Smooth versus contoured quadrupole pole-ends (FFA)

Jay Benesch

5 December 2024

Abstract

All of the quadrupoles used in CEBAF have a contoured pole end designed to reduce 12-pole and 20-pole allowed terms. As a follow-up to TN-24-053 I replaced the smooth hyperbolic pole end used there with a scaled contoured pole. Quadrupole term dropped 9.5%. 12-pole dropped to a third of the value without contour and 20-pole to about a tenth. The trade-off may be desirable in the quads with 1" beam pipe - detailed simulations are required. It seems unlikely that it is desirable in the quads with larger bore.

Lamination

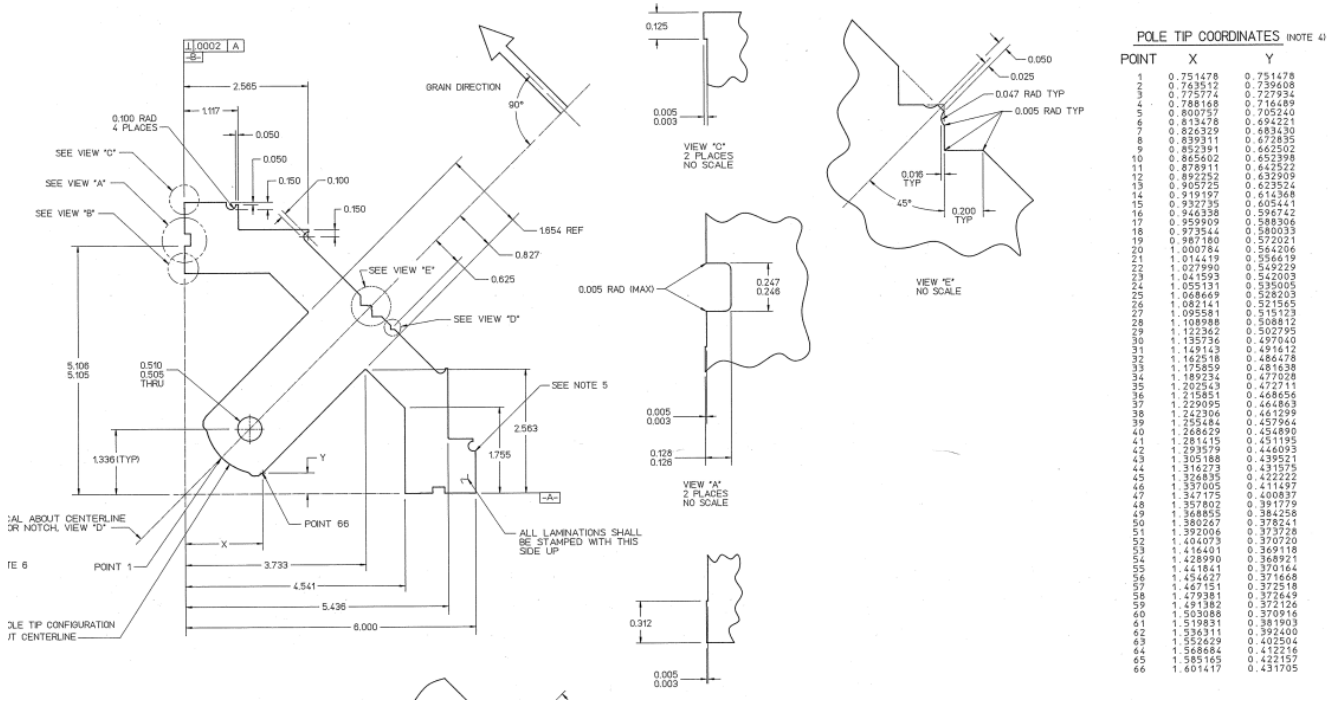

Figure 1. Relevant portion of 21122-D-0002, QB Magnet Lamination. This lamination is used in both QB and QC quadrupoles. It is scaled in the QA, QP and QR quadrupoles. The contour is defined by the 66 points, 65 line segments, in the table at right. Getting this into Opera was tedious.

Quadrupoles for FFA

TN-24-053 defines a quadrupole which will fit and function in a weak-focusing triplet on the minimum length girder in the CEBAF linac after all-metal valves are installed. End views of models with smooth and contoured poles are shown on the third page.

