IMPACT OF HIGHER-ORDER MULTIPOLE ERRORS IN THE NSLS-II QUADRUPOLES AND SEXTUPOLES ON DYNAMIC AND MOMENTUM APERTURE

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Abstract

Successful operation of NSLS-II requires sufficient dynamic aperture for injection, as well as momentum aperture for Touschek lifetime. We explore the dependence of momentum and dynamic aperture on higher-order multipole field errors in the quadrupoles and sextupoles. We add random and systematic multipole errors to the quadrupoles and sextupoles and compute the effect on dynamic aperture. We find that the strongest effect is at negative momentum, due to larger closed orbit excursions. Adding all the errors based on the NSLS-II specifications, we find adequate dynamic and momentum aperture.

INTRODUCTION

NSLS-II is a low emittance, third-generation light source to be built at Brookhaven National Laboratory[1]. In order to assure sufficient injection efficiency and Touschek lifetime, the non-linear dynamics effects must be carefully controlled. The lattice design and tuning optimization is discussed further in [2]. Here we discuss the effect of higher-order multipole errors in the quadrupoles and sextupoles on the non-linear dynamics. These fields must be kept within tolerance to assure that they do not impact the functioning of the storage ring.

Higher-order multipole errors are mainly important for particles with large amplitudes. Particles may obtain large amplitudes during normal operation for two reasons. First, during injection, the particles start at a large off-set (15 mm) and return to the particle core through radiation damping. Here, the issue is to maintain an adequate on-momentum dynamic aperture to preserve injection efficiency. The second issue is Touschek lifetime. Scattering within the bunch occurs constantly and leads to some particles being lost. For adequate lifetime, a reasonable dynamic momentum aperture must be achieved. In addition to momentum off-sets, scattered particles will also have transverse off-sets as they oscillate about the dispersive closed orbit. For particles scattering in the dispersion region to relative momentum deviations of $\delta P/P = \delta = 2.5\%$, the electrons will oscillate as much as 30 mm. This results in a strong impact coming from higher-order multipole errors in the magnets in the dispersion region.

Because $\delta = 2.5\%$ scattered particles from the dispersion region have larger amplitudes than for the injection process, here we are concerned with higher-index multipoles. For the purpose of injection, we consider the $\delta = 0$ effect of the next three higher-order multipole errors ($n = 4, 5, 6$). For the purpose of Touschek scattering, we consider the first three allowed higher-order multipole errors at $\delta = 0, \pm 2.5\%$. These are $n = 6, 10, 14$ in quadrupoles, $n = 9, 15, 21$ in sextupoles. We have found that this is high enough order to model the fields accurately out to the required amplitudes.

We find that higher-order multipole errors decrease the dynamic aperture. While the precise details of the fields would be important for a resonance effect, we find that the decrease in dynamic aperture is not easilly described as resulting from driving a particular resonance. This partially results from the dynamic aperture optimization in which no one resonance dominates the dynamics.

MULTIPOLE ERRORS

The integrated magnetic field for a magnet may be described with a multipole exansion:

$$\int_0^L ds(B_y + iB_x) = (B\rho) \sum_{n=1}^{\infty} (ia_n + b_n)(x + iy)^{n-1} \quad (1)$$

$$= \sum_{n=1}^{\infty} (iA_n(r) + B_n(r)) e^{i(n-1)\phi} \quad (2)$$

The b_n are the normal multipole components and the a_n are the skew multipole components. Here, $n = 1, 2, 3$ are for the regular dipole, quadrupole and sextupole fields respectively. $(B\rho)$ is the magnetic rigidity. The B_n and A_n are the Fourier components of the field strengths. They may be measured by a rotating coil system. Since the multipole fields will typically scale with the excitation strength of the magnet, we define a normalized strength.

$$B_n^{(N)}(R) \equiv R^{n-N} \frac{b_n}{b_N} \quad (3)$$

Here N is the index for the design field, and n is the index for given higher-order multipole field. R is the reference radius at which the multipole strengths are specified. $B_n^{(N)}(R)$ may also be described as the ratio of the field B_N to the field B_n at a distance R from the center.

