ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPC83

TEST OF PARALLEL BEAM-BASED ALIGNMENT AT NSLS-II

M. Song*, X. Yang, J. Choi, Y. Hidaka, G. Wang, Brookhaven National Laboratory, Upton, NY, USA
X. Huang, SLAC National Accelerator Laboratory, Menlo Park, CA, USA

Abstract

Misalignment of magnets in the storage rings causes trajectory deviation when the beam traverses through magnets, resulting in the degraded performance of linear optics and nonlinear dynamics. The beam-based alignment (BBA) technique is commonly used to steer the beam passing through the centers of magnets. Recently, a new method has been developed to determine the centers of multiple magnets simultaneously. In this paper, the test of this fast BBA method at NSLS-II is presented.

INTRODUCTION

The survey and positioning technology for accelerator magnets have been improving over the past few decades. Even so, misalignment is unavoidable in magnets. The misalignment causes the beam orbit to have an offset from the centers of magnets, affecting the performance of storage ring detrimentally. The effects result from misalignment of quadrupoles and sextupoles will distort the linear optics, induce the chromatic errors, and worsen the nonlinear beam dynamics performance. Therefore, to minimize these negative effects in the actual machine, it is necessary to steer the beam through the centers of magnets found by the beam-based methods. The standard method, called beam-based alignment (BBA), has been widely used during machine commissioning and operation.

On the one hand, the model-dependent BBA uses the lattice model to obtain the offsets of quadrupole magnets [1]. On the other hand, the model-independent BBA steers the beam orbit with a corrector and observes the beam position at a quadrupole, until the orbit is unchanged with varied quadrupole strengths. The so-called "bow-tie" method [2] is usually used by changing the set points of a corrector and fitting the linear curves of orbit shifts at many or all beam position monitors (BPMs) to beam orbit at an adjacent BPM for the measured quadrupole, where the zero-crossing point of BPM reading corresponds to the center of a quadrupole. This BBA approach finds one quadrupole center at a time and is not affected by the lattice errors.

Recently, a parallel beam-based alignment (PBBA) method [3] has been proposed to find the centers of a number of quadrupole or sextupole magnets simultaneously. This approach corrects the beam orbit by minimizing the induced orbit shift (IOS) arising from a group of modulated quadrupoles. It has been successfully tested on the SPEAR3 storage ring and features a fast measurement of magnet centers. In this paper, we demonstrate its application in experiments with the NSLS-II quadrupole magnets.

* msong1@bnl.gov

EXPERIMENTAL TEST AT NSLS-II

National Synchrotron Light Source II (NSLS-II) is a third-generation storage ring light source operating at 3 GeV with a circumference of 792 m. The NSLS-II has a total of 30 cells, each configured with a double bend achromat (DBA) structure. In each cell, there are 10 quadrupoles in total. Four of these quadrupoles are in dispersion region (have two symmetrical quadrupole strengths, labeled as "QM1" and "QM2), three of them are in the high beta straight section (labeled as "QH"), and the remaining three are in the low beta straight section (labeled as "QL").

In the stage of preparing data, the response matrix of the IOS with respect to the corrector kick angles is calculated from one NSLS-II model lattice. Because of the symmetry of the storage ring, the quadrupoles in cells with even or odd numbers are grouped for measurement. For example, the "QM1" in cells 30, 2, 4, 6, · · · , 28 are grouped in "group1" and nearby BPMs are used. Within one group of quadrupoles, they are modulated with alternate signs to avoid large tune shifts, i.e., the modulation factors are -1, +1, -1, · · · , -1. In NSLS-II, the total number of correctors and BPMs are both 180.

Since last December, we have tested PBBA method in several beam studies and explored the best machine settings, including testing different scale factors (unit conversion from mrad to Ampere), quadrupole modulation amplitudes, and the number and selection of correctors. In last December, we tested PBBA for "QH1 group1", "QH1 group2", "QL1 group1", "QL1 group 2" and "QM1 group1". The preliminary results show that using 30 correctors could lead to faster convergence in IOS correction and potentially mitigate the degeneracy. In February, we found that the performance of PBBA depends on the initial beam orbit, and horizontal and vertical corrections show different features. In the recent beam study in April, the optimal settings were found, including keeping the same number of correctors as quadrupoles, choosing correctors close to the measured quadrupoles, and modulating the quadrupoles within a range of [-5, 5]%.

