ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-THPL059

STUDY OF NSLS-II STORAGE RING SEXTUPOLE BBA MEASUREMENT*

J. Choi†, Y. Hidaka, G. Wang, BNL, Upton, NY 11973, USA

Abstract

In designing the synchrotron light sources like NSLS-II, non-linear perturbation from the sextupoles are thoroughly studied to secure dynamic apertures large enough for the high-performance operation. Also, it can be well understood that the offsets in sextupoles affect the overall machine performance, closed orbit, linear optics, coupling and dispersion. In this paper, we introduce our preliminary results.

SUBMISSION OF PAPERS

BIn storage ring light sources, beam-based alignment (BBA) which adjusts the BPM centers to the quadrupole magnet centers is a common practice to maintain the machine performance. For more reliable and conveneint BBA process, in the design of the storage ring, BPMs are located as close as possible to the quadrupoles. The most common method is scanning the position of the beam at the BPM (equivalently at the adjacent quadrupole) and find the position where the quadrupole strngth change does not give change in the closed orbit.

While beam offsets in the quadrupoles give rise to the closed orbit distortions, offsets in sextupoles affect the overall machine performance, closed orbit, linear optics, coupling and dispersion. Therefore, even though usually sextupoles are considered as the non-linear perturbation which corrects the chromatic effect and the effect can notsignificant, we need to identify them and correct them if needed.

Because the sextupole offsets changes various parameters, several different mathods can be used in measuring them. First, as in LOCO [1] the response matrix fit method is used [2] and proved to produce reliable results. In NSLS-II also, they have been measured [3] using ACLO [4] which adopts response matrix fit technique. For the LOCO or LOCO like techniques to be successful, the machine is required to have a very trustful model and especially to measure the small sextupole effects the requirement is more strict. Furthermore, the measurement should have even higher signal-to-noise accuracy and results need to be confirmed in various ways. As other parameters, tune [5] and orbit changes [6, 7] can be used.

Compared to the quadrupole BBA, for the sextupole BBA, numerous complications are involved. First of all, there is no design consideration in locating BPMs and we cannot choose a BPM which can represent the beam position at the sextupole and accordingly there is no pairing between sextupoles and BPMs. Sencondly, the sextupole offset effects are not not straight-forward by including non-linear, as well as coupling, are also their strengths can be too weak to measure.

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

And, finally, most serious complication involved for NSLS-II storage ring is that sextupoles are powered not individually but in family and that means when we want to measure the offset of a specific sextupole and change the current, all offsets in the same family affect the measurement. That means the position scanning at the specified sextupole is not so useful. Once a sextupole has an offset, it will distort the closed orbit and optics around the ring. Because we cannot control the beam position and the field strength at the specified sextupole, identifying the individual effect should be far more diffcult than measuring quadrupole BBA.

IN NSLS-II storage ring, we started sextupole offset measurement with the feasibility study. Our method is based on reconstruction of accurate model representing the machine. Representing does not mean including all information but regenerating all the measurement data for the analysis. One advantege in measuring the sextupole BBA is that the beam survives even one family is powered off. We measured the beam properties with various field strengths and analyzed them based on the model. As the first study, we chose the simple family having only two elements. In this paper, we introduce the process and the results are presented.

SEXTUPOLE OFFSET EFFECTS

In general, the multipole field B_x and B_y can be expressed as the function of x and y,

$$B_y + iB_x = \sum_{n=0}^{\infty} (b_n + ia_n) \frac{(x+iy)^n}{n!}. \tag{1}$$

where b_n and a_n are representing the normal and skew components of the field respectively. Usually, in beam physics calculations, the new notations KN_n and KS_n are introduced for the convenience which are b_n and a_n are normalized by the beam momentum as

$$KN_n = \frac{b_n}{B\rho} \quad KS_n = \frac{a_n}{B\rho} \tag{2}$$

where B and ρ are nominal dipole field and curvature of the ring.

