ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPC04

SEXTUPOLE OFFSET EFFECTS ON THE STORAGE RING LINEAR OPTICS*

J. Choi†, Y. Hidaka, G. Wang, BNL, Upton, NY, USA

Abstract

Even though the strengths are weaker, different from quadrupole offsets, sextupole offsets are causing more complicated disturbances on the storage ring optics. They are making orbit distortion and quadrupole kicks as well as couplings. The offsets in chromatic sextupoles can affect the correction of chromaticity too. The closed orbit corrections in modern storage rings are fast and reliable, but their main focus is correcting the orbit to the quadrupole centers and the orbit distortion from a sextupole offset can make orbit offsets at other sextupoles which can be iterated. In this paper, we study the impact of the sextupole offsets on the linear optics in NSLS-II storage ring.

INTRODUCTION

In operating the synchrotron light source, NSLS-II [1], even with well prepared unit conversion tools, there are always non-negligible deviations in linear optics using the model constructed from the magnet power supply currents and alignment data. Of course, the ring parameters can be optimized using various tools, like LOCO [2], to yield the design performance, and there is no issue in satisfying the users. The correction is usually working well, and we can say the process restores the optics, but we cannot say that it identifies the source of the deviations.

Besides the errors in quadrupole strengths, we can easily assume that the primary source of the deviation in linear optics could be the sextupole offsets. And we studied their contributions to the optics deviations from the model. To avoid the BPM calibration errors in measurements, we use only the phase advances from turn-by-turn data. We could obtain quite reliable data through cautious filtering process and using NAFF algorithm (Numerical Analysis of Fundamental Frequencies) [3]. However, by using the operation lattice where the coupling is so well corrected with skew quadrupoles, the signal to noise level of coupling related data were too poor for any analysis, and we focus on the linear lattice analysis without coupling. It is well known that effects of horizontal and vertical sextupole offsets on the linear optics are uncoupled betatron oscillation and coupling [4]. That means the vertical offset effects from the sextupoles are not studied and, only the horizontal offset effects are analyzed. Using various Bmad optimization methods [5], we tried to estimate the quadrupole errors and sextupole offsets which could explain the lattice parameter deviations.

* Work supported by DOE under contract No. DE-SC0012704
† jchoi@bnl.gov

LATTICE CHARACTERIZATION

In practical optimization of the NSLS-II storage ring, the design lattice is use as the basic model because the machine is well tuned to the design lattice and all the design parameters provide excellent representations of the real ring. The model constructed using actual magnet strengths obtained from the magnet field measurement data is quite far from the real machine. However, in this paper, because the purpose of the study is not the correction of the lattice but the estimation of error effects on the linear optics, we start with the model constructed from currents of magnet power supplies. The tunes are good example showing the difference between design lattice and the actual lattice. The measured horizontal and vertical tunes are 33.21 and 16.27 which are very close to the design tunes 33.22, 16.26. On the other hand, the tunes calculated from the actual model are 33.42 and 16.45.

The NSLS-II storage ring consists of 30 cells with 15 super periods having alternating high-beta and low-beta straight sections. Each cell has 10 quadrupoles and 9 sextupoles. The quadrupole families are names as QH1, QH2, QH3, QL1, QL2, QL3, QM1, and QM2. QH1, QH2, QH3 families are used for matching the high-beta straight sections and QL1, QL2, QL3 families are used for low-beta straight sections. Therefore QH and QL families are located at non-dispersive regions, and QM1, QM2 families are located at dispersive regions where they can adjust chromaticity as well as the dispersion function. The tune feedback system is using the QL families.

By using the quadrupole errors and horizontal sextupole offsets as the knobs, we tried to find the solution which can be expected from the real machine. To find the matching conditions, we used the measured BPM to BPM phase advances as the target data the solution should satisfy. First, we reviewed the Jacobian matrix to see if any specific errors have significant impact on the phase advances and correcting those errors can be solutions. From correlations from the matrix and the deviations of phase advances, we found the sources are distributed around the ring and we approached with general matchings.

