Low–Sextupole Steering Dipoles For the MIT–Bates SHR*

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Abstract

The South Hall Ring (SHR) requires use of iron–core steering dipoles in the ring lattice, each capable of bending 1–GeV electrons by 1mr. Acceptable second order aberration effects require a very low integrated sextupole strength. We have studied, in detail, double–axis "$\cos\theta$" coils, single axis current sheets with rectangular box frames as well as conventionally wound box frames. The multipole content of each unit was determined by a fit to the measured two–dimensional field map . In conventional box frames lower sextupoles were achieved by increasing the ratio of width/gap, and by optimizing the shape of the pole plates of the frame box. Our latest design and results to date are discussed.

1 Introduction

The SHR under construction at the MIT–Bates Linear Accelerator Center will be a high intensity pulse stretcher facility with high quality cw electron beams of up to 1.0 GeV, operating in both storage and extraction modes. The ring lattice will consist of over 200 electromagnets distributed over a ring circumference of 190 m. A description of the ring is given in ref. [1]. The ring requires over 30 pairs of iron-core steerers in the ring lattice, each capable of bending 1–GeV electron beams by 1mr. The steering dipoles should have (a) low sextupole strength, (b) relatively low costs, and (c) minimum overhead for installation or removal.

The net deflection of a charged particle passing through a magnet is proportional to the integrated strength of the component of the magnetic field normal to the particle trajectory. For small deflections in the midplane (Y=0) of dipoles with small non–uniformity in the transverse direction X, the integral can be expanded to

$$\int_{-\infty}^{\infty} B_Y(X, Z, Y=0)\cdot dZ = a + bX + cX^2 + \cdots \qquad (1)$$

with X=0 on the symmetry axis of the coil, and a, b, and c representing the dipole, quadrupole and sextupole strengths respectively. Acceptable second order aberration effects in the ring require that the integrated sextupole strength of each coil relative to its dipole strength (c/a) be smaller than 7×10^{-4} at a radius of 1 cm [2]. The design should also allow for easy installation without breaking vacuum in the beam pipe.

We have studied a commercially available unit, and several in–house designs have been studied by making two dimensional field maps. The integrated sextupole strength was extracted from these data and the results are presented here.

2 Measurement of Multipole Content

The multipole content of each coil was determined by a fit to the measured two-dimensional field map. For instance, the quadrupole and sextupole strengths relative to the dipole strength at a distance X from the center are determined by:

$$\frac{bX}{a} = \text{Relative Quadrupole} \qquad (2)$$

$$\frac{cX^2}{a} = \text{Relative Sextupole.} \qquad (3)$$

Magnetic fields were mapped on a two dimensional grid using a Hall probe mounted on a narrow arm attached to a highly automated mapping table [3]. The steerers were carefully aligned relative to the location of the Hall probe and to its axes of motion. Complementary measurements were made using a harmonic analyzer [5] consisting of a rotating coil with 45 degrees opening angle. A Fast–Fourier Transform (FFT) of the integrated signal determined the harmonic content of the coils. The sextupole content from the two measurements were consistent, given the fact that the rotating coil samples the field on the circumference of a circle while the grid measurement only probes the field on the midplane. Figure 1. show a typical grid measurement of one of the coils.

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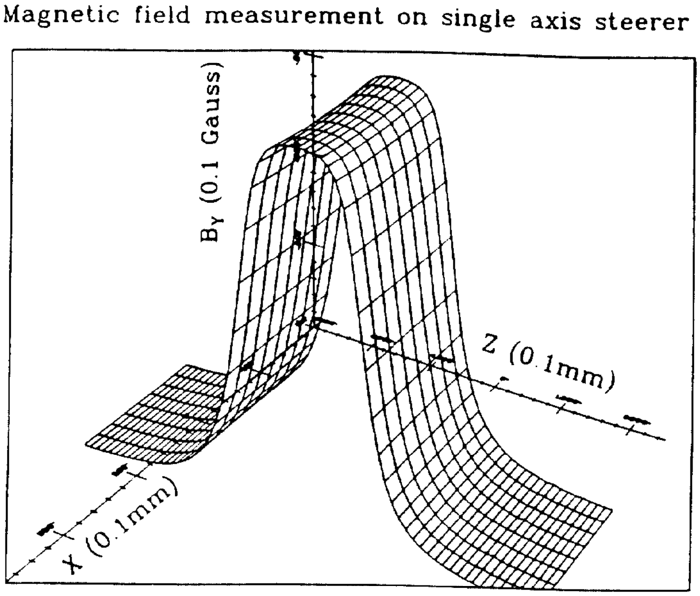

Figure 1: Grid measurement of iron–core steering dipole with an automated mapping table.