A complete set of data for the measurement of "QM1 group1" was taken from the beam study in April. The top left plot of Fig. 1 shows the measured IOS at 5 quadrupole levels at iteration 0. The top right plot indicates the corresponding kicks at quadrupole locations calculated using the quadrupole-to-BPM response matrix. After 3 iterations of the IOS correction, the IOS is minimized to a level of 10 µm, as shown in the bottom left plot of Fig. 1. The corresponding quadrupole kicks are calculated and presented in the bottom right plot of Fig. 1.

Table 1 shows the deduced 15 quadrupole centers in both planes from the measured IOS, where x and y are initial orbits before modulation, x_{corr} and y_{corr} are orbit-to-center

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPC83

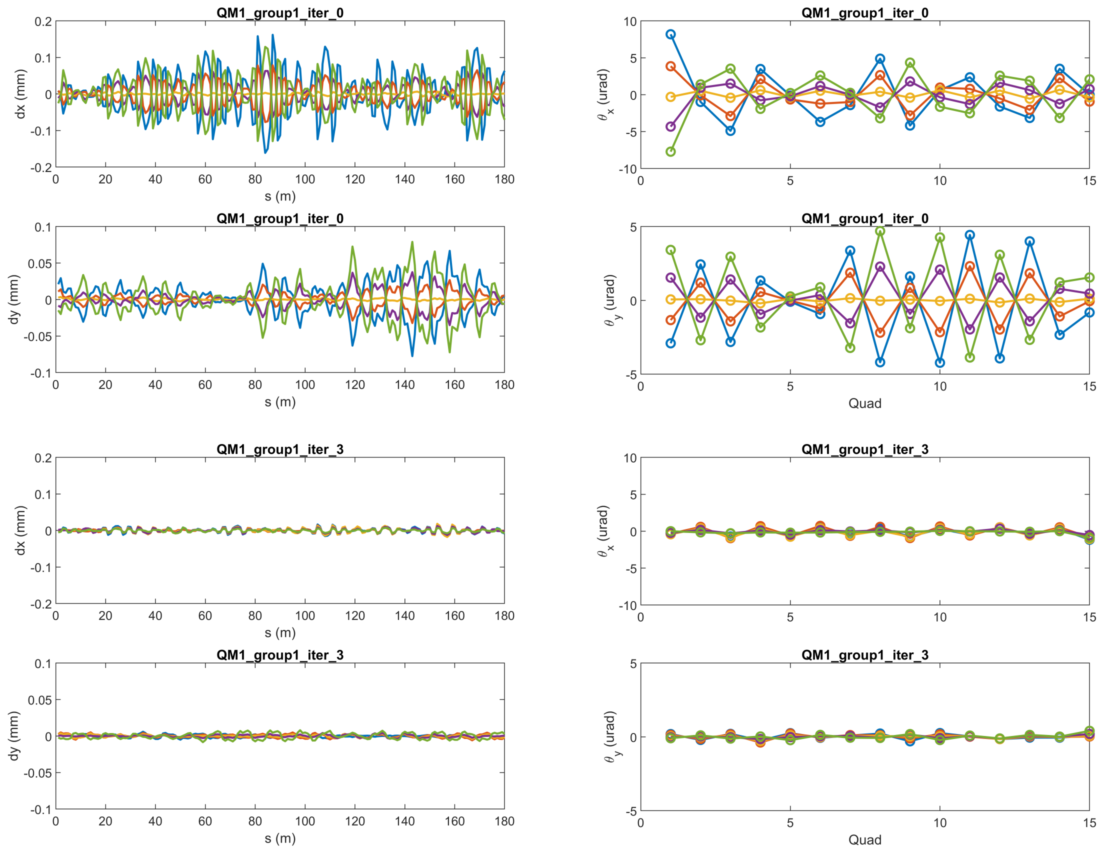

Figure 1: Measurement of induced orbit shift with 5 levels of quadrupole modulations at iteration 0 (top left) and iteration 3 (bottom left), along with calculated kicks at quadrupole locations at iteration 0 (top right) and iteration 3 (bottom right).

distances, and x_q and y_q are quadrupole centers on BPMs. The bold values indicate the correction of orbit offset after 3 iterations. It is found that root mean square (rms) values of quadrupole centers reduced from (72 µm, 107 µm) to (37 µm, 27 µm) in both planes. According to Table 1, PBBA found the large value of quadrupole center (x_q = 0.594 mm) on BPM, which are consistent with the routine BBA measurement (0.494 ± 0.019 mm).

