REPRODUCIBILITY ISSUES OF NSLS-II STORAGE RING AND MODELING OF LATTICE*

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Abstract

As other facilities, in operating NSLS-II, we develop the lattices based on theoretical and simulation studies. Then the lattice is applied and the machine is optimized to have the desired design parameters. This process is very typical and works well and, furthermore, there is a general understanding that a model with the field measurement data is not realized as it is. However, it is evident that if the model represents the real machine close enough, there are lots of advantages we can take. One of them can be producing the lattice with changing environments. In this paper, we discuss the NSLS-II reproducibility status and efforts to construct the faithful realistic model.

INTRODUCTION

In order to reproduce optimal lattice and orbits, NSLS-II is implementing MASAR (MAchine Snapshot Archiving and Retrieve) [1], a snapshot archiving and retrieving system connected to NSLS-II EPICS (Experimental Physics and Industrial Control System). 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 is a specific PV set. The most commonly used storage ring configurations are "Orbit Configuration" and "Lattice Configuration". They are sets of PVs which can determine the closed orbit and optics of the storage ring, respectively. The main purpose of MASAR is to provide the same optimal environment to the user experiments for the extended time period, by saving all the set-point values when satisfactory machine status is obtained. The reproducibility should be considered from the long-term perspective as well as from the short-term perspective, where long-term covers several user operations and short-term means before and after beam dump or one or two day maintenance. The short-term reproducibility is turned out to be very reliable with cycling the magnets. In Ref. [2], we discussed the long-term reproducibility based on MASAR system. In the following sections, we will show the status of long-term reproducibility from a different point of view and introduce models which can be used to improve the reproducibility.

LONG TERM REPRODUCIBILITY

As recently constructed facility, NSLS-II is not yet operating with the target performance but improving it step by step as planned.

From 16th user operation of 2016, which started on June 30, the beam current was increased to 250 mA and operated at the current through the mid February 2017, then the operating current was increased to 275 mA. Therefore, we will study and discuss some issues of the reproducibility from 17th user operation through the last user operation (28th) of the year because 16th operation was partly used with different damping wiggler gaps.

Figure 1 shows the tune variations through the user operations 17~28, 2016. These tunes are read from the bunch-by-bunch feedback system [3] and continually being recorded in the archive system. In a single user operation, because

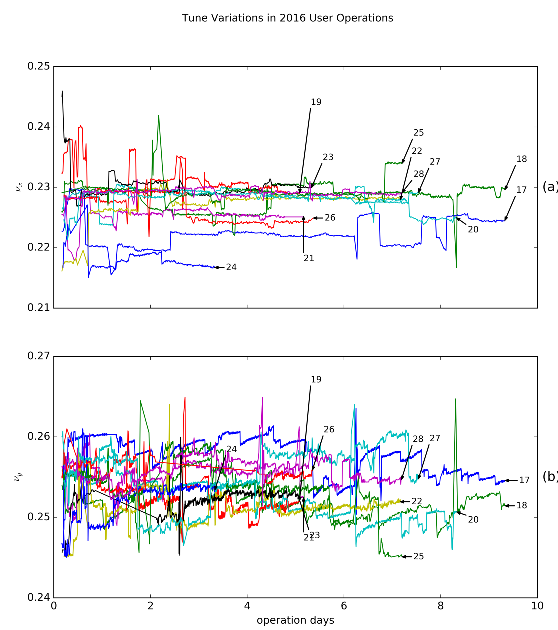

Figure 1: (a) Horizontal and (b) vertical tune variations from the17th to the 28th user operations of 2016.

of the insertion device (ID) gap changes, the vertical tunes are far more fluctuating. However, the reproducibility from operation to operation is in similar orders ~0.1, which are not so big but not quite satisfactory either. Because of the tune variation, time to time, the dynamic aperture reduces too much and we need to correct the tune for satisfactory injection efficiency and beam lifetime.

NSLS-II storage ring consists of 30 cells with 2 cells 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. As can be seen in Fig. 2, there are three quadrupole family sets, QH, QL, and QM. Three QH families and three QL families are surrounding high-β_x and low-β_x straight sections, respectively. And two QM families are placed in the dispersive region. NSLS-II is now operating 3 damping wigglers (DW) and QH families are used to compensate the effect from the IDs especially

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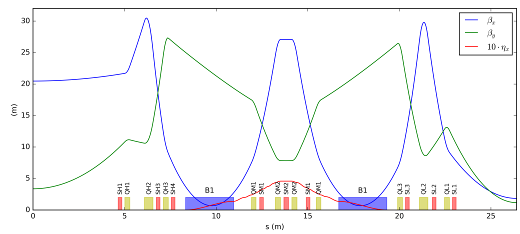

Figure 2: One supercell (2 cell) of NSLS-II storage ring lattice.

from the DWs. Therefore, QL families are used for the tune correction when needed and we can see the biggest variations in QL families.