As the result, we could find a solution giving tunes as 33.22 and 16.27 with reasonable error levels and the expected errors from the solution are shown in Fig. 1.

From Fig. 1, we can see it is very probable that errors in QH2 family are acting as the major sources of the lattice deviations from the model. For QL families, they are always moving to correct the tunes and we can expect some contributions from the them. As for sextupole offsets, they are rather bigger than we expected, but it is not unreasonable

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPC04

because no special efforts have been spent to correct the beam offsets at the sextupoles.

The reductions in differences of horizontal and vertical phase advances between measurement and model are shown in Fig. 2.

Figure 3 shows the separate contributions to the matching from quadrupole errors and sextupole offsets. From Fig. 3, we can find the adjusting quadrupole field errors are more effective in matching the optics deviations in vertical plane while sextupole offsets are more effective in matching the horizontal optics,

EFFECTS FROM INDIVIDUAL SEXTUPOLE VARIATIONS

In section 2, we found some reasonable machine errors which can explain the linear optic deviations from the model constructed from the magnet power supply currents. In this section, we study the effects of the sextupole field variation on the linear optics.

In the NSLS-II storage ring, while each of the quadrupoles has its own power supply, sextupoles are connected in series and they cannot be controlled individually. Among 30 cells of the ring, each 6 cells are grouped as a pentant, and basically all the sextupoles of the same family in the pentant are powered by single power supply. The exceptions are regions surrounding the damping wigglers (DW). NSLS-II storage ring has 3 DWs to reduce the emittance, and to compensate the strong effects from the DW, the 3 sextupole couples at the region have power supplies for each couple. The three DWs are located at straight sections 8, 18, and 28, and the sextupole families around the straight section 8 are named as DW08-SH1, DW08-SH3, and DW08-SH4. Among them, we chose the DW08-SH1 family, and studied the effects when the magnetic field strengths are changed.

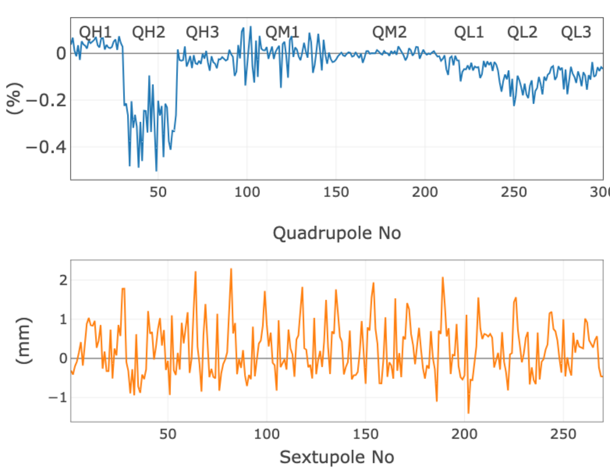

Figure 1: The quadrupole field errors and sextupole horizontal offsets which can generate horizontal and vertical phase advance matching to the measurements.

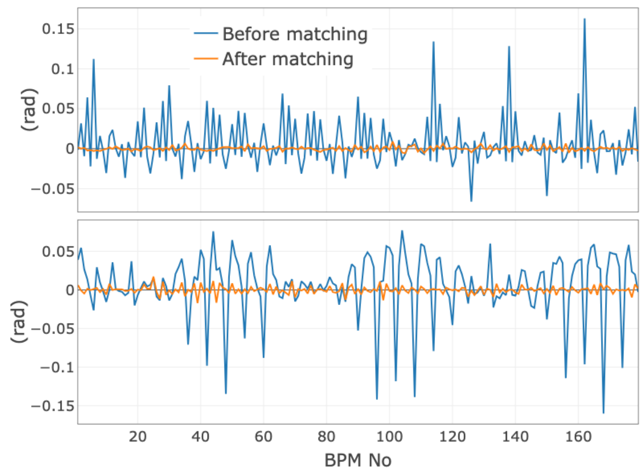

Figure 2: The differences between measurements and model phase advances in horizontal and vertical planes before and after the model matching process.