Figure 2 displays the orbits in both planes after IOS correction at iteration 1 and 3. In the top left and right plots, it is clear to observe that the orbits get better in both planes after 1 iterations, which is demonstrated by the correction of IOS. In the bottom left and right plots, it is found that orbits converge after 3 iterations.

CONCLUSION

The PBBA method, as a useful tool for magnet alignment, was preliminary tested at NSLS-II. After minimizing the IOS, the center offsets of quadrupoles were corrected, and orbits were improved. Further work on studying optimal settings for PBBA will be carried out in future beam studies.

ACKNOWLEDGEMENTS

This manuscript has been authored by Brookhaven Science Associates, LLC under Contract No. DE-SC0012704 with the U.S. Department of Energy.

REFERENCES

[1] P. Röjsel, "A beam position measurement system using quadrupole magnets magnetic centra as the position reference," *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 343, no. 2, pp. 374–382, 1994. doi:10.1016/0168-9002(94)90214-3

[2] G. Portmann, D. Robin, and L. Schachinger, "Automated Beam Based Alignment of the ALS Quadrupoles," in *Proc. PAC'95*, Dallas, TX, USA, May 1995, pp. 2693–2695.

[3] X. Huang, "Simultaneous beam-based alignment measurement for multiple magnets by correcting induced orbit shift," *Phys. Rev. Accel. Beams*, vol. 25, p. 052 802, 2022. doi:10.1103/PhysRevAccelBeams.25.052802

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPC83

Table 1: Deduced 15 quadrupole centers from measured induced orbit shift. x and y are initial orbits before modulation, x_{corr} and y_{corr} are orbit-to-center distance, and x_q and y_q are quadrupole centers on BPM. Plain and bold values indicate the values at iteration 1 and iteration 3.

x (mm)		y (mm)		x_{corr} (mm)		y_{corr} (mm)		x_q (mm)		y_q (mm)	
0.452	**0.588**	-0.147	**-0.003**	-1.194	**-0.067**	1.239	**-0.290**	0.571	**0.594**	-0.023	**-0.032**
-0.110	**-0.098**	-0.153	**-0.052**	0.215	**-0.018**	-1.084	**0.511**	-0.088	**-0.099**	-0.045	**-0.103**
-0.055	**-0.172**	-0.124	**-0.057**	0.953	**0.134**	0.568	**-0.227**	-0.150	**-0.185**	-0.067	**-0.080**
0.185	**0.090**	-0.139	**-0.062**	-0.856	**-0.075**	-0.443	**-0.111**	0.099	**0.083**	-0.094	**-0.051**
-0.161	**-0.148**	-0.042	**-0.067**	-0.110	**-0.027**	-0.780	**-0.081**	-0.150	**-0.145**	-0.120	**-0.075**
-0.200	**-0.065**	0.044	**-0.040**	0.810	**0.442**	1.128	**0.071**	-0.119	**-0.021**	-0.068	**-0.047**
-0.117	**-0.144**	-0.003	**-0.085**	0.187	**0.070**	-0.886	**-0.085**	-0.135	**-0.151**	-0.091	**-0.093**
0.112	**-0.052**	-0.027	**-0.091**	-1.328	**-0.161**	1.090	**-0.224**	-0.021	**-0.068**	-0.135	**-0.069**
-0.078	**-0.158**	0.013	**-0.116**	0.654	**0.084**	-1.398	**0.428**	-0.143	**-0.167**	-0.126	**-0.074**
-0.088	**-0.026**	0.061	**-0.136**	0.349	**0.126**	1.807	**-0.302**	-0.053	**-0.013**	-0.119	**-0.106**
-0.067	**-0.039**	0.092	**-0.043**	-0.337	**0.106**	-1.085	**-0.075**	-0.033	**-0.050**	-0.016	**-0.050**
0.053	**0.046**	0.084	**-0.045**	0.045	**-0.077**	-0.075	**0.125**	0.058	**0.038**	0.012	**-0.057**
0.040	**-0.095**	-0.050	**-0.076**	1.065	**0.063**	-0.080	**0.169**	-0.066	**-0.102**	-0.058	**-0.059**
-0.006	**-0.011**	-0.133	**-0.106**	-0.205	**0.008**	-0.153	**-0.177**	-0.026	**-0.011**	-0.117	**-0.088**
-0.198	**-0.129**	-0.204	**-0.049**	-0.247	**1.336**	1.762	**-0.420**	-0.173	**-0.263**	-0.028	**-0.091**

