BNL-82307-2009-CP

Design of NSLS-II High Order Multipole Correctors

M. Rehak, G. Danby, Jo Bengtsson, J. Jackson, J. Skaritka, C. Spataro

Brookhaven National Laboratory, Upton, NY 11973-5000, USA

Presented at the PAC09 Conference
Vancouver, Canada

May 4 – 8, 2009

National Synchrotron Light Source II Project

Brookhaven National Laboratory
P.O. Box 5000
Upton, NY 11973-5000
www.bnl.gov

DISCLAIMER

DESIGN OF NSLS II HIGH ORDER MULTIPOLE CORRECTORS*

M.Rehak#, G.Danby, J.Bengtsson, J.Jackson, J. Skaritka, C. Spataro,
Brookhaven National Laboratory, Upton, NY 11973, U.S.A.

Abstract

Feasibility studies for two families of corrector magnets for NSLS-II are presented. The first family of magnets are generalizations of figure eight quadrupoles using rotationally symmetric breaks in the return yoke to fit in available space. Properties specific to figure eight magnet are identified. The second type of magnet is a combined sextupole/dipole trim.

PHYSICS MOTIVATION

While the NSLS-II design is essentially robust, by the use of Damping Wigglers, the introduction of Three-Pole Wigglers (TPWs) adjacent to the main dipoles has pushed the (linear) optics to a level where e.g. tighter tolerances are required for the magnets in the dispersive sections than the state-of-the-arts for medium energy third generation light sources (SLS, SOLEIL, DIAMOND). Furthermore, the magnitude of the momentum dependence of the (linear) optics is such that, to control the chromaticity, terms up to 3rd order in the momentum deviation must be included. Therefore, first chromatic octupoles (to control the 2nd order), and then decapoles (to control the 3rd order) have been considered. However, by addressing the root cause, i.e., the momentum dependence of the optics, this could eventually be simplified by introducing a third chromatic sextupole family [1]. However, since the control of the nonlinear dynamics is essentially a matter of "solving" (in a least-square sense) a highly overly constrained nonlinear system of algebraic equations, satisfactory "solutions" can only be obtained if the dynamic system has a sufficient level of internal symmetries; which requires a creative engineering approach. In particular, since, while the magnetic lattice is essentially reflection symmetric, the beam pipe is translation symmetric (due to the synchrotron radiation). In addition, while the latter implementation is (mechanically) compatible with up to 15 TPWs (owing to a yoke with "clover leaf" symmetry), the desire to push this to 30, would require the (nontrivial) integration of an adjacent horizontal/vertical dipole corrector with such a sextupole.

FIGURE EIGHT MAGNETS

Multipole magnets have been built with rotationally symmetric interruptions in the return yoke taking advantage of the symmetry of Maxwell's equations. This technique was first introduced for quadrupoles in [2] and is commonly used in sextupoles. The concept of introducing radially symmetric breaks while maintaining a return flux path is applied to a sextupole corrector and extended here to octupole and decapole magnets. Specifications are given in Table 1 under the form of normalized integrated multipole strength $(b_N L)$ defined as $(b_N L) = (B_N L)R^{1-N} / (B\rho), (B\rho) = 10$

Field and excitation are related for all multipoles by

$$\mathrm{N}I = \frac{kB^{(N-1)}R^N}{N!\,\mu}, B_{poletip} = \frac{B^{(N-1)}R^{N-1}}{\eta(N-1)!}$$

where N=2 quadrupole, 3 sextupole, etc.., k=1 for coils around pole tip, k=2 for coils around the yoke's backleg. NI current in Amperes turns, R radial aperture in m, L magnet length in m, $B^{(N-1)}$ nth order derivative of field B in T. $\mu = 4\pi 10^{-7}$ Tm/Amp, $\eta \approx 1$ is the magnet efficiency.

Coils are wound around the backleg in order to fit in available space at the cost of doubling the current. The pleasing economy of design associated with symmetry allows the use of the elementary unit cell defined as the smallest building block from which the magnet can be reconstructed. It eliminates numerically spurious harmonics. Table 1 summarizes the design parameters that will satisfy the strength requirements for each multipole.

Sextupole Corrector

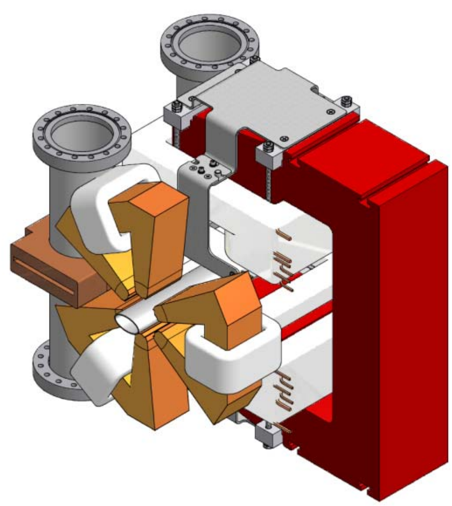

Figure 1: Sextupole corrector and Dipole corrector.