According to the above equations the normal sextupole field with offsets (x_0, y_0) can be written as

$$\begin{aligned} B_y &= \frac{1}{2} b_2 [(x-x_0)^2 - (y-y_0)^2] \\ &= \frac{1}{2} b_2 (x^2 - y^2) - b_2 (x_0 x - y_0 y) + \frac{b_2}{2}(x_0^2 - y_0^2) \\ B_x &= b_2 (x-x_0)(y-y_0) \\ &= b_2 xy - b_2 (x_0 y - y_0 x) + b_2 x_0 y_0. \end{aligned} \tag{3}$$

As can be seen in the above equation, horizontal offset x_0 induces focusing effects in both planes while the vertical offsets y_0 make coupling. And they also make dipole components which distort the closed orbit.

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-THPL059

MODEL RECONSTRUCTION

We scanned one sextupole family with two elements starting from no power (0 ampere). Then we increased the power step by step up to the upper limit of the power supply. The step is unit integrated field, i.e., $KN_2 \times L = 1\,\mathrm{m}^2$ where L is the length of the magnet. The field can be increased upto $9.0\,\mathrm{m}^2$ and measured the closed orbit and turn-by-turn data at each step.

The tune and orbit variations for the scanning are shown in Figs. 1 and 2. Figure 3 shows the measured Mais-Ripken parameters β_{XII} and β_{YI}.

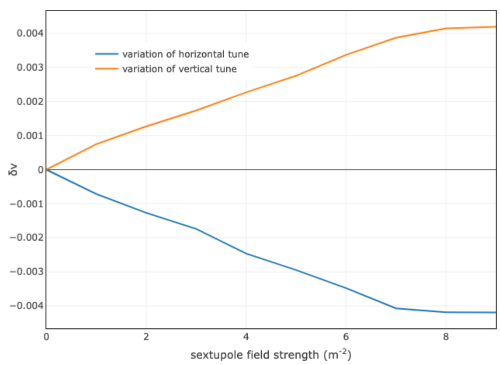

Figure 1: Tune variations depending on the sextupole strength.

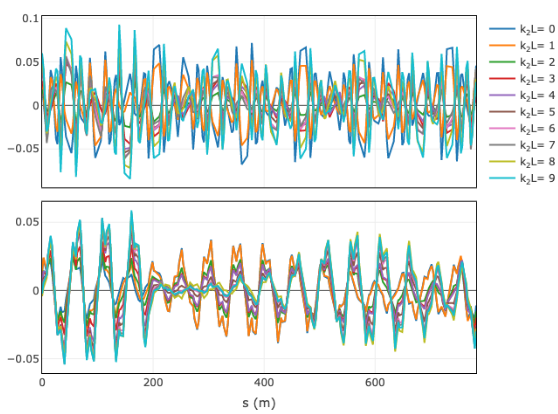

Figure 2: Tune variations depending on the sextupole strength.

To reconstruct lattice as the basic model, MAD-X [8] is used with the measured data at no field. By manipulating quadrupoles, skew quadrupoles in non-dispersive region, we could regenerate phase advances and the Mais-Ripken parameters [9] very accurately at the beam position monitors (BPMs).

The differences of reconstructed phases and the measured phases are shown in Fig. 4 We can see the deviations are quite small compared to the NSLS-II horizontal and vertical tunes which are 33.22/16.27. The peaks might show the BPMs with issues.

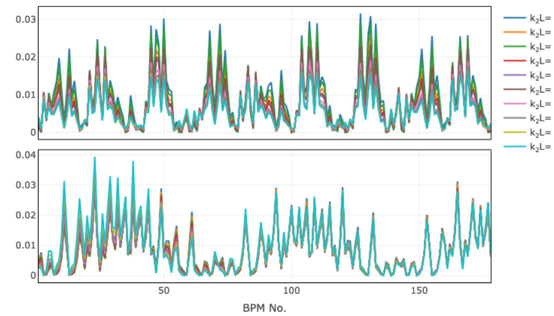

Figure 3: Measured β_{XII} and β_{YI} depending on the sextupole strength.

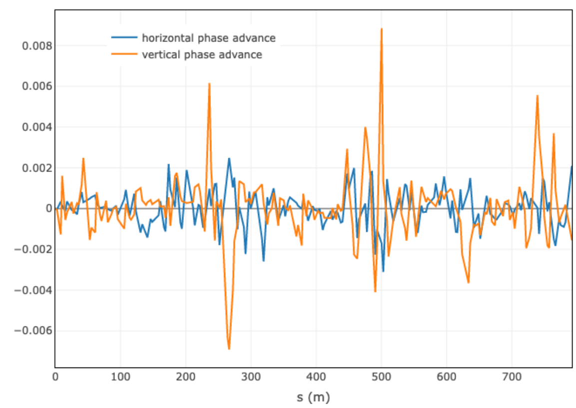

Figure 4: Phase deviations between reconstructed model and the measurements.