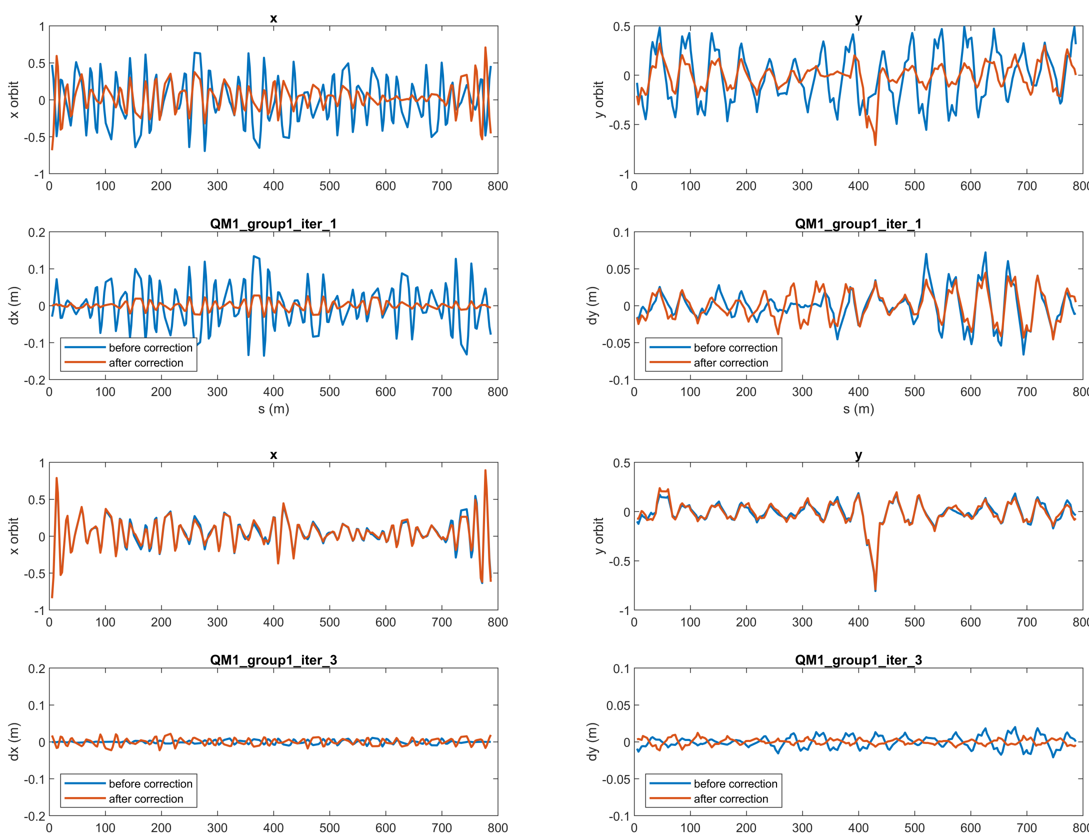

Figure 2: Orbit and induced orbit shift in the horizontal plane at iteration 1 (top left) and iteration 3 (bottom left), along with orbit and induced orbit shift in the vertical plane at iteration 1 (top right) and iteration 3 (bottom right).