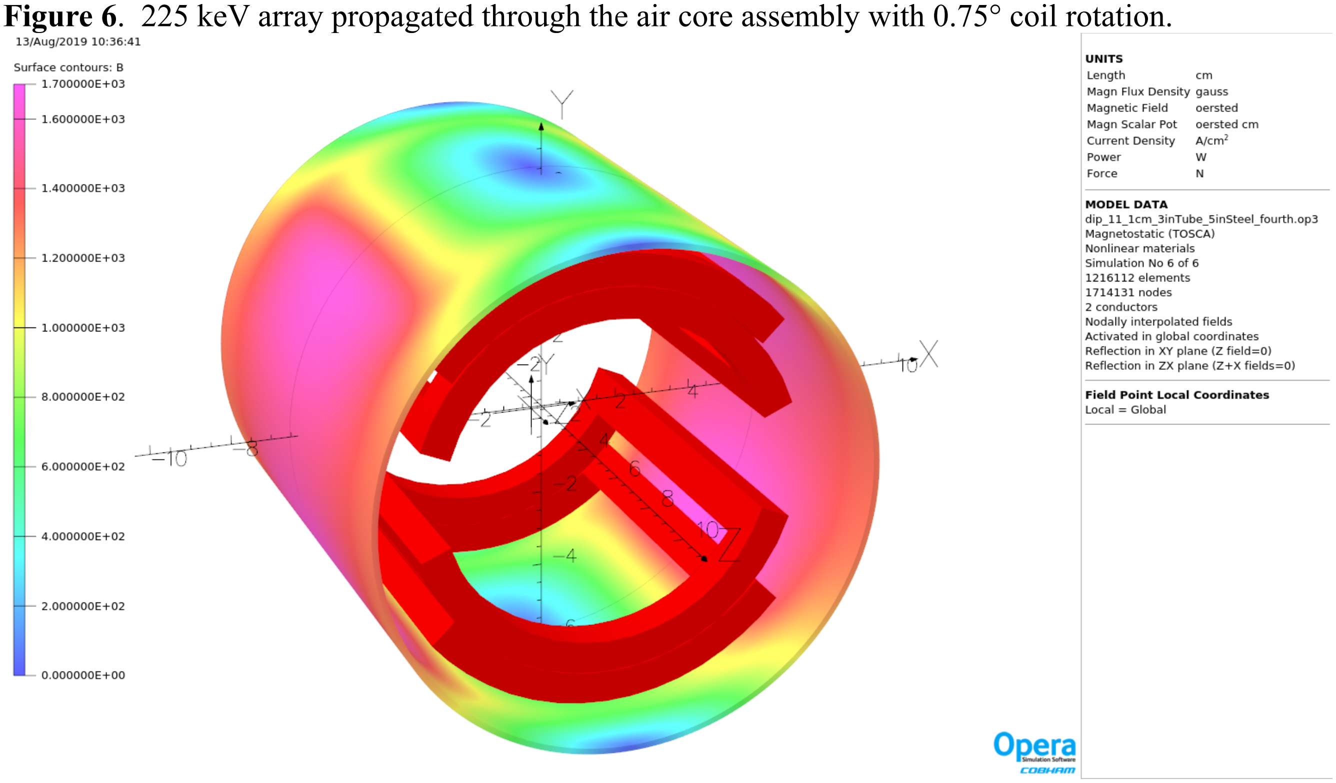

Figure 7. Field in steel for 472.5 keV beam deflected 15° aka ±7.5°. Peak 1660 G. 3.8% current increase needed for 500 keV. Low field (blue) regions on top and bottom could be machined away to allow access to flats or fiducials on the coil former to check coil rotation angles without removing the steel.

Summary

It is hoped that this is the last entry in my series of TNs on the 15° bend. Earlier entries: 15-037, 17-042 and 19-026. My earliest model dates to March 2009; I'm not sure why that work wasn't written up.

A copy of drawing 32709-C-0358 will be marked up with new dimensions and submitted to ME. The coil recesses in that drawing have flat bottoms. Machining them with a radius to have full fidelity to the design would be time consuming, hence expensive. Additive manufacturing, aka 3D printing, of any non-magnetic metal might be less expensive. Or the Division could stay with flat bottoms, accepting the modest deviation from the model.