IMPACT FROM FIELD ERRORS

In order to evaluate the effects of the multipole errors, we include them one at a time and compute the dynamic aperture for each case. We use the tools based on the Tracy tracking library for these studies. See [4] for further details. The results for random errors in the quadrupoles and sextupoles for on-momentum dynamic aperture is given in Figures 1 and 2. Magnet specification for higher-order multipoles are given for a reference radius of $R = 25$ mm. See Tables 1 and 2. However, we have noted the interesting result that if we plot DA vs. multipole strength, we obtain approximate similar curves for the different orders by choosing a reference radius of $R = 40$ mm. This suggests a scaling law for dynamic aperture which would be interesting to investigate further. In any case, we find that with a relative integrated field error of 4×10^{-4} at $R = 40$ mm for the quadrupoles, the drop in dynamic aperture due to the multipole errors is less than 10%. Errors in the sextupoles are seen to have less impact, with random multipoles of 20×10^{-4} giving a 10% drop.[1]

The impact from the first three systematic multipole errors is shown in Figures 3-5. We compute the effect at $\delta = 0, \pm 2.5\%$. We start with a bare lattice and turn on the errors incrementally, computing the dynamic aperture for each value of the errors. We find a substantially larger impact at $\delta = -2.5\%$. This has been understood and traced back to the asymmetric momentum dependence of the closed orbit and beta functions. This is discussed further in [3]. As a result of this effect, larger aperture magnets are used in the maximum dispersion region.

These considerations, together with input from magnet design and modeling and expected mechanical errors went into determining the specifications shown in Tables 1 and 2. The total impact from the specified quadrupole and sextupole field error tolerances is given in Figure 6. For this calculation, a bare lattice including damping wigglers and correction was given the specified multipole errors scaled with each quadrupole and sextupole. Smaller errors in the dispersion region were also added, consistent with the large aperture values in the tables.

CONCLUSIONS

We have done parametric studies of impact of random and systematic multipole errors on dynamic aperture for NSLS-II. We have given the tolerances for the quadrupoles and sextupoles for NSLS-II, pointing out the need for tighter tolerances in the magnets at the maximum dispersion. Adding all the errors to a current NSLS-II lattice, we find acceptable impact on both on and off momentum dynamic aperture.

ACKNOWLEDGMENTS

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[1] An older lattice was used for these studies, but we do not expect the results to be particularly sensitive to small changes in magnet position or lattice tuning.

Table 1: NSLS-II tolerances for Quadrupoles (R=25 mm)

Allowed	Norm.[$\times 10^{-4}$]	Large Ap.[$\times 10^{-4}$]
B_6^2	1	1.0
B_{10}^2	4.5	0.5
B_{14}^2	4.0	0.1
Unallowed		
B_1^2	1.0	1.0
B_3^2	3.0	3.0
B_4^2	1.0	1.0
B_5^2	0.1	0.1
B_{7-9}^2	0.1	0.1
$B_{11-13,15-20}^2$	0.1	0.1
Skew Terms		
A_1^2,A_3^2	1	1
$A_{>4}^2$	0.1	0.1

Table 2: NSLS-II tolerances for Sextupoles (R=25 mm)

Allowed	Norm.[$\times 10^{-4}$]	Large Ap.[$\times 10^{-4}$]
B_9^3	1.0	0.5
B_{15}^3	1.0	0.5
B_{21}^3	4.0	0.5
Unallowed		
B_1^2	1.0	1.0
B_3^2	1.0	3.0
B_4^2	1.0	1.0
B_{5-7}^2	0.5	0.5
B_8^2	0.1	0.1
B_{10-14}^2	0.2	0.2
Skew Terms		
A_1^2,A_3^2	5	5
$A_{>4}^2$	1.0	1.0
$A_{\geq 5}^2$	0.1	0.1

REFERENCES

[1] http://www.bnl.gov/nsls2/project/PDR/

[2] W. Guo et. al., "New Approaches in Lattice Design and Optimization with Insertion Devices", Proc. PAC '09

[3] B. Nash, et. al. "Touschek Lifetime Calculations for NSLS-II", Proc. PAC '09

[4] B. Nash, "Command Line Interface to Tracy Library",Proc. PAC '09

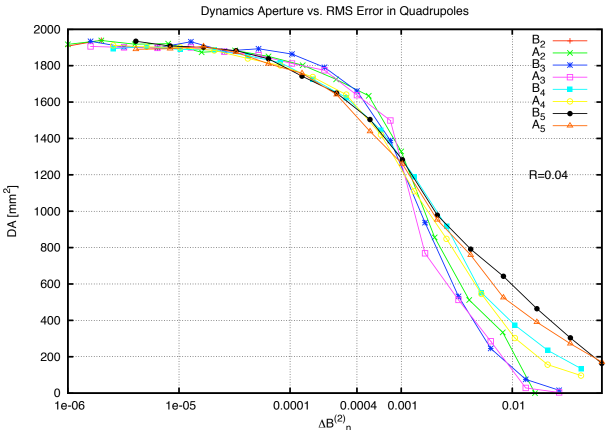

Figure 1: Impact of individual random multipole errors in quadrupoles on Dynamics Aperture area.