MATCHING PROCESS

With the reconstructed lattice, we performed the matching process using the MAD-X. The horizontal and vertical sextupole offsets of the 2 sextupoles. The constraints are obtained from orbits and turn-by-turn data measured at each scanning step. The matching process are applied to find the offsets satisfying the constraints with the reconstructed model.

As mentioned, because the sextupole offsets disturb closed orbit, focussing, as well as the coupling, it is desirable that the constraints also reflect all these aspects. For focussing and orbits, the measured values are included. For the coupling parameters, the Mais-Ripken coupling parameters β_{XII} and β_{Y1} are considered to be a good choice. Unfortunately, the parameters are measured with the operational lattice, which is well tuned to minimize the coupling, and the maximum values of measured β_{XII} and β_{Y1} are about 3 cm and the agreements to the model values are not so good as linear parameters. Still at several positions they agree perfectly and add the coupling constraints only at those positions.

RESULTS AND SUMMARY

The matching results are slightly different each other depending on the given weights, and the typical ones are shown in Fig. 5

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-THPL059

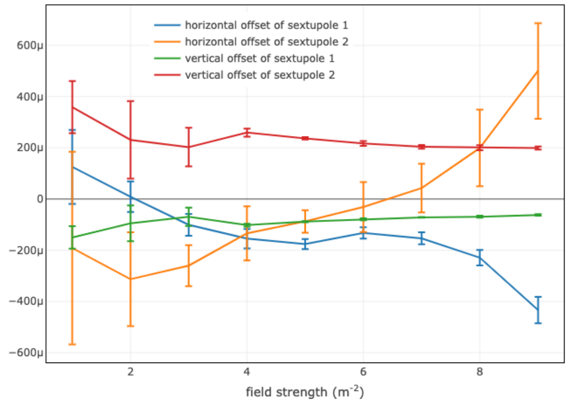

Figure 5: Expected sextupole offsets obtained from the model matching.

The vertical offset measurement looks more reliable. The large error bars in the lower field region can be expected from the low signal to noise ratio. However, the variations at the low and high field region look systematic. Especially in the high field region, the horizontal offsets are showing strong non-linear variations.

Even though the measurements are not giving clear numbers as in the quadrupole offset measurements, we could get some ideas about sextupole offsets. Once these values are verified and the method can be applied to other families, we believe that we can improve the machine performance with updated understandings of the system.

REFERENCES

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

[2] V. Sajaev and A. Xiao, “Simultaneous measurement of all sextupole offsets using the response matrix fit.,” in *Proc. 1st Int. Particle Accel. Conf. (IPAC’10)*, Kyoto, Japan, May, 2010, pp. 4737–4739.

[3] X. Yang, “Applying multi-frequency ac loco for finding sextupole erros,” *NSLS-II Technical Note*, no. NSLSII-ASD-TN-342, 2020.

[4] X. Yang, V. Smaluk, L. Yu, and K. Ha, “Multi-frequency ac locl: A fast and precise technique for lattice correction,” in *Proc. 8th Int. Particle Accel. Conf.*, Copenhagen, Denmark, May, 2017, pp. 831–834.

[5] M. Borland, “Measurement of sextupole orbit offsets in the aps storage ring,” in *Proc. 18th Particle Accel. Conf. (PAC’99)*, New York, NY, USA, Apr.-May, 1999, pp. 1587–1589.

[6] Y.-C. Chao, “A technique for aligning sextupole systems,” 1992.

[7] A. Xiao and V. Sajaev, “Beam-based alignment of sextupoles at the aps,” in *Proc. 20th Particle Accel. Conf. (PAC’03)*, Portland, OR, USA, May, 2003, pp. 463–465.

[8] W. Herr and F. Schmidt, “A mad-x primer,” in *CERN Accelerator School and DESY Zeuthen: Accelerator Physics*, 2004, pp. 505–528.

[9] G. Ripken and F. Willeke, “Methods of beam optics,” DESY, Tech. Rep., 1988.