REPRODUCIBILITY OF ORBIT AND LATTICE AT NSLS-II*

J. Choi†, T. Shaftan, BNL, Upton, NY 11973, USA

Abstract

In operating a high-end synchrotron light source, like NSLS-II, it is important to understand the machine accurately and have the ability to reproduce the desired machine state when needed. The obstacles, we can imagine, include the magnet hysteresis effect and some environmental effects. To minimize hysteresis effect, we cycle the magnets and it was proved working properly. On the other hand, from the point of long-term operation, we are not yet satisfied with the reproducibilities given by the same set of magnet currents and the machine needs additional tuning processes. In this paper, the experience of NSLS-II operation and studies are presented.

INTRODUCTION

NLSL-II is now operating in top-off injection mode and providing satisfactory beams to users. The operational lattice, at this moment, is one of the 3 damping wigglers (DW28) closed. Time to time, we are tuning the lattice and orbits for user runs. Also, during the user operation, orbit and tune feedback systems are working for stable lattice and orbit. As the result, all the user operation conditions are quite stable.

However, to keep the lattice and orbit in stable conditions, we find better values for the magnet currents during the tuning and save them as the operational lattice and orbit. And, after several changes, the set point magnet currents are quite away from the starting points.

NSLS-II storage ring consists of 30 cells and 2 cell are making one supercell. At one end of the supercell there is a long straight section with high β_x and at the other end there is a short straight section with low β_x.

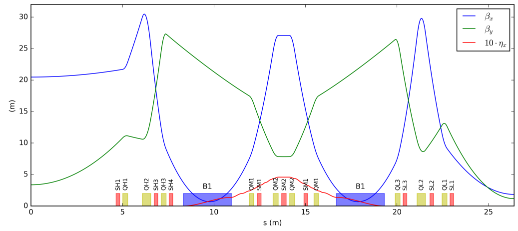

Figure 1: One supercell (2 cell) of NSLS-II storage ring lattice.

As can be seen in Fig. 1, there are three quadrupole families, QH, QL, and QM. Three QHs and three QLs are surrounding high-β_x and low-β_x straight sections, respectively. And two QM families are placed in the dispersive region. With DW28 closed, QH family is used to compensate the effect from the wiggler. And, if we change the strengths of any QM family member the dispersion matching will be disturbed. Therefore, QL family is used for the tune correction and can expect biggest variations of QL family. We studied the variations set point currents of all quadrupole in detail.

Different from quadrupoles, all correctors are continually changed to correct orbit. Over the long period, they can move the orbit in some given direction or they can just increase the strengths competing each other. To see the more meaningful results, we show that corrector variations in physics unit and also show expected orbit variations corresponding to corrector variations.

LONG TIME VARIATION

NSLS-II is implementing MAchine Snapshot Archiving and Retrieve (MASAR) [1] which is a snapshot archiving and retrieving system connected to NSLS-II Experimental Physics and Industrial Control System (EPICS). Each snapshot is a group of key-value pairs where keys are EPICS Process Variables (PVs). The snapshots are organized by configurations where each configuration has specific PV sets.

NSLS-II MASAR is maintaining lattice and orbit configurations to keep the optimized sets for specific purposes, including user operations, and to retrieve easily the desired ones whenever needed. To track the long term variations of lattice optics and orbits of NSLS-II storage ring, because of the lack of measured data for the user operations, we tracked the MASAR snapshots which are believed to be stable for reasonable periods and provide satisfactory beams to users.

During the operation from June 2015 to April 2016, we found 19 major combinations of lattice and orbit which are used heavily for the user service. Figure 2 shows the selected dates with the line colors to be used in this paper. We investigated the variations of magnet setpoint currents from the ones set on June 10, 2015. Because the power supplies have been proved to be extremely stable and the unit conversions between magnet currents and the physical strengths are also believed to be very reliable, the variations expected from changes of the magnet set-point currents are believed to change the lattice and orbit to some extent as model expected. However, these variations do not mean the real variations of optics and orbits. On the contrary, a lot efforts are invested to keep the lattice and orbit not moving, we can say by

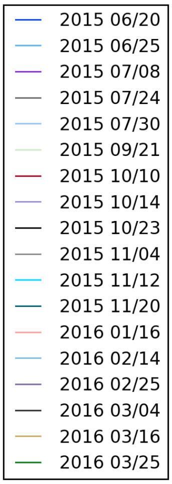

Figure 2: Selected dates.