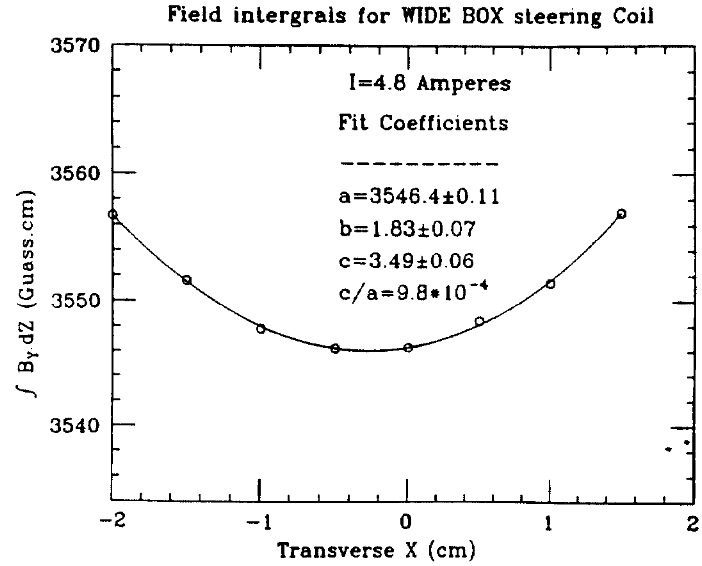

Figure 2: Integerated field as a function of transverse position X.

3 Comparison of coils

The "$\cos\theta$" X–Y beam steerer with two sets of windings on a common yoke [4] has sextupole strength with a c/a of $3 \times 10^{-4}(1/\mathrm{cm}^2)$, which is a factor of two smaller than the tolerance. However, the yoke is of one piece requiring breaking vacuum for removal and installation on the beam line.

The current sheet coils tested have sextupole strength of c/a=-3×10^{-3} $(1/\mathrm{cm}^2)$, a factor of five larger than the tolerance and mainly attributable to large end effects. Hysteresis effects were not investigated for either design.

Next we studied steerers with conventional single axis box frames. Two frames were made with 1/4 inch 1018 commercially available ground steel plates, one 83 mm wide the other 132 mm wide with both having a gap of 67 mm. Our measurement showed that the relative sextupole strength, c/a, is roughly proportional to $1/W^2$ with W being the width. The c/a for the wide steerer was about 1×10^{-3}, close to the tolerance level. Figure 2 shows the integrated field as a function of X for the wider box. Given the simplicity of the design, and the encouraging low sextupole content, we have decided to improve the design by modifying the shape of the pole plates as will be described in the next section.

3.1 Optimization of Box Steerer

The box frame with square edge pole plates has higher integrated field on the sides than on the middle, as had been suggested by a positive c/a value (Figure 2). Therefore, the sextupole strength can be reduced by reducing the effective mechanical length toward the edges. This was accomplished with pole plates with simple convex ends characterized by R, the radius of curvature of the pole plate ends (see Figure 3). It can be shown that the amount of steel added to the pole plates at a distance X_0 from the sides of the plates is proportional to X_0^2/R. This will add more steel to the middle than to the sides, thus making the integrated field distribution more uniform. A simple interpolation between our first convex plate with a radius of 10.25 inch and the straight edge with an infinite radius suggested an optimum radius of 27 inches. Our measurement however, showed a reduced positive c/a but not as small as predicted. We found that the sextupole strength for these magnets is very sensitive to hysteresis effects (or to cycling procedures). For instance, when we remeasured the R=∞ plate, but this time cycling the coil between +5V and −5V prior to the measurement, we measured a c/a as small as 1.2×10^{-4}. In order to reduce the sensitivity to the hysteresis, we had all the plates annealed [6] . Measurements of a treated steerer with a radius of 77 inches still showed some residual hysteresis effects. Figure 4 show the c/a for several radii with and without cycling. The cycling procedure consisted of applying current of one polarity slightly exceeding the current needed for 1mr kick for about one minute, back to zero current for 30 seconds, applying the current with opposite polarity for one minute and back to zero again, repeating the cycle for half a dozen times. For a pole plate radius of 77 inches, we measured a c/a ranging from -7.4×10^{-5} to -1.2×10^{-4} depending on the cycling procedure used. When the frame was "decycled" by tweeking the current by about 10% around 4.6 A, a c/a of -3.3×10^{-4} was measured, still a factor of two better than the tolerance.

