ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPHA009

NSLS-II STORAGE RING COUPLING MEASUREMENT AND CORRECTION*

G. Wang#, L. Yu, Y. Li, T. Shaftan, L. Yang, BNL, Upton, NY 11973, USA

Abstract

The National Synchrotron Light Source II (NSLS-II) is a state of the art 3 GeV third generation light source at Brookhaven National Laboratory. To achieve the goal, 8 pm level vertical beam emittance, the coupling due to the misalignment in quads and vertical beam offset in sextuples must be corrected. Traditional method, based on response matrix, such as LOCO, is wildly used measure and corrects the coupling. In this paper, we present a new method to measure and correct the coupling with BPMs TBT data from fast kickers or pingers excited betatron oscillation. Besides the TBT data, other method, is also used to characterize the coupling.

INTRODUCTION

The National Synchrotron Light Source II (NSLS-II) is a 3 GeV third generation light source [1,2] with ultra-low horizontal emittance (1 nm-rad). In the vertical plane, the designed emittance is < 8 pm-rad, reaching the x-ray diffraction limit. They are very critical to increase NSLS II brightness $>10^{21}$ photons s^{-1} mm^{-2} $mrad^{-2}(0.1\%BW)^{-1}$ and affect beam lifetime.

The vertical plane emittance main contributions are the betatron coupling and vertical dispersion [3]. The linear coupling comes from the misalignment (rolling) of quadrupoles and the vertical orbit displacement through sextupoles induced skew quadrupole effect. The vertical dispersion comes from the coupling contribution (such as all coupling errors from quads roll, sextuples offsets, main dipole magnets pitch, skew quadrupoles at locations with non-zero horizontal dispersion) and non-coupling contribution (such as vertical offset in quadrupoles induced dipole kick).

The common method to assess the linear coupling is to measure the minimum tune separation [4] between two coupling modes. Experimentally, the minimum tune separation is measured by tuning quadrupoles to bring horizontal and vertical tunes as close as possible. Another common way used in storage ring to assess the coupling to fit orbit respond matrix non-zero off-diagonal elements with LOCO [5] algorithm to identify coupling source and the needed corrector strength. There are other ways to observe the coupling effect, such as the vertical beam size, beam lifetime and horizontal excitation betatron oscillation effect on vertical residual betatron oscillation.

In this paper, a new method is discussed to measure and correct the betatron coupling with BPMs TBT data from fast kickers or pingers excited betatron oscillation. As the turn by turn data cannot reflect the vertical dispersion effect, the coupling correction is separated into two steps. First, the vertical dispersion is corrected with dispersive skew quadrupoles. Then the coupling is corrected with the non-dispersive skew quadrupoles from turn by turn data. This order cannot change, as dispersive skew quadrupoles affect both dispersion and coupling, but non-dispersive skew quadrupoles only affect betatron coupling.

One big advantage of this method is that this method only takes seconds to excite the beam, collect the data and apply the correction.

VERTICAL RESIDUAL BETATRON OSCILLATION MINIMIZING

If beam is excited by one injection kicker (horizontal plane only, with negligible vertical component), with initial offset $\vec{x}_0 = [0, \Delta x', 0, 0]^T$ at the location of the kicker, and it will do the betatron oscillation in the following turns. Ignoring the radiation damping, the subsequent BPM readings for next several turns are written as

$$\vec{x}_n = R^n \vec{x}_0$$

where n is the turn index and R is the storage ring's one-turn transport matrix. $\vec{x}_n = [x, x', y, y']^T$ includes BPMs reading in horizontal and vertical plane. We measure the dependence of the vertical residual oscillation on the skew quadrupoles currents, and write it as a matrix

$$M_{n,ij} = \frac{\Delta y_{i,n}}{\Delta I_j}$$

where ΔI_j is the current change of the j^{th} skew quadrupole, $\Delta y_{i,n}$ is the i^{th} BPM's n^{th} $(n \geq 1)$ turn y readings.

Thus the needed skew quadrupoles strengths for coupling correction can be obtained by solving the following linear equations

$$y_{i,n} = M_{n,ij} I_j.$$

The minimum number of turn-by-turn data should cover a full betatron oscillation. Usually several iterations are needed to let the solution to converge.