The main ring 68 mm aperture sextupole magnet design [3] is used here as a starting point. The coils are wound around the yoke which has been cut back to make room for a flange and clears the exit absorber chamber.

One concern with figure eight magnets is the effect of the radial breaks on the fringe field, in particular in the radial direction. Studies show that radial field decay rates

* Work supported by DOE contract. DE-AC02-98CH10886.
#rossum@bnl.gov

are comparable to the case of an uninterrupted yoke. An increase of 4 to 7 Gauss is observed on the outer circumference due to the breaks in the yoke. Another concern is the loss of shielding coming from a continuous yoke on the good field region, and the influence of magnetic material in the magnet's vicinity. Parametric studies show only modest changes in harmonics when placing a piece of iron inside the break. Another difference in figure eight magnets comes from the multiplicity of parts that increases assembly errors, yet these may also be acceptable for a trim magnet.

Octupole Corrector

Figure 2: Octupole corrector

The pole tip shape was approximated by a circle whose diameter is the pole width. As the radius of curvature increases there is a decrease of b12 by 30%, followed by a plateau, b20 and b28 remained invariant. End chamfering does not reduce harmonics presumably because of the narrow width of the pole.

Decapole Corrector

Figure 3: Decapole corrector

Use of a regular decapole was excluded because the pole roots would be so long and narrow as to overly saturate.

Harmonics are less sensitive to the pole tip shape (N>2) and end chamfering (N>3) as N increases. In addition figure eight magnets loose one reflection symmetry with respect to the center line on the pole. The regular multipole symmetry constraint $F_n\left(\vartheta+\frac{\pi}{N}\right)=-F_n(\vartheta)$ becomes $F_n\left(\vartheta+\frac{2\pi}{N}\right)=F_n(\vartheta)$ where F is a complex function satisfying Laplace equation. Allowed harmonics are $n=Nm, m=1,2....$ instead of $n=N(2m+1)$.

Figure eight magnets differ from regular magnets in several aspects: radial fringe fields, lack of shielding and allowed harmonics, none of which are numerically significant for present application.

Table 1: Parameters and Integrated Field Strength

N	L m	R m	B T	$B^{(N)}$ T/ m^{n-1}	NI At	$(b_N L)$ 1/ m^{n-1}
3	0.15	0.034	0.10	192	2000	1
4	0.5	0.045	0.25	18.5e3	5025	154
5	0.5	0.050	0.23	1.3e6	5250	2638

COMBINED SEXTUPOLE-DIPOLE CORRECTOR

An alternate solution to the sextupole corrector was needed to increase the number of TPW. Adding trim coils to a quadrupole to generate a sextupole corrector gives rise to undesirable harmonics. However adding correction coils to a dipole leads to compatible higher order harmonics but was not practical here due to space and current density limitations. The preferred solution is to replace the existing 156 mm gap horizontal and vertical dipole correctors (shown next to the sextupole in figure 1) with combined function sextupole/dipole corrector. This type of corrector cannot have more than one break in the yoke in order to provide return flux for the dipole fields and will therefore be asymmetric. Dipole/sextupole correctors have been implemented in ESFR, SUPERACO, SLS [4]. The single break in the yoke to make room for the antechamber of the beam tube increases the quadrupole and octupole terms by less than an order of magnitude when compared to a regular sextupole in this instance. This increase may be acceptable for a corrector magnet.

The method used here is to generate horizontal (figure 5) or vertical dipole fields (figure 6) with a primary set of coils and improve field quality with auxiliary coils correcting the sextupolar component induced by the shape of the iron. As in [5] fully independent vertical and horizontal dipole correction are possible by adjusting the ratio of currents in main and auxiliary coil sets. Requirements are 300 gauss, field quality ± 1%; good field region $0 \le |x| \le 15$ mm ; $0 \le |y| \le 10$ mm. This is only a preliminary 2D feasibility study.

Horizontal Dipole Field

Three sets of coils are needed: a) main: coils around the 30 degree poles 1300 A. b) auxilliary: sets of vertical coils, 345 A and 455 A with reversed polarity, to keep the current density at 2 A/mm^2. The error on the horizontal field is shown in figure 7 to be 0.1% at 15 mm.

Vertical Dipole Field

Three sets are also needed a) main:2 sets coils around the vertical poles, 733 A and around the 30 degree poles 733A. b) auxilliary: 2 pairs of pole face windings nested inside main2 with inverse polarity, 50 A. Current densities are 2 A/mm^2 in the main coils but 0.3 A/mm^2 in the auxilliary coils. The error of the vertical field is shown in figure 8 where value are +/- 0.4%.

