# MINIMISATION OF HIGHER ORDER HARMONICS FOR LARGE APERTURE SUPER-FERRIC QUADRUPOLE MAGNET

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*Abstract*

We have analysed the magnetic field of finite length (effective length of 1200mm), large bore (pole radius of 350 mm) super conducting quadrupole magnets for use in Low Energy Branch of Super FRS with the program TOSCA. In particularly we have tried to minimize the 12-pole and 20-pole components, which would contribute to geometric aberrations. At the same time we have tried to keep the gradient field uniformity at reference radius 300 mm within ±8.0E-04.

## INTRODUCTION

Low Energy Branch (LEB) of Super FRS in Facility of Antiproton Ion Research (FAIR, GSI, Darmstadt, Germany), is mainly dedicated to precession experiments with energy-bunched beams stopped in gas cell. This branch is complementary to the ISOL (Isotope separator On-Line) facilities since all elements and short-lived isotopes can be studied. As the emittances of the fragment beams are inevitably large, a large aperture spectrometer with the necessary high resolving power is needed to compensate for the energy spread [1]. In VECC we are designing some of the large aperture super ferric quadrupole magnets [Table 1], which will be used in LEB.

## 3D DESIGN

Approximate cross sectional pole shape was investigated with the POISSON 2D code [2,3]. 3D design calculation was carried out with opera 3d (TOSCA) [4] considering 1/16$^{th}$ of model symmetry. Throughout the calculation conductor cross-section (43.7358x95.615 mm$^2$) and race-track shape of the conductor was not varied. The fourier analysis of the radial componet of magnetic field (Br) was performed with the Vector Field/ OPERA postprocessor.

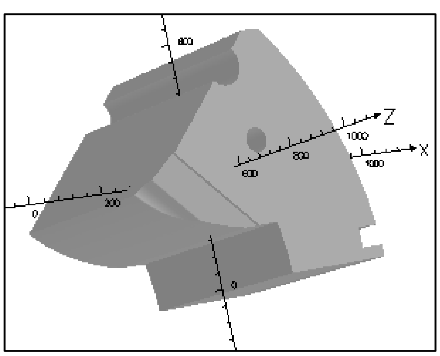


Figure 1: 1/16th geometry with end details.

Due to the very high value of required pole tip field [Table1] the pole ends were completely saturated. 3D geometry of the 1/16$^{th}$ model with end shaping is shown in Fig. 1. Without any end chamfer majority of higher order harmonics were coming due to 12(6$^{th}$ harmonic) and 20-pole (10$^{th}$ harmonic) components [Fig. 2]. At around 550 mm from centre and at 300 mm radius, contribution of 12-pole component was almost 500 gauss (w.r.t main harmonic ~420.0E-04) though at centre it was 9.5 gauss (w.r.t main harmonic ~3E-04). To reduce the net effect over the effective length different combinations of 'hyperbolic end' and end chamfer were investigated.

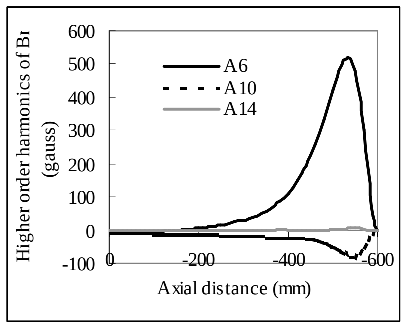


Figure 2: Higher order harmonics without end chamfer. A6, A10 and A14 are respectively 6$^{th}$, 10$^{th}$ and 14$^{th}$ order harmonics.