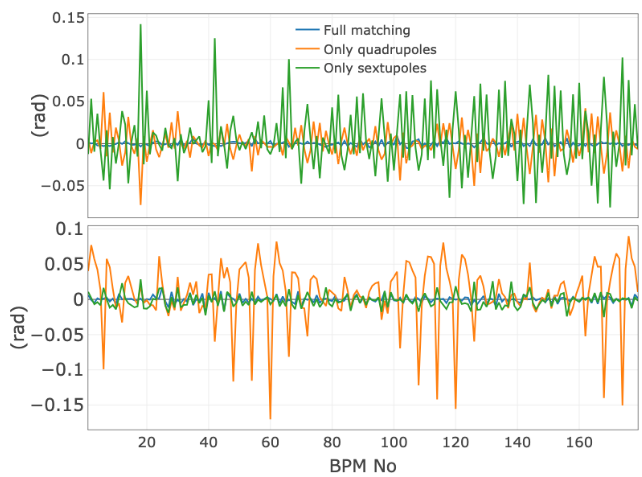

Figure 3: Contributions from quadrupole errors and sextupole offsets to the horizontal and vertical phase matchings.

The nominal operation currents of DW08-SH1 is 47.5 A, and we collected the data also for the currents at 0 A, 20 A, 40 A, and 80 A

Figure 4 shows the variations of closed orbit while the sextupole strengths are changed.

It turns out that the variations in the closed orbit are not the results of the isolated perturbations from the sextupole strengths. The effects on the closed orbit from the sextupole offsets are second order and the kicks are not enough to make such distortions. Even though we did not perform the step-by-step simulations, we can argue that the quadrupole mis-alignments should be involved. The closed orbit distortions would be amplified by quadrupoles while the small perturbation is propagated along the ring.

The phase advances depending on the sextupole currents are also calculated and are shown in Fig. 5. While the closed orbit variations show regular deviations depending on the sextupole strengths, the effects on phase advances look al-

ISBN: 978-3-95450-247-9
ISSN: 2673-5490
doi: 10.18429/JACoW-IPAC2024-THPC04

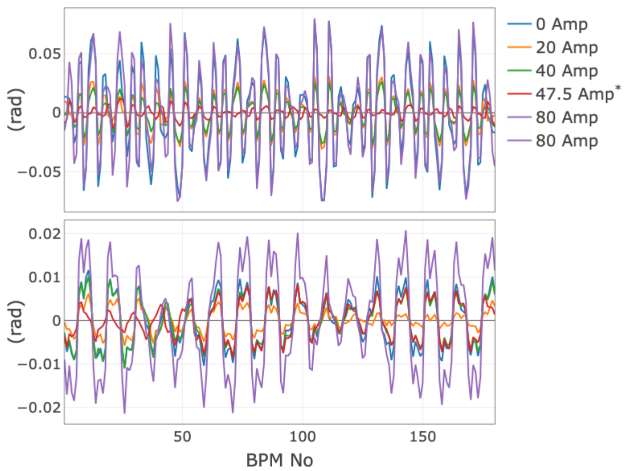

Figure 4: The horizontal and vertical closed orbit variations depending on the sextupole DW08-SH1 power supply currents. The operational nominal current is 47.5 A and is marked as "*".

most random except there are more spikes for bigger changes in strength. In fact, the tune changes are not showing the linear dependence on the sextupole strength, and the variation ranges are also too small ($\delta\nu_x < 0.0005$ and $\delta\nu_y < 0.0003$) to derive any argument.

In summary, neither the closed orbit distortions nor the variations in phase advances cannot be explained as an isolated sextupole strength change, and we could confirm it by the wave analysis [6].