Figure 3 shows the current changes of all the 90 QL family members and the tunes during the 18th user operation 2016. From the figure, we can understand some pattern as 1) the vertical tune deviates from the ID gap changes 2) at some point, the tune is corrected to improve the dynamic aperture 3) horizontal tune is also changed. Including these

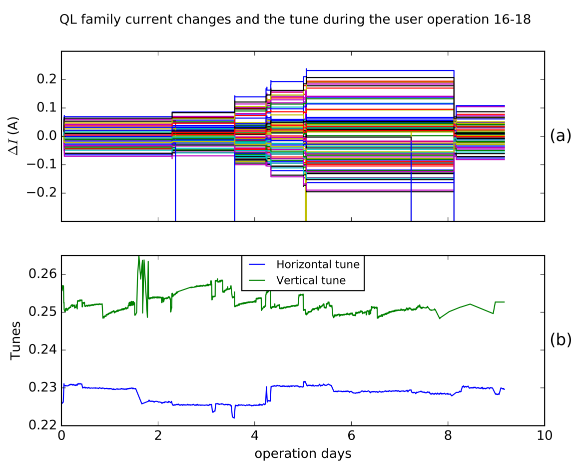

Figure 3: (a) Power supply current changes of QL family from the initial values for the tune correction and (b) the tune variations during the 18th user operation of 2016.

precesses, other environmental variations are also added and the machine may going away from the initial state. Still the machine is continually optimized to provide consistent synchrotron beams for the experiments. And after several user operations, we can expect the magnet power supplies are generally quite away from the starting values. Finally, even if we put all available set-point values of the machine back to the desired time stamp, the machine is not reproducing the desired parameters.

Figure 4 shows the general variations of all quadrupole families during the 12 user perods in 2016. Because each quadrupole has independent power supply, showing all the variations in quadrupole currents will be too complicated. The figure is a very simplified version and, still, we can see the quadrupole current values are moving away from the initial values. At some level, we understand the reasons of these variations and know how to fix them. However, as

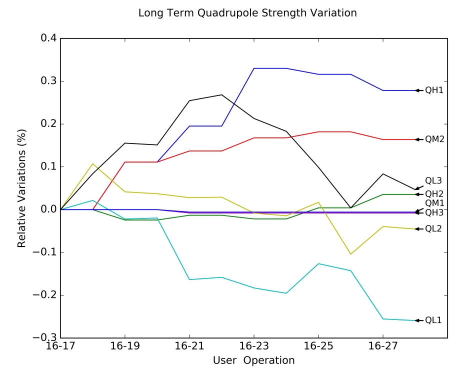

Figure 4: Quadrupole power supply current changes through the user operations of 2016.

mentioned early in this section, the machine itself has not arrived at final stage and optimizing for each user operation is working well, and identifying detailed reasons is not of high priority at this moment. However, if we have very faithful model which can reflect the real machine in detail, it can be very useful in identifying them. Therefore, we are also working on developing more reliable model and the status is described in the next section.

LIVE MODEL

The running machine has parameters close to the design model and we use this model when we need analytic calculation or simulations. On the other hand, we have very reliable unit conversion table and we can have the live model from the magnet power supply currents. In general, tune can be measured very accurately [4], we compared the measures tunes with the ones from the models. From Table 1, the live

Table 1: Measured and Model Tunes

	Horizontal Tune	Vertical Tune
TbT Measurement	33.199	16.270
Design Model	33.219	16.254
Live Model	33.220	16.397

model gives similar horizontal tune but the vertical tune is very different from others and the design model looks more reasonable than the live model. However, this can be just the result of the efforts to optimize the machine parameters to the design parameters and we cannot expect all the details are following the design model.

Together with tunes, the phase advances can be quite accurately measured from the turn-by-turn data because they are not sensitive to the BPM errors. We obtained them using model independent analysis (MIA) [5] and Fig. 5 shows the differences between the measurements and the expected ones from the models. In the horizontal plane, we can see the similar differences as can be expected from Table 1. In the vertical plane, however, the live model shows better matching locally and the errors are accumulated giving very different tune. On the other hand, design model is showing large oscillation in local phase advance and finally gives the more correct tune with the errors being canceled out.

