Quad concept for FFA linacs

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Abstract

The present concept for the energy upgrade linac requires a triplet between each pair of cryomodules. Per ACC1200120-0185 Rev A Warm Region Interface Drawing the flange to flange distance available between two C100 modules with all-metal gate valves is 35.25” (89.5 cm). If one assumes 10 cm and 20 cm steel and copper like the 2” beam tube QB magnets, the triplet requires 31.75” of this length. A bellows is required for alignment. No space remains for BPMs, skew quads or correctors. The QP ends total 1” less than the QB ends, buying 3” and reducing beam tube to 1.375” from 2”. The concept below changes to a hollow copper conductor from solid wire conductively cooled as now and admits a 1.625” OD beam tube. It is hypothesized that the 650 MeV injection energy and smaller linac beta functions will allow the smaller beam tube with minimal beam loss. This must be checked.

Discussion

I began with the 50 cm long, 104 mm ID quadrupole described in JLAB-TN-23-018. I scaled it by 0.4 in all planes. On scaling the conductors I determined that the number of layers in the large coil would be seven - not practical. I therefore scaled x and y by 1.05, net scaling was 0.42 in (x,y) and 0.4 in Z.

The conductor chosen is Luvata #8529, 4 mm square with 2 mm hole and 0.5 mm corner radius. I assumed 5 mil (125 micron) half-lapped glass or polyimide insulation for a total conductor size of 4.5 mm square. Luvata will insulate with this thickness polyimide. Bend radius 14 mm to minimize keystoning, 16 mm better. The larger coil in Figure 1 is then seven turns by eight layers (56T) and the smaller three turns by four layers (12T). Current density of 500 A/cm2 was used as a starting point and proved appropriate for this point in conceptual development. Actual current is then 101.25A. Each double pancake in the larger coil, 14T, is ~7 m long. Using my usual pressure drop resource, 6.3 bar will push 10 cc/s through the conductor. Resistance at 60 C is 11.1 mΩ so power 113 W. If LCW inlet is 35C the conductor will reach only 46 C with this water flow so cooling should not be an issue. The water manifold will be an interesting exercise. One could level-wind the coil with a net resistance of 44.4 mΩ and still have 80C exit temperature with 10 cc/s but the pressure required to get this flow is absurd, so double-pancakes it is. The small coil could be wound as a single unit as its length is ~6 m.

Half-length of the magnet shown below is 13.6 cm. Water manifold and current connections between the pancakes will add length. Assume 30 cm overall for the quad with 20 cm steel and 20 cm overall for each of the two 10 cm steel quads. Total is 70 cm. This leaves 19.5 cm total for a short BPM, short corrector and alignment bellows. Assume 5.5 cm including flanges for a welded bellows as formed bellows would not have enough compliance in that length. That leaves 7 cm gaps between the quads in the triplet for a short machined BPM and a short corrector. JLAB-TN-20-039 discusses a corrector design for which ETI quoted an impossible price so it's never been built - but one variation is 7.5 cm long by 1.5” ID so it's close to what's needed here. It should be possible for someone to improve manufacturability to get cost down. Winding the coils flat, bending and capturing, for example.

Field integrals at 1 cm radius per Opera are **cos1 75368 G, cos5 -237 G**. The quad has a smooth pole, not the profile used in accelerator quads to reduce cos3 and cos9 terms. Still, cos3 is only 3 ppt of primary field. Perhaps a ±125 A, 30 V supply for each quad including lead resistance from surface.

