**Adding a counter-wound solenoid where MQJ0L01 now resides? Jay Benesch**



envelope of beam from exit of quarter CM to quad 0L05 per Alex's injector deck. MQJ0L01=0



envelope of beam when pair of 10 cm solenoids with 15 cm gap, powered as counter-wound pair, replaces MQJ0L01. Peak size in X 2.32 mm vs 2.65 mm in nominal optics.

Twiss parameters are matched at IPM0L04, in front of quad 0L04, so 0L matching region and 0R chicane don't change. Twleve percent reduction in beam size. Additional reduction is not significant if more 0L quads are invoked.

Solenoid field is 0.8864 kG in a hard-edged 10 cm solenoid. Matching this with the "real" solenoid design summarized in https://jlabdoc.jlab.org/docushare/dsweb/Get/Document-94987/14-022.pdf requires a current ~8.75A into two 1.8 ohm coils per package, too much for a single trim card when wired in series within each package. Either four trim cards or one 20A/75V trim supply would be required to drive the pair of solenoids, each containing two coils. The solenoids weigh about 25 kg each. 4" ID, 8.5" OD, 4" long.

Reza stopped by. I showed him the page above. He asked first about steering. We examined this and found that the solenoid will steer offset beams towards zero: good. He then asked whether the beam parameters could be measured with harp 0L03 by turning the quads off and using just the solenoid. At the harp with quads off, the beam radius is about 5 mm at nominal solenoid setting, 0.8864 kG, declines to 2 mm at 0.53 kG, and then begins to increase again as solenoid is lowered further. These seem to me too large to get a good measurement, but I don't know what the normal range is at IHA0L03; the standard optics suggests the size could go as high as 3 mm during the quad sweep.

The key table of TN14-022 is reproduced below with minor modifications:



One sees in the bottom of the table that the spherical aberration is 3.7% for the FA solenoids and 4.5% for the FL across the 6 mm apertures which define the beam. Across the chopper slits the aberration is -15% to +23%, far larger, on existing 3 cm diameter circle. The new design cuts the on-axis aberration a factor of ten and the chopper aberration a factor of four.

Reza also asked whether replacing the two quad doublets with counter-wound solenoids would provide a greater benefit. It does. As shown below, it reduces the peak beam size in the 0L region from 2.65 mm in the original optics to 1.31 mm in the new case. A 0L04 doublet is required; the field of the new quad is small enough (15G), that an air core quad would suffice. The skew quads can do 60 G. This is inserted between the Faraday cup and the differential pumping station. There is a an electrostatic precipitator in this location which would have to be replaced with standard beam pipe. Twiss parameters are the same at the drift after MQB0L10 as they are in the standard optics, so match into the 0R chicane should be fine. Solenoid fields here are 80% of those needed when only one unit is placed at 0L01 so two standard trim cards each would work for 0L01 and 0L02. 7A, 3.6 ohms per package, ~180W. 0L03 needs more during Twiss measurement as discussed below.



Three counter-wound solenoids where 0L01, 0L02/2A and 0L03A/3 now live, plus a small quad between Faraday cup and DP station. Scale is the same as in the first two figures. Beam envelope is much more uniform and half the nominal value.

The 0L03 counter-wound solenoid would have to be water-cooled to sweep through the fields necessary to measure Twiss parameters at IHA0L3. Each of the packages would need its own 20A/75V power supply (~13A/52V needed to get well past waist.)

If one wants to retain the capability of running beams up to 15 MeV KE, all three counter-wound solenoid sets after the quarter would have to be water cooled and have twice the original end plate thickness, 1/4" instead of 1/8". The water cooling concept in the original design is cooling only the 0.25" wall 4.5" OD copper tube on which the coils are mounted. There are 64 oz (0.0863") copper spacers between coil and steel end plates of 1.75" radial extent to conduct some heat down to the copper tube, thermal grease interface. This might suffice for the 6.8A at ~4 ohms needed for the focusing shown in the figure above (assumes 50C copper wire). It might even suffice for the Twiss measurement if done quickly, relying on heat capacity.

I talked to Ernie Ihloff (MIT) at the MOLLER collaboration meeting 8/12. He reminded me of a design I learned 40 years ago and forgot 30 years ago. The pair of 1/8" steel annuli at the center of the package provide only magnetic continuity at the OD. If the four copper and steel annuli at the center are replaced with one 10.8 mm copper annulus, this could be water cooled via a tube pressed into a machined groove and might suffice, with ID cooling, to keep the coil at an acceptable temperature. FEA still needed, but this would preserve the 8.5" OD envelope. One of the two steel tubes in the package would have to be extended by 0.25", but that shouldn't increase cost too much. Worse case replace end copper annuli with the thicker one. Magnetics not modeled until thermal FEA says it's needed.

**It is proposed that 16 of the solenoids described in TN14-022 be purchased, eight to replace the existing injector solenoids, six for use after the quarter cryomodule, and two as spares. If the gun group wishes to purchase units for the UITF, these should be added to the buy to lower unit cost. Less economically, the engineering and two prototypes could be purchased in FY16 for use at 0L01 after the quarter and the other fourteen purchased/installed when the 200 kV gun and new quarter are installed.**

At the B team meeting 8/11 Geoff Krafft asked about the effect of different incoming Twiss parameters, recalling that Nick Serrano had converging beam coming out of the quarter. I played with this in Optim with the following results.



envelope of beam from exit of quarter CM to quad 0L05 per Alex's injector deck. MQJ0L01=0



Adding 1 to incoming alphas to get converging beam and matching to entrance of MBL0R01 improves things a bit



Adding 1 to incoming alphas and halving incoming betas, not as good as just adding 1.



Setting incoming alphas to zero and incoming betas to 300 cm (vs x 310, y 280). Better.

**Conclusions**

Putting the waist due to MFL0I07 and RF focusing at the end of the quarter cryomodule is likely better than alternatives.

Solenoid focusing is better yet.

A solution for the thermal problem in the high momentum region may have been found. Thermal FEA is still required.