Table 1: LEB Quadrupole Magnet Specifications

| Parameters | Unit | Value |
|---|---|---|
| Maximum gradient | T/m | 5.2 |
| Minimum gradient | T/m | 0.1 |
| Average operating gradient | T/m | 3.5 |
| Effective length | mm | 1200 |
| Useable horizontal aperture | mm | ±300 |
| Useable vertical aperture | mm | ±250 |
| Gradient field quality | | ±8.E-04 |
| Pole radius | mm | 350 |
| Maximum pole tip field | T | 1.82 |
| Overall length | mm | 1150 |
| Overall width | mm | 1760 |
| Forbidden harmonics | relative | Within 4.E-4 |

With 23.95 deg of chamfer angle w.r.t vertical axis followed by a near elliptic end profile [Fig3], desired result was obtained. 6th and 10th order harmonics, calculated at 300 mm of radius, change sign as we go away from the axis [Fig4]. So overall effect also gets reduce.

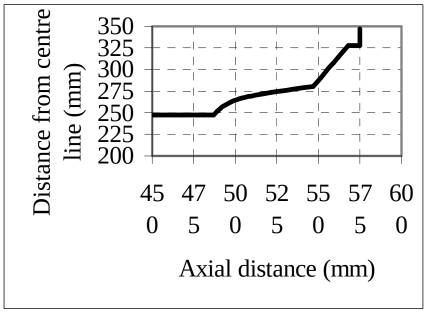


Figure 3: Axial end chamfer shape.

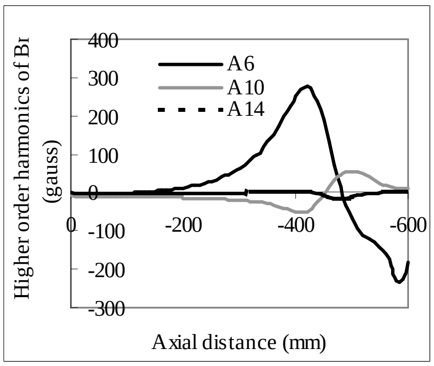


Figure 4: Higher order harmonics with end chamfer.

The radial dependence of each multipole componet (A6, A10, A14) up to the pole tip radius 350 mm is depicted in Fig 5.

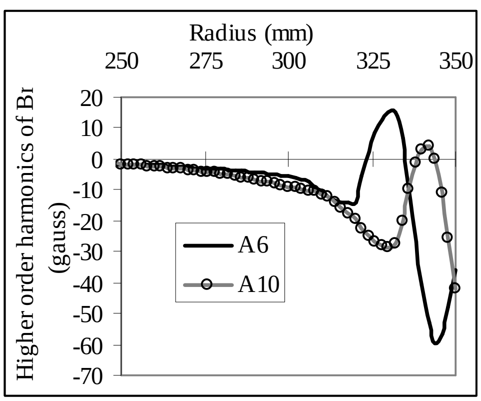


Figure 5: Radial dependence of 12th and 20-pole component at the centre of the magnet at the excitation of maximum gradient.

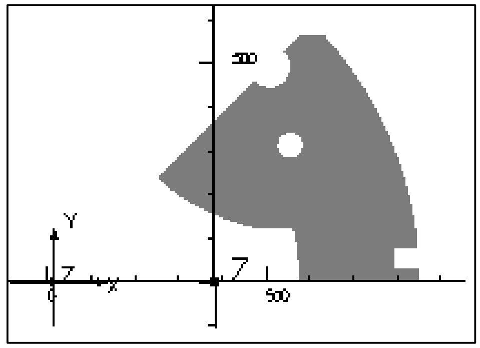


Figure 6: Cross-sectional shape.

Finally integrated average of 12-pole and 20-pole components due to optimised and un-optimised pole end-shape over the effective length was calculated and shown in Table2.

Table 2: Integrated average

| | 12-pole | 20-pole |
|---|---|---|
| Un-optimised | 8.5E-03 | 1.86E-03 |
| Optimised | 1.93E-04 | 3.0E-04 |

## REFERENCES


[1] Technical Design Report for the Super-FRS at FAIR Dated 12.03.2008. http://www.gsi.de/nustar

[2] G Pal, et al, Current Science - accepted

[3] 2D POISSON code, Los Alamos Accelerator Code Group, http://www.laacg1.lanl.gov/laacg/

[4] Vector Fields, UK, http://www.vectorfields.com/