EXPERIMENTAL RESULT

NSLS II is designed as 30 cell double-bend-achromatic lattice, 15 super periods. In order to control the vertical beam size, each cell is designed to have a skew quadrupole. In the odd numbered cells, they are located in

* This manuscript has been authored by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy.
#gwang@bnl.gov

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPHA009

the dispersive region, which can be used for vertical dispersion compensation. And in the even numbered cells, they are located in non-dispersive regions, which are used for linear coupling correction.

Dispersion Measurement and Correction

Dispersion was measured by changing RF frequency to change beam energy

$$\delta = -\frac{\Delta f}{\alpha_c f},$$

where Δf is the master oscillator frequency change, f is the master oscillator frequency and α_c is the momentum compaction factor. By changing frequency in several steps within +/-0.3% and monitor the beam position change in y plane, the linear dispersion in each BPM are fitted.

The dispersion correction based on response matrix, the vertical dispersion responding to the dispersive skew quads. The theoretical matrix along with magnet unit conversion was used, which works very well, similar as our experience on orbit correction and beta beat correction. Figure 1 shows the vertical dispersion before and after correction.

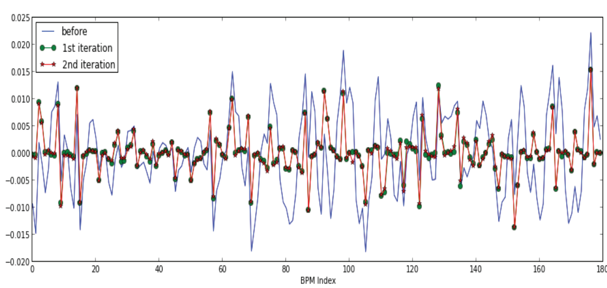

Figure 1: Vertical dispersions before and after correction.

Coupling Measurement and Correction

One IS kicker kicks the beam in horizontal plane at 1/3 Hz to excite the same horizontal betatron oscillation and it couples to vertical plane. The vertical plane residual oscillation from turn 4 to turn 15 were measured and used as the correction object. 12 turns' BPMs response matrix to all non-dispersive skew quads was measured and response matrix dimension is $(12 \times 180) \times 15$.

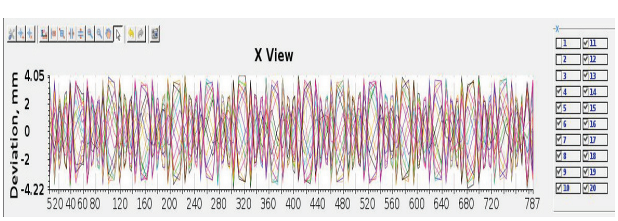

Figure 2: Horizontal betatron oscillations with one horizontal kicker excitation.

The horizontal oscillation peak is ~4mm with one kicker excitation (Fig. 2). The vertical residual oscillation amplitudes before correction and after correction are shown in Fig. 3. The betatron oscillation peak was suppressed from ~ 1.8 mm to 0.25 mm.

Figure 4 shows all the skew quads current for the coupling correction. The peak current is less than 1.5 A.

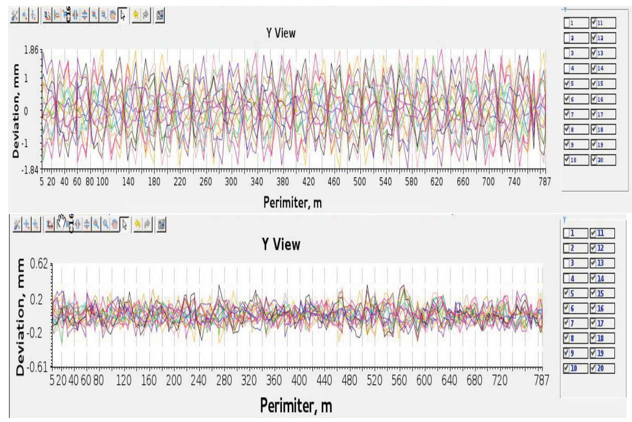

Figure 3: Residual vertical oscillations before (upper) and after (lower) correction with the same kicker excitation.