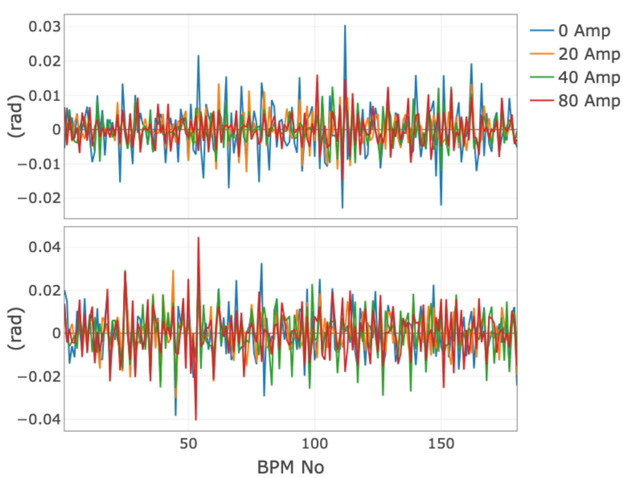

Figure 5: The horizontal and vertical phase advances depending on the sextupole DW08-SH1 power supply currents. The values are the differences from the ones at the nominal current, 47.5 A

DISCUSSION

We found a reasonable solution which can explain the deviation in horizontal and vertical phase advances of NSLS-II storage ring, using the quadrupole field errors and sextupole horizontal offsets. We could also find the solution when we use only quadrupole field errors or use only sextupole offsets. However, the errors for the solutions should be too big to be realistic, and they could not be the reasonable solutions.

In fact, we used 570 variables (300 quadrupole errors and 270 sextupole offsets) to match 360 constraints (358 horizontal and vertical phase advances between BPMs and tunes). The situation could be shown not so optimal because the under constraint optimization process can make solutions which is not real and also become easily degenerate. We took the disadvantage to use only the highly reliable data which are phases at the BPMs. We spent quite an efforts to filter the data and, also, the condition that the errors should be reasonable is very restrictive and the solution should be meaningful.

Unfortunately, we have no effective control over the beam offsets at the sextupole positions, that is, we cannot correct the NSLS-II storage ring with the obtained solution. However, because quadrupole offsets are maintained using the beam based alignments, there will be some methods to estimate the beam offsets in sextupoles. The fact that the design parameters for the magnet alignment tolerance on the same girder is 30 µm while the girder to girder alignment tolerance is 100 µm [1], will be helpful in estimating the sextupole offsets. Once the matching solution is verified, by scaling the quadrupoles according the solution, we can find out the pure effects from the sextupole offsets.

Also, what we found is that, once a satisfying lattice is obtained, the perturbation from the limited number of sextupole offsets hardly affect the phase advances, which represent the betatron oscillations. Therefore, we can say that correcting the orbits also means that the correcting the perturbation from the beam offsets at sextupoles.

REFERENCES

[1] S. Dierker, *NSLS-II Preliminary Design Report*. 2007. `doi:10.2172/1010602`

[2] J. Safranek, "Experimental determination of storage ring optics using orbit response measurements," *Nucl. Instrum. Meth. Phys. Res, Sect. A*, vol. 388, pp. 27–36, 1997. `doi:10.1016/S0168-9002(97)00309-4`

[3] J. Laskar, C. Froeschlé, and A. Celletti, "The measure of chaos by the numerical analysis of the fundamental frequencies. application to the standard mapping," *Physica D: Nonlinear Phenomena*, vol. 56, no. 2, pp. 253–269, 1992. `doi:10.1016/0167-2789(92)90028-L`

[4] V. Sajaev and A. Xiao, "Simultaneous measurement of all sextupole offsets using the response matrix fit.," in *Proc. 2010 International Particle Accelerator Conference*, 2010, pp. 4737–4739.

[5] D. Sagan, "Bmad: A relativistic charged particle simulation library," *Nucl. Instrum. Meth. Phys. Res., Sect. A*, vol. 558, pp. 356–359, 2006. `doi:10.1016/j.nima.2005.11.001`

[6] D. Sagan, "Betatron phase and coupling correction at the cornell electron/positron storage ring," *Phys. Rev. Spec. Top. Accel. Beams*, vol. 3, p. 102 801, 10 2000. `doi:10.1103/PhysRevSTAB.3.102801`