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When we constructed the live model, we did use the field measurement data for the quadrupoles and sextupoles. Since the correctors and skew-quadrupoles are used to correct errors, we did not include them. For the main dipole and the accompanying independent trims, from the practical reasons, we used simple angle $\frac{2\pi}{60}$ for all dipoles neglecting the trims assuming the dipole trim coils compensate the dipole errors.

Therefore, we tried the correction by assigning the quadrupole components to all dipoles and optimize their strengths to make the resulting phase advances and tunes closer to the measured values. As the result, vertical tune approached to the measured value while the horizontal tune is over corrected. Because these optimization parameters need not be real and used just to get some idea about the error sources, we compensated the over-correction by giving the horizontal focussing fields to the correctors. In the optimization, we used the Levenberg-Marquardt algorithm [6] rather than other methods involving line searches because it is more probable that the lattice solution can diverge in the line search. The resulting horizontal and vertical tunes from

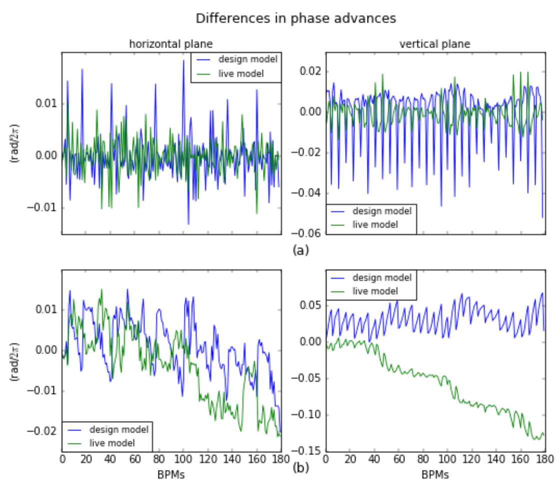

Figure 5: (a) Differences in phase advance from BPM to BPM between measurements and models. (b) The differences in cumulated phase advances.

the corrections are (33.196, 16.311). Still, the vertical tune is not satisfactory compared to the measured one. We tried many ways to correct the vertical tune by adding artificial linear elements which focus the beam only in the vertical direction. However, by any method, we could not make the vertical tune closer to the measured value and tentatively concluded that the deviation is coming from non-linear effects.

We added the results from the corrected live model to Fig. 5 and Fig. 6 shows them with the label, "corrected live". We also compared the β functions and the differences for the models are shown in Fig. 7.

CONCLUSION

We have seen the lattice variations for multiple user operations as well as during one single user operation. In addition, NSLS-II does not yet arrive at final stage and it gives more

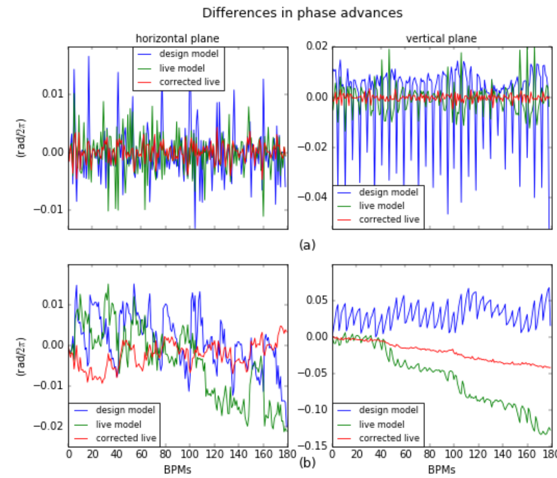

Figure 6: Same sa Fig. 5 with the corrected live model being added.

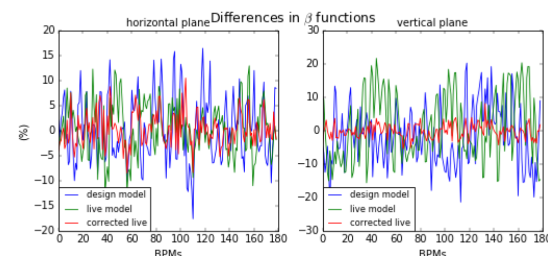

Figure 7: Relative differences between measured β functions and model β functions.

difficulties in improving the reproducibility. However, If we have a faithful realistic model, the reproducibility can be more easily implemented by identifying the sources which causes the differences in machine and we are optimistic to develop such a model.

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