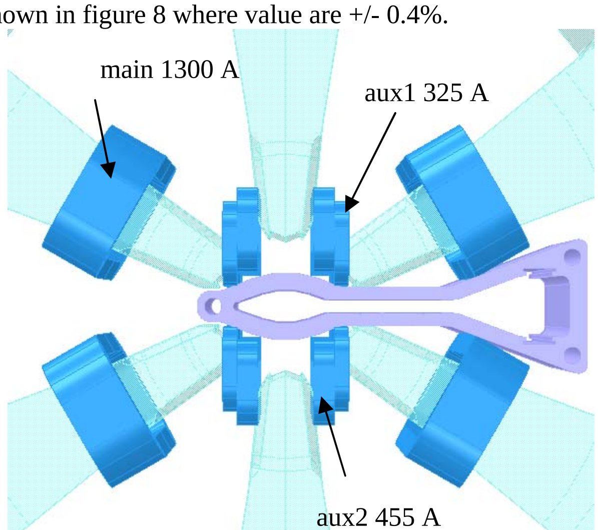

Figure 5: Horizontal dipole field.

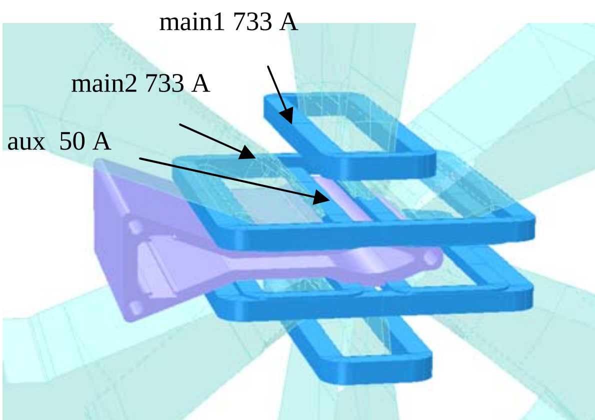

Figure 6: Vertical dipole field.

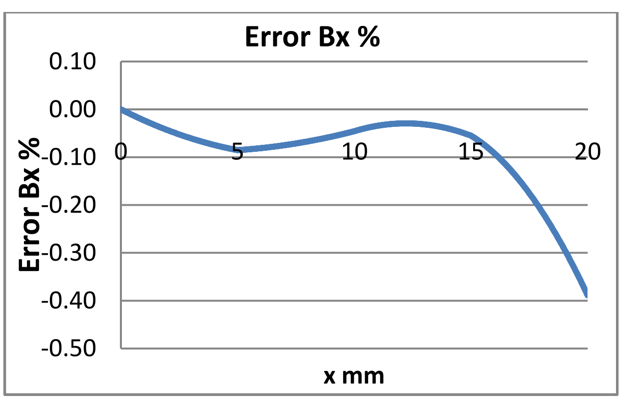

Figure 7: Horizontal dipole field homogeneity at y=0.

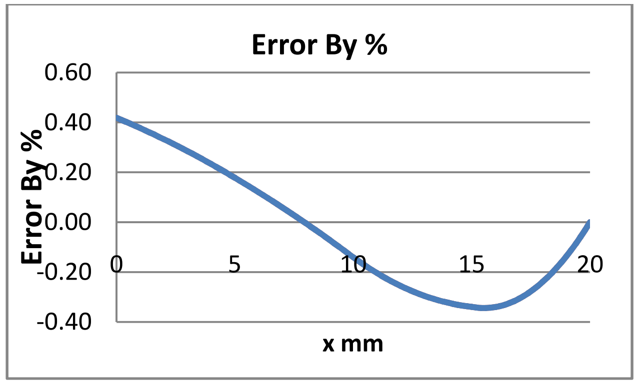

Figure 8: Vertical dipole field homogeneity at y=0.

REFLECTIONS ON SYMMETRY

Symmetry, rotational and reflection, unifies multipole magnets with a common mathematical expression. Additionally, translational symmetry determines their placement in the ring. The beauty of physical laws is embodied in the physical object with its emphasis on geometry and symmetry which drive its aesthetics. Yet each magnet type has a unique effect on particle trajectories despite their complex dynamics, even though underlying laws are simple. In summary, a successful design of a complex system is based on a recursive application of symmetry.

CONCLUSIONS

Iterations in physics lattice design combined with practical engineering considerations drove the evolution and diversity of these magnets designs. Various preliminary studies for figure eight multipoles (3D) and sextupole/dipole combined corrector (2D) have been summarized. Further detailed engineering design is needed to fully assess their feasibility.

REFERENCES

[1] J.Bengtsson, “NSLS-II: control of Dynamic Aperture," Brookhaven National Laboratory, BNL-8170-2008-IR

[2] G.Danby, J.Jackson, “Theory, Design and Measurement of the Brookhaven Narrow Quadrupoles, IEEE Transactions on Nuclear Science, June 1967IEEE

[3] J.Skaritka, et al, “Design and Construction of NSLS II Magnets**,"** Pac'09 MO6PFP008.

[4] Synchrotron Radiation Sources, H. Winick.

[5] J.A.Clarke and N.Marks,"Sextupole Magnets for DIAMOND" MAGNETS FOR DIAMOND". CLRC, Daresbury Laboratory, Warrington WA4 4AD, UK.