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† jchoi@bnl.gov

tracking the expected results from the variations of MASAR snapshots, we can possibly find some reasons which can explain the discrepancies between the expected variations and stable real beams.

Variation of Lattice

Even though the offset effect at the sextupoles cannot be neglected, assuming the lattice is decided only by the quadrupole strengths, we studied the variations of optics following the quadrupole currents.

First, Fig. 3 shows the tune variations. Despite the large deviations, the tunes stay around the original values. Figure 4 shows the variations of quadrupole currents for each family. As mentioned, variation of QM family is very small compared to other families. We can see that the amounts of QH and QL variations are not going together. The big jumps of QH and QL at the end of the ring are coming from role exchange and can be easily corrected.

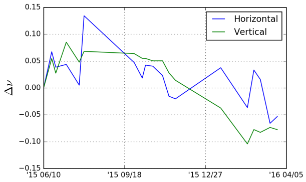
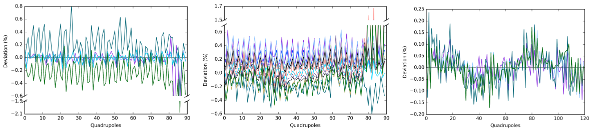


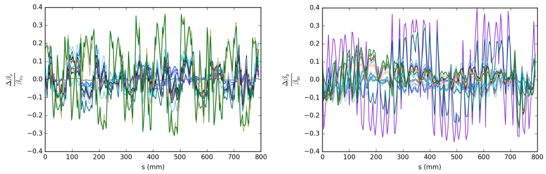
Figure 3: Tune variations



(a) QH (b) QL (c) QM

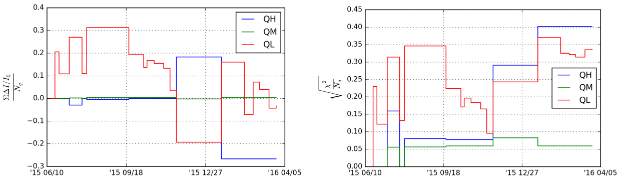
Figure 4: Variations of quadrupole currents for each family.

Also the expected variations of horizontal and vertical betatron functions shown in Fig. 5 are big but not coherent. Considering the quadrupole strength are changed to compensate the optics variation which are caused by the orbit offsets from some parameter or environment changes, we can say that they are moving up and down which is also shown in Fig. 6(a). However, Fig. 6(b) shows that the overall deviations of QH and QL families are becoming bigger and bigger as time goes.



(a) (b)

Figure 5: Variation of expected (a) β_x and (b) β_y functions.

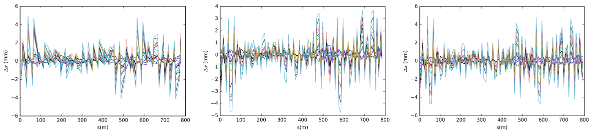


(a) (b)

Figure 6: Variation of (a) sum and (b) χ^2 of quadrupole.

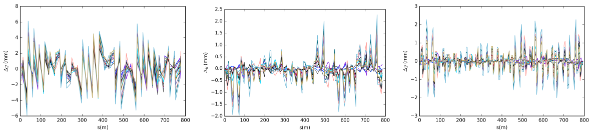
Variation of Orbits

We calculated expected orbit variations corresponding corrector strengths variation and the result are shown in Fig. 7 and 8. We can clearly see the difference between orbit movements at dispersive and non-dispersive regions. We need more study to understand the fact that the difference is also shown in the vertical direction.



(a) (b) (c)

Figure 7: Expected horizontal orbit variations at (a) BPMs of dispersive region (b) BPMs of non-dispersive region (c) all BPMs.



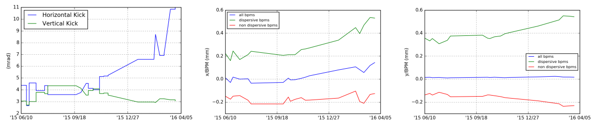
(a) (b) (c)

Figure 8: Expected vertical orbit variations at (a) BPMs of dispersive region (b) BPMs of non-dispersive region (c) all BPMs.