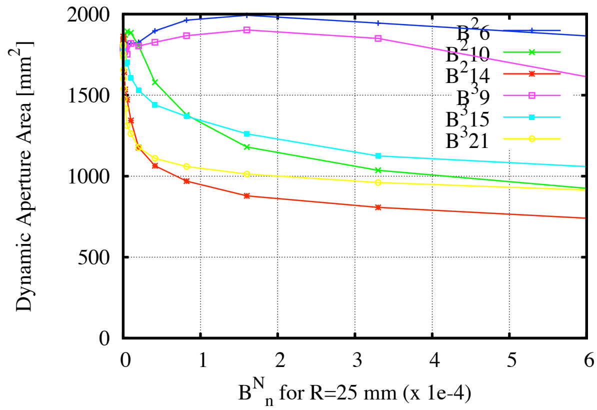

Figure 4: Impact of systematic multipole errors on dynamic aperture area at $\delta = 0\%$.

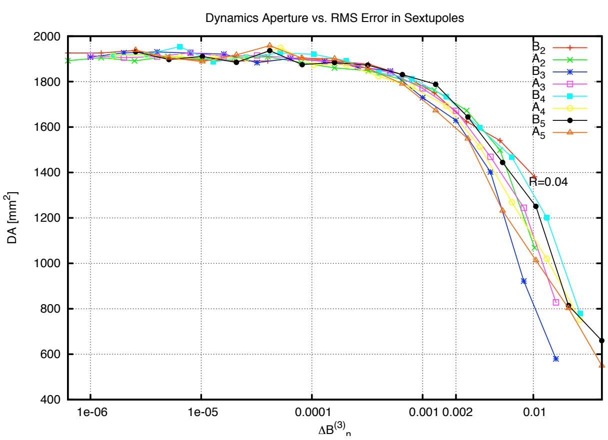

Figure 2: Impact of individual random multipole errors in quadrupoles on Dynamics Aperture area.

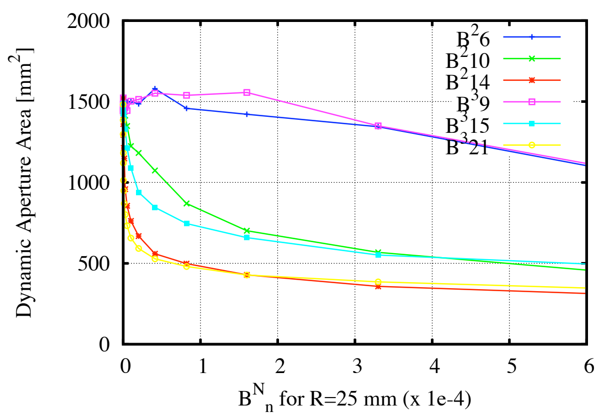

Figure 5: Impact of systematic multipole errors on dynamic aperture area at $\delta = -2.5\%$.

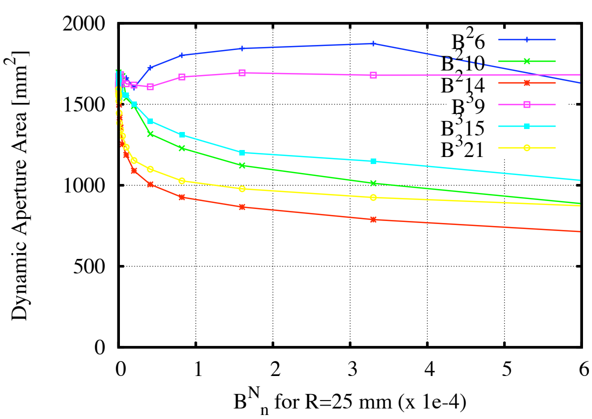

Figure 3: Impact of systematic multipole errors on dynamic aperture area at $\delta = 2.5\%$.

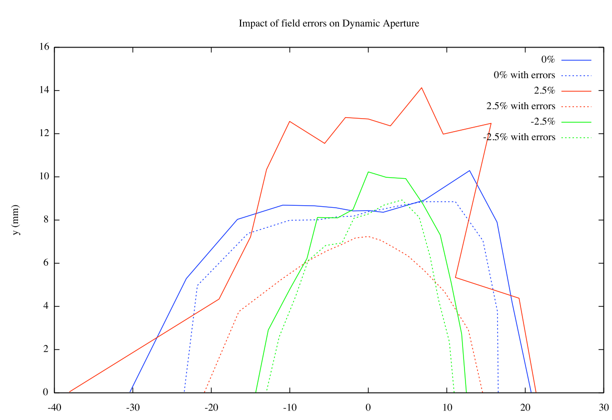

Figure 6: Impact of field errors within tolerances given in Tables 1 and 2 on Dynamic Aperture.