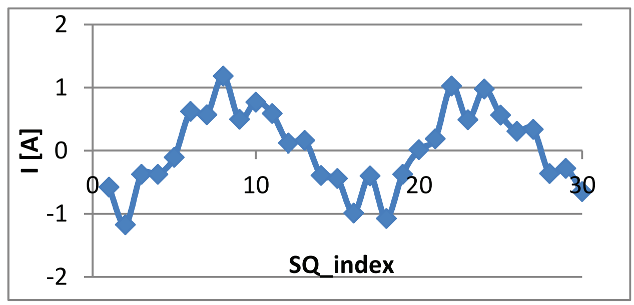

Figure 4: Skew Quads current to correct coupling.

COUPLING MEASUREMENT WITH OTHER WAYS

After the above coupling correction was implemented, the related data was also collected to characterize the coupling effect.

Tune Separation

The betatron coupling can be measured by the tune split method. The coupling ratio [6] κ is calculated

$$\kappa = \frac{\varepsilon_y}{\varepsilon_x} = \frac{C^2}{C^2 + 2\Delta^2}$$

Where Δ is the difference between horizontal and vertical fraction tune, C is the minimum separation between the horizontal and the vertical tunes when the tunes are scanned by changing quadrupoles.

The tune separation curve is measured by varying three quads families in the non-dispersive low-beta function section. The tune separations before and after correction are measured and shown in Fig. 5. The minimum tune separation C reduced from ~0.011 to ~0.0015 and $\Delta = 0.04$. The betatron coupling factor is suppressed from 3.6% to 0.07%.

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPHA009

In NSLS II, other ways were also used to correct coupling. One is to minimize the non-zero off-diagonal elements in the orbit respond matrix [7]. Another is to use BPMs turn by turn data. From the BPMs data, Hamiltonians describing the coupled linear dynamics are extracted. Four plane-crossing terms in Hamiltonian directly characterize the coupling between the horizontal and the vertical planes. Coupling correction is accomplished by utilizing the dependence of the plane-crossing terms on skew quadrupoles and direct minimizing plane-crossing terms [8].

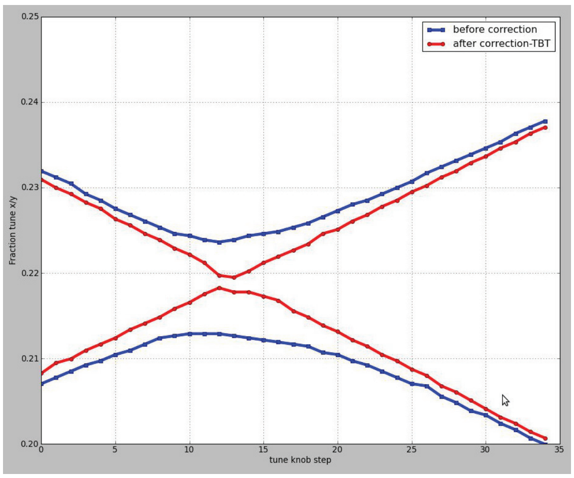

Figure 5: Tune separation measured before and after correcting linear coupling.

CONCLUSIONS

In this paper we discussed a new method to correct coupling based on BPMs turn by turn data. It has some limitation, such as the betatron excitation from kicker tilt or the BPMs tilt effect on beam position reading cannot be separated. But this method is more obviously and faster to check the coupling, comparing with the tune separation curve measurement or LOCO. The correction result is verified in other way.

ACKNOWLEDGEMENTS

We are grateful for support from the NSLS-II. This work is supported in part by the U.S. Department of Energy (DOE) under contract No. DE-AC02-98CH1-886.

REFERENCES

[1] F. Willeke, Commissioning Results of NSLS-II, IPAC15, 2015.
[2] G. Wang, Results of the NSLS-II commissioning, Bulletin of the American Physical Society, Vol. 60, Num. 4, APS April Meeting 2015.
[3] C. Liu et. al, Analysis and correction of vertical dispersion in RHIC, BNL-96408-2011-IR, 2012
[4] M.G. Minty, Measurement and Control of Charged Particle Beams, Springer, 2003.
[5] J. Safranek, G. Portmann, A. Terebilo, C. Steier, “MATLAB-based LOCO”, proceedings of the 2002. European Particle Accelerator Conference, Paris, France (2002).
[6] Guignard G. Betatron coupling and related impact of radiation. Phys Rev, 1995, 51(6): 6104–6118.
[7] G. Wang, et al., NSLS II Commissioning report. Tech. Note 168.
[8] Y. Li, et.al, Characterization and control of linear coupling using turn-by-turn beam position monitor data in storage rings, to be submit in PRST-AB.