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FAST BEAM-BASED ALIGNMENT OF BPMS AND QUADRUPOLE MAGNETS FOR SPring-8-II

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Abstract

For the SPring-8-II project, a low-emittance upgrade of the SPring-8 light source, an alignment accuracy of 10 µm or better between each BPM and the center of its neighboring quadrupole magnet is required to achieve the design performance. With 340 BPMs in SPring-8-II, a fast beam-based alignment (BBA) method is essential for efficient commissioning. We will install fast power supplies on some steering magnets to rapidly scan the beam orbit, and use auxiliary power supplies or remote-controlled shunt resistors to vary the strength of the target quadrupoles. To assess the feasibility of this method, we conducted a fast BBA experiment at the current SPring-8 storage ring using new MicroTCA.4-based BPM readout electronics, which enable a 10 kHz data acquisition rate. We modulated the strength of a quadrupole magnet adjacent to a BPM with the new readout and scanned the electron beam across the center of the quadrupole by sweeping the strength of a steering magnet. The BPM offset relative to the quadrupole center was determined by analyzing data from all BPMs connected to the fast readout. The BBA precision was estimated to be approximately 10 µm, which satisfies the requirement for SPring-8-II.

INTRODUCTION

To achieve the design performance of modern low-emittance electron storage rings for high-brightness light sources, precise beam orbit control is essential. The SPring-8-II project [1], a major upgrade of the SPring-8 storage ring aiming for a natural emittance of below 100 pm rad, requires an orbit accuracy of 10 µm. Beam-based alignment (BBA) is a powerful technique for aligning the electrical center of a BPM with the magnetic center of an adjacent quadrupole magnet. Since SPring-8-II will have 340 BPMs [2], performing BBA for all of them would be time-consuming. Therefore, a fast BBA procedure is necessary for efficient beam commissioning.

A fast BBA method has been proposed and demonstrated at the Spanish light source, ALBA [3]. In this approach, specific orbit corrector magnets are sinusoidally excited at several Hz, and beam position data from each BPM is collected with a high sampling rate of 10 kHz. The magnetic center of a target quadrupole is identified by modulating its strength and finding the beam position that remains invariant. This technique allows the BBA for all BPMs to be completed in approximately 10 minutes at ALBA.

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At SPring-8, we have replaced the readout electronics of single-pass BPMs with new ones based on MicroTCA.4 (MTCA.4) [4], prior to the complete replacement of the main BPMs for Closed Orbit Distortion (COD) measurement. The new electronics have both single-pass and COD BPM readout capabilities and provides three data rates of the COD, 209 kHz turn-by-turn (TbT), 10 kHz fast acquisition (FA), and 10 Hz slow acquisition (SA). Since the 10 kHz FA data is suitable for the fast BBA procedure, we considered possible setup for the fast BBA at SPring-8-II and tested a similar method at the current SPring-8 storage ring.

FAST BBA FOR SPring-8-II

The fast BBA method requires dedicated steering magnets capable of rapidly scanning the beam orbit. In the SPring-8-II lattice, there are ten steering magnets per unit cell for both horizontal and vertical planes: two are independent magnets, six are integrated into sextupoles, and two are integrated into octupoles. However, these magnets are used for COD correction during normal operation and are driven by conventional DC power supplies. Since these power supplies cannot generate sinusoidal patterns at several Hz, these magnets are unsuitable for the fast BBA method.

Each unit cell contains four octupoles, all of which have additional coil windings to generate either of a steering dipole field or a skew quadrupole field. While two of them are already allocated as standard steering magnets, the remaining two are available for other purposes. The number of required skew quadrupoles is estimated to be one per two cells, leaving three octupoles every two cells. These can be utilized for fast BBA by equipping them with pattern-capable fast power supplies. The number of fast steering magnets required is estimate to be about four.

The maximum kick angle of the steering magnet integrated with the octupole is 0.2 mrad. Based on the magnet response, a beam position variation of ±0.5 mm is expected at the BPMs when a suitable steering magnet is chosen. This scanning range is considered to be sufficient, since the initial error of the BPM electrical centers is anticipated to be 0.1 mm std. level before BBA.

To determine the magnetic center of a quadrupole, it is necessary to slightly vary its strength and compare the resulting orbits. However, since quadrupoles at the same location in each cell are powered in series by a single large power supply, an additional method is required to individually change the excitation current for BBA. As shown in Fig. 1, there are seven BPMs in each cell, but targeting five quadrupoles is

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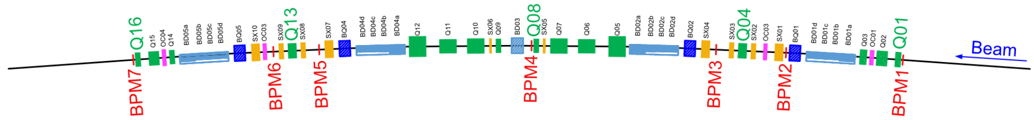

Figure 1: Layout of magnets and BPMs for a normal cell. The quadrupole targeted for BBA are indicated by green letters.

sufficient, since two pairs of BPMs are located close to a single quadrupole each (BPM 2/3 near Q04 and BPM 5/6 near Q13). Therefore, the strengths of five quadrupoles per cell should be changed individually. One of these quadrupoles (Q13) will be equipped with an auxiliary power supplies for individual adjustment for correcting betatron function distortion, etc. The strengths of the other four quadrupoles per cell will be modulated using remote-controlled shunt resistors, since this method is significantly more cost-effective than using auxiliary power supplies. The shunt resistance will be chosen to reduce the quadrupole field by approximately 3 %, which is considered to be sufficient to achieve the 10 µm BBA precision.