The simple box design of such steerers with removable pole plates makes the installation and removal of the box easy and eliminates the need for breaking vacuum. However, it is essential to keep the mechanical dimensions of the plates, the gap uniformity, and the symmetry between

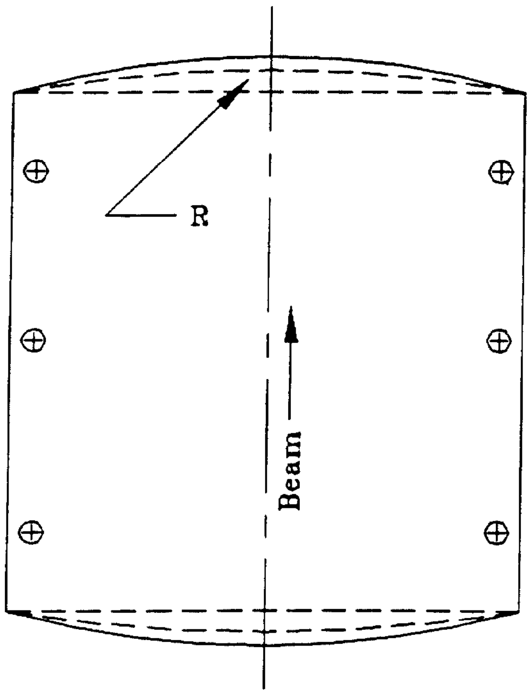

Figure 3: Plan view of the pole plates for SHR box steerer.

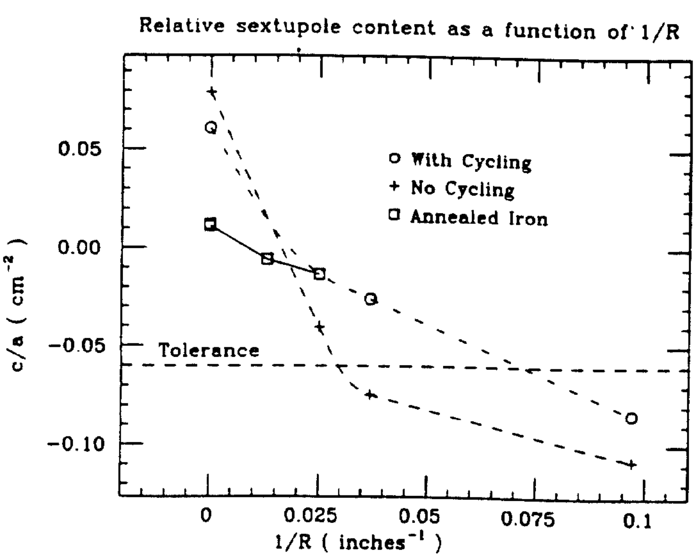

Figure 4: Relative sextupole strength for box steerer as a function of 1/R with and without cycling. It also shows results for annealed iron.

the coil windings under tight control.

4 Conclusion

Our latest design of a box frame steerer meets the sextupole requirements for the SHR and has removable pole plates with convex edges with R=200 cm . However, in order to minimize sensitivity of the coils to the hysteresis effects, all plates need to be annealed or steel of higher quality should be used. While the simple design simplifies installation and removal, the mechanical and electrical tolerances must be carefully maintained.

References

[1] J.B. Flanz et al., Proceedings of the 1989 IEEE Particle Accelerator Conference, March 20-23, 1989, p.34.

[2] The actual specified tolerance is $7. \times 10^{-3}$ at 90% of the half aperture of the ring with a ring aperture of 67 mm.

[3] Two dimensional mapping table, on loan from NIST.

[4] Model # 3521, On loan from GMW Associates.

[5] W.G. Davies, N. Bray, and R. Howard, Chalk River Nuclear Laboratories, Chalk River, Ontario, Canada; and W.G. Davies, submited to Nuclear Instruments and Methods.

[6] Annealed to 1800 °F for four hours and oven cooled.