Figure 9 shows the variations of sums of all horizontal and vertical correctors with unit conversion as well as expected average orbit variations in horizontal and vertical direction. In horizontal direction, the sum of variations are moving positive independent of the region of the BPM locations. However, in vertical direction, the orbits at dispersive regions are going positive and the orbits at non-dispersive regions are going negative so that the net sum of all orbits stay quite stable all the time. It should be reminded that these orbit variations are not the real variations and the expected orbit changes corresponding to the corrector strengths. Therefore, the real orbit variations of due to the other reasons are expected to go to the reverse direction.

EFFECT OF MAGNET CYCLING

Whenever needed, the magnets, except correctors, are cycled to remove hysteresis. To see the effects, we measured



(a) (b) (c)

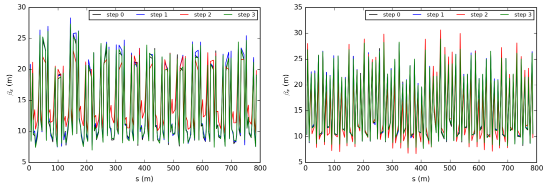
Figure 9: (a) The variations of sums of all horizontal and vertical correctors with unit conversion. Expected average orbit variation in (b) horizontal and (c) vertical directions.

the turn-by-turn data before and after the cycling and compared the β values. The performed procedure is: step 0) load a recent bare lattice MASAR snapshot and cycle the magnets. step 1) reduce all quadruple currents to 90% and back to the initial values. step 2) increase all quadruple currents to 110% and back to the initial values. step 3) cycle the magnets. The study was performed just once with five kicks for each step. Even though we cannot say that these data are statistically meaningful, we applied the Model Independent Analysis (MIA) [2] and obtained the phase advances.

Table 1: Tune Variations for Each Step

Step	Horizontal tune	Vertical tune
Step 0	16.2958 ± 0.40	33.2461 ± 0.83
Step 1	16.2994 ± 0.37	33.2359 ± 0.84
Step 2	16.4243 ± 0.37	33.8118 ± 1.15
Step 3	16.2978 ± 0.37	33.2463 ± 0.86

Table 1 shows the tune variations for each step. As you can see, they have huge error bars, because of lack of data points and poor reproducibility of pinger conditions. But we developed a process by combining MIA with the optimization method to obtain expected optics and the results are Fig. 10 and fig:11 which show the absolute and variations of β functions for all steps.

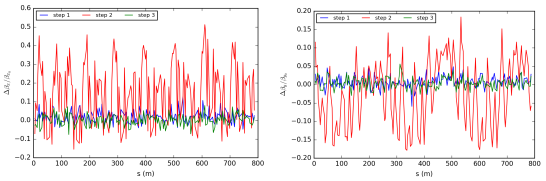


(a) (b)

Figure 10: Expected (a) β_x and (b) β_y functions.

The recovery of optics with magnet cycling is quite satisfactory but the fact that the variation at step 1 is comparable to the variation after cycling should be noted and be studied further.

As mentioned, the results can be quite unreliable because only a few measurements are available. We need to accumulate more data for meaningful analysis.



(a) (b)

Figure 11: Expected variations of (a) β_x and (b) β_y functions.

SUMMARY

As expected, cycling magnets is not perfect. But hysteresis effects are not enough to explain the long-term variations. On the other hand, even though the amount is not so significant, the fact that the corrector strengths and corresponding expected orbits are changing in one direction suggests that some parameters or environment variables are very slowly but constantly moving. Time to time, we rebalance the corrector strengths to reduce the burden of heavily loaded ones. However, when total sum is constantly increasing or decreasing, this rebalancing will be limited someday and we need more fundamental optimization for the changed and changing machine status.

REFERENCES

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[2] C. Wang, V. Sajaev, and C. Y. Yao “Phase advance and β function measurements using model-independent analysis,” *Phys. Rev. ST Accel. Beams*, vol. 6, p. 104001, Oct. 2003.