EXPERIMENT AT SPring-8

To demonstrate the feasibility of the proposed method, a fast BBA experiment was conducted at the current SPring-8 storage ring. In this experiment, 21 BPMs equipped with MTCA.4-based electronics were utilized for the analysis. Two BPMs of them, BPM-C08-3 and BPM-C24-5, were located near quadrupoles that had auxiliary power supplies for individual control. The target quadrupoles were Q-C08-5 for BPM-C08-3, and Q-C24-8 and Q-C24-9 for BPM-C24-5. The remaining BPMs served as reference monitors. For the orbit scan, steering magnets were selected to maximize the beam position response at the target BPM.

The beam position at the target quadrupole was scanned over a range of approximately ±1 mm. The minimum ramping time of the steering magnet power supply was about 3 s, resulting in a 6 s duration for one round trip. For each measurement, BPM data was acquired for five scan periods at a 10 kHz sampling rate, as shown in Fig. 2. This procedure was repeated after modulating the strength of the target quadrupole by 3 %. As shown in the correlation plot in Fig. 3, the relationship between the target and reference BPMs exhibits a slight curvature due to nonlinear kicks from sextupole magnets. Therefore, a quadratic function was used for fitting the data. The magnetic center of the target quadrupole was then determined from the intersection point of the fitted curves obtained with and without the quadrupole strength modulation.

The intersection points obtained from each BPM combination for a typical BBA dataset are plotted in Fig. 4. The intersection points for different quadrupole strength (−3 % or +3 %) are shown by different colors. The error bar for each data point represents the fitting error of the intersection point multiplied by a scaling factor that was determined by scattering width of the data points assuming a normal distribution. This ensures that the error on each data point is consistent with the distribution width of the data. The weighted mean value of the intersection points and its standard deviation are also shown in this figure. In this particular dataset, the results for different quadrupole strengths (−3 % and +3 %) deviate by approximately two standard deviations. The cause of this discrepancy is still under investigation.

BBA results of the combination of BPM-C08-3 and Q-C08-5 are plotted in Fig. 5. Since we used two steering magnets for orbit scan and two quadrupole strengths for this measurement, there are 4 data points in each of these plots. The weighted mean and its error are also shown by the dashed

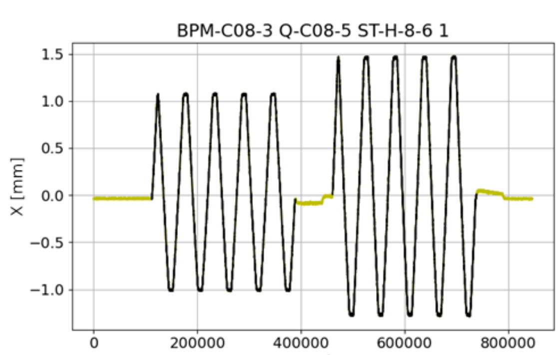

Figure 2: A typical beam position trend graph during a BBA measurement. Only the data corresponding to the black line, representing the beam scan, was used for the analysis.

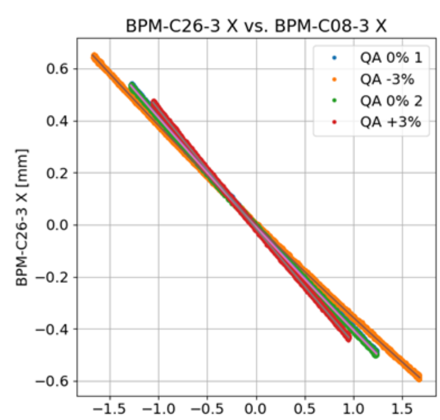

Figure 3: A typical correlation plot between the target BPM (C08-3) and a reference BPM (C26-3). Blue and green dots are the beam position data with the nominal quadrupole strength (0 %) and are almost overlapped. Orange and red dots show beam position data with quadrupole strength modulations by −3 % and +3 %, respectively. Solid lines represent quadratic fits to the data.

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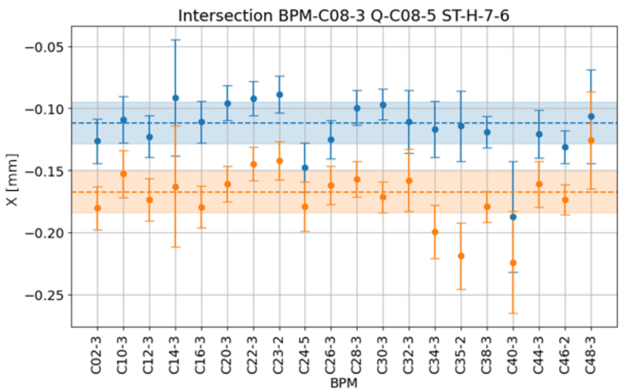

Figure 4: Intersection points derived from correlations with each reference BPM for a typical BBA dataset. Blue and orange dots correspond to measurements with the quadrupole strength modulated by −3 % and +3 %, respectively. The dashed lines and shaded areas indicate the weighted mean and the ±1 standard deviation range for each condition.

line and filled area, respectively. The error on the mean value was approximately 10 µm, which meets the required precision for SPring-8-II. However, some measurements appeared as outliers, such as the orange data point in the upper plot of Fig. 5. The source of these outliers requires further investigations to improve the BBA accuracy.

The weighted mean values from all the combinations in this experiment is listed in Table 1. The errors on the mean values were sufficiently small except for the vertical measurement of the combination, BPM-C24-5 and Q-C24-9. The large error in this case was considered to be attributed to the small vertical betatron function of less than 10 m, whereas the other quadrupoles had the betatron functions of more