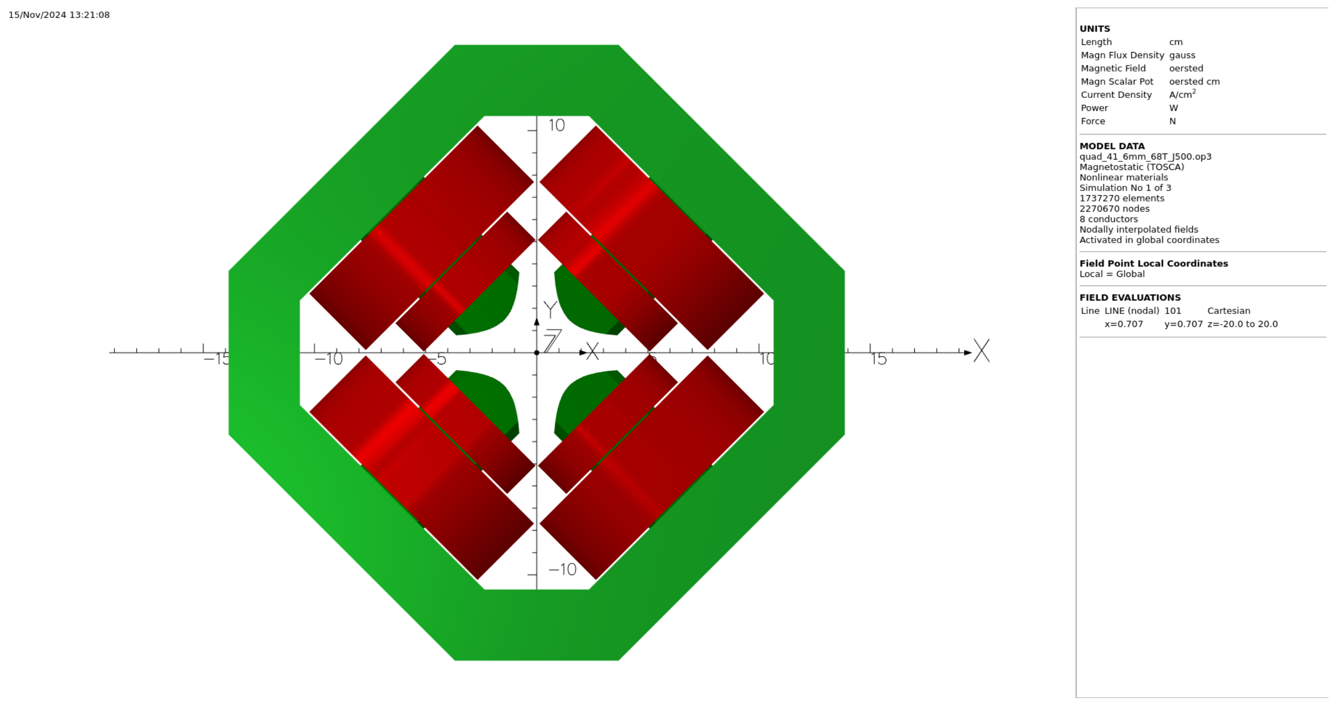

Figure 1. End view

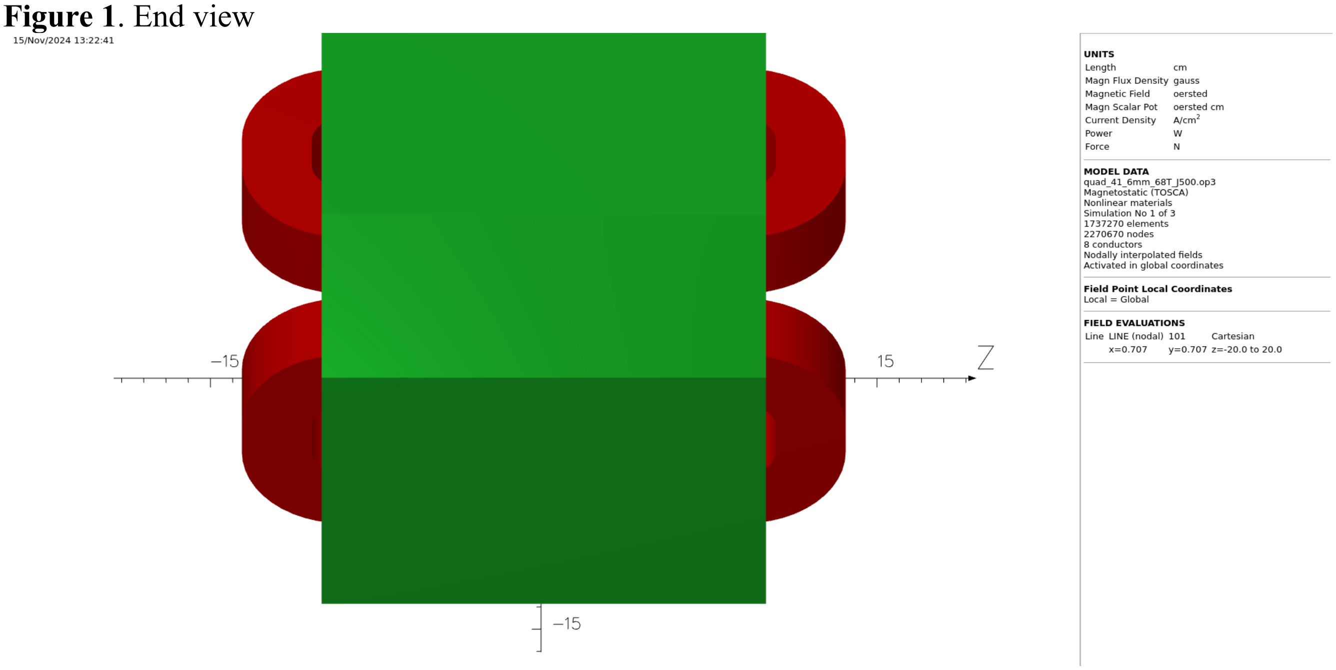

Figure 2: side view

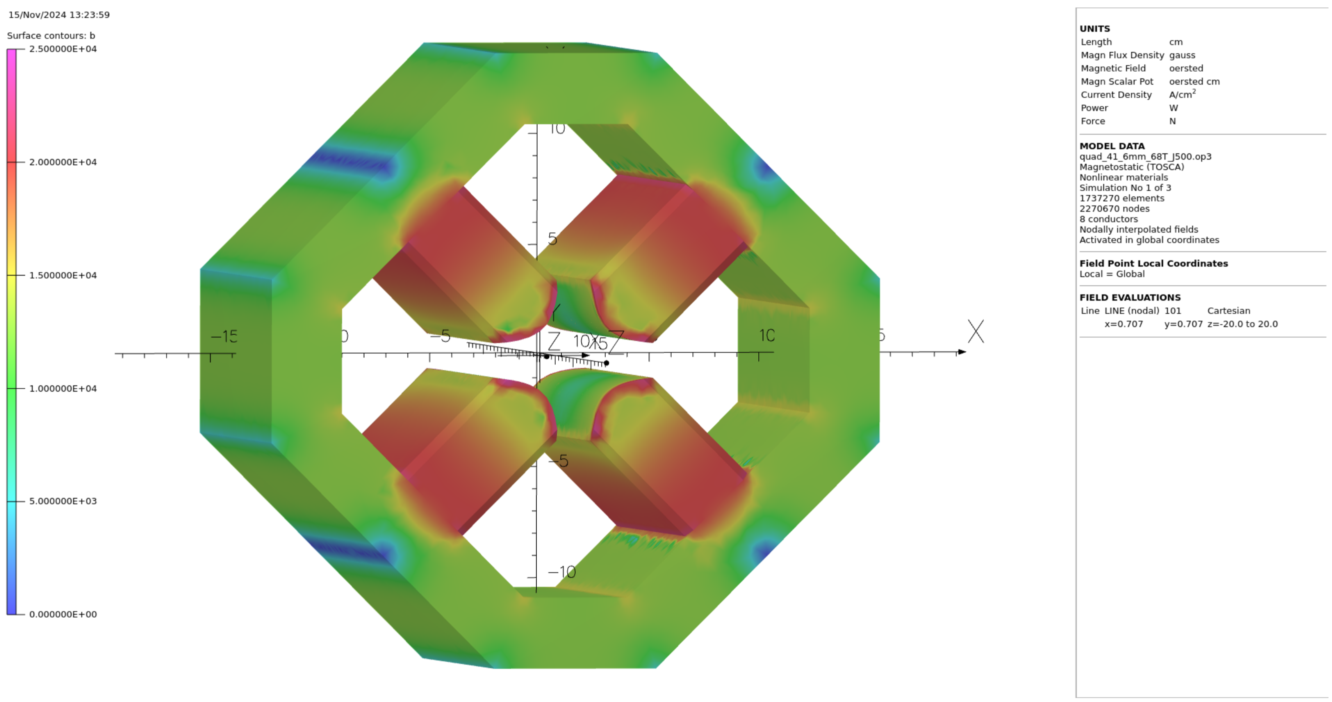

Figure 3. |B| on the surface of the steel. Note that scale ends at 25 kG. Pole could be tapered so base is 1 cm wider than the tip to reduce saturation but this would increase the coil cost substantially since the double-pancakes would also have to be tapered, requiring five mandrels and molds instead of two.