TN-23-009 has the Hall C line optics and magnet requirements at 22 GeV. TN-23-011 covers Hall A. TN-23-021 Hall B. For A and C an extended QR with 51 cm steel is needed. For B I found that I needed a bit more focusing, to a length of 52 cm steel, 66.76 cm overall. I checked and there's space in the A and C lines for the 52 cm steel quads there, as noted in 23-021. I did NOT check whether the conductive cooling used in QRs would work with the additional length. The QR quad has 5.33 kG/cm

focusing for 35.56 cm steel length. For the 22 GeV Hall lines, the integral 278 kG at 52 cm has modest headroom. I decided to scale the quad from 24-053 to 28.6 cm ID, same as QA and QR, with 50 cm steel length. Smooth and contoured poles were again modeled. Exclusive of water and current connections, the resulting quad is 56 cm long. Pole edges are chamfered to keep to this length with conductor bending radius at 14 mm to minimize keystoning. With the connections, certainly under 60 cm. Call it a 7 cm reduction in length over a stretched QR which has not had cooling verified.

Since the straight sections of the coils are now 50 cm long versus 20 cm in TN-24-053, a conductor with a 2 mm diameter hole for cooling water does not work. Luvata 6844, 4 mm square with 2.5 mm hole, is assumed instead. 0.005" polyimide, half-lapped, is again assumed for insulation to keep coil compact. Large coil has 20 turns and small coil 8 turns. J = 1000 A/cm^2 so I=202.5 A in these models. The on-line pressure drop calculator I use shows 6.1 bar for 14 cc/s. The double pancakes have ten turns, resistance is ~20 mΩ so power ~830 W and δT 60 ºC. This is marginal for the present LCW system but the dipoles in the Hall arcs at 22 GeV require much more than 6.1 bar; cooling these quads would not be an issue.

Table 1: Fourier harmonics of fundamental and allowed terms integraded over 100 cm length. Fields calculated at 60 points on 1 cm radius circles and then decomposed.

shape	half-width (mm)	ID (mm)	Cos1 (G)	ratio	Cos5 (G)	ratio	cos5/cos1	Cos9 (G)
pure hyperbola	20	44	75368		-237		-0.0031	1.93
QC profile	20	44	68225	0.905	57	-0.24	0.0008	-0.10
pure hyperbola	13	28.6	313113		-4866		-0.0155	174.83
QC profile	13	28.6	282380	0.902	1651	-0.34	0.0058	-28.13

One sees that the 28.6 mm ID version, 50 cm steel, fulfills the requirements for 22 GeV quads for the Hall lines with the QC profile. The use of the pure hyperbolic pole would allow another 2 cm to be cut from the length but the 1.55% of fundamental in the 12-pole harmonic gives me pause. Since the 0.6% of 12-pole with the QC profile is what we live with in the QA and QR magnets now, that profile may suffice. Simulation is still required since the beam will be so much larger in the horizontal plane than it is in 11 GeV CEBAF due to synchrotron radiation and the emittance growth in the splitters.

Conclusion

Use of the pure hyperbolic pole is desirable in the FFA linacs as the 10.5% additional focusing available is likely more important than the 3 ppt of 12-pole at 1 cm radius. In the Hall lines and wherever a strong quad with 26 mm (or 1") beam tube is needed the QC profile is likely preferred for the factor of three reduction in 12-pole albeit with 9.5% reduction in focusing. Simulations needed.

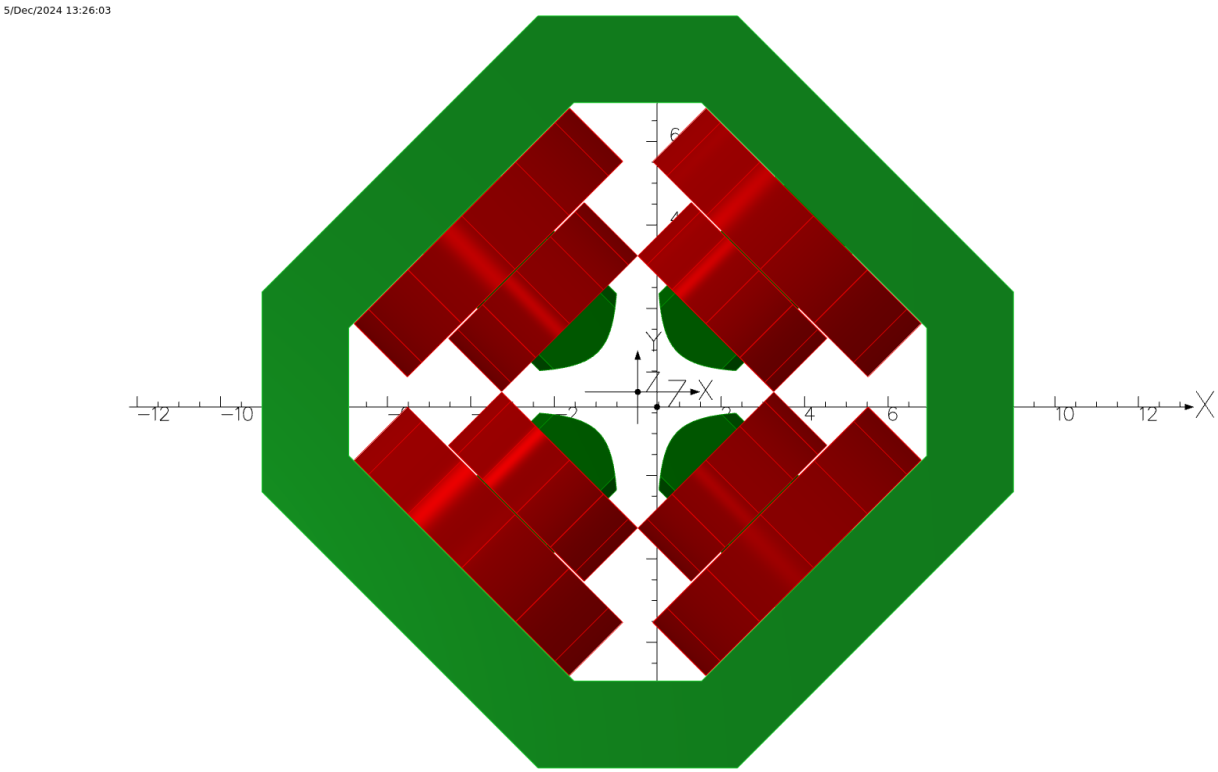

Figure 2. End view of 28.6 mm ID quad with smooth poles.

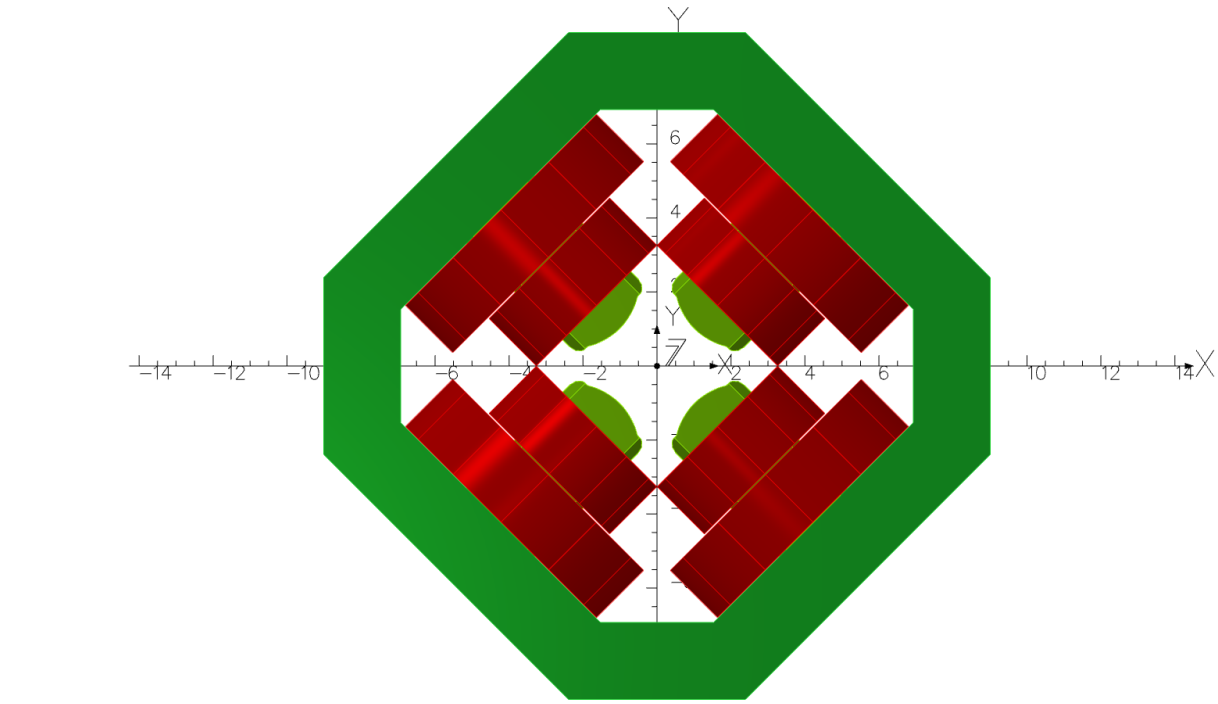

Figure 3. End view of 28.6 mm ID quad with QB contour poles.