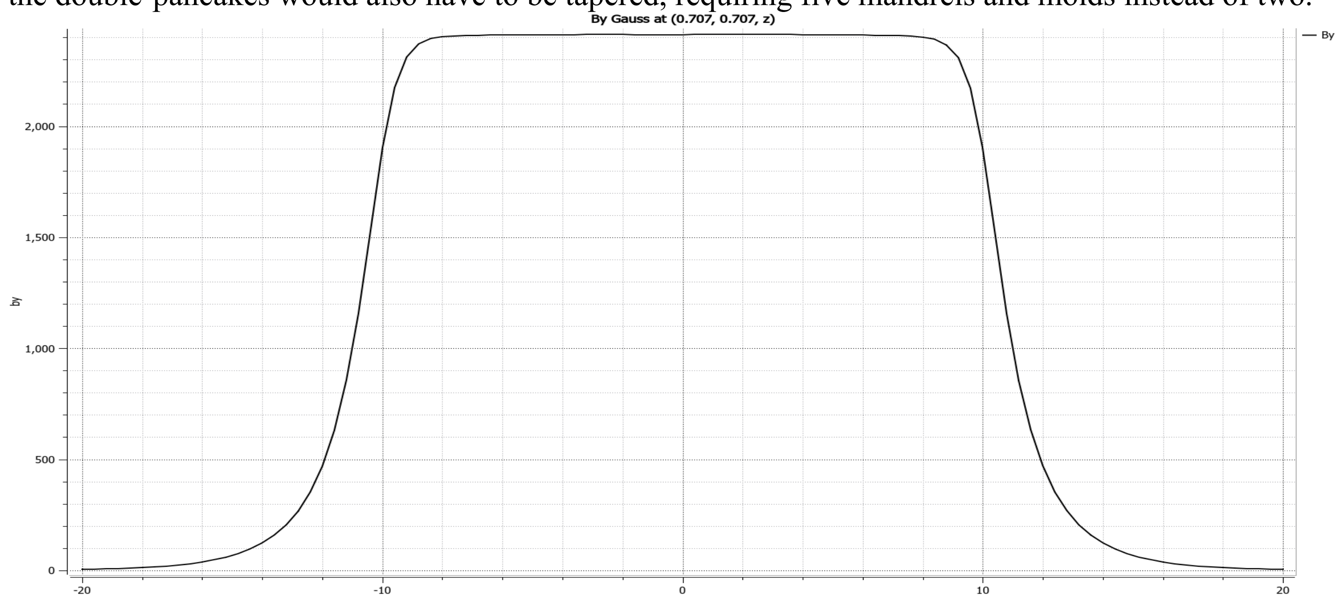

Figure 4. By(0.707, 0.707, z) Gauss

Conclusion

It is possible to design and fabricate a quadrupole with 3.7 kG/cm gradient that is short enough to fit a triplet on the minimum length girder in CEBAF with sufficient space for BPM, corrector and alignment bellows. Tapering the pole and coil might get one to 4 kG/cm. Higher gradients are possible only with much smaller beam tubes. The QR with tapered pole and 1" beam tube does 5.3 kG/cm with longer ends than the quad here.

I am told that the strong focusing triplet optics used in the present FFA lattice requires 10.8 kG/cm at the end of the South Linac, three times what is possible.

Addendum

If one extends the steel poles so the ID is 40 mm (1.575”) instead of 43.68 mm as above, leaving the coils as is, gradient will increase perhaps 8% to 4 kG/cm. This results in 1.5” OD beam tube.

Addendum 2 (2 December 2024)

Changing from a pure hyperbolic pole end to the contoured end of the QC pole reduces cos5 by two-thirds but lowers cos1 by 10%, clearly counterproductive. Increasing current density 10% recovers about half the loss, still not worthwhile.

1.625” stainless tube with either 0.049” or 0.065” wall is available only in SS304
42 mm OD stainless tuve with 1 mm wall, 40 mm ID, is available in SS316 from metricmetal.com
The latter is clearly superior and provides 69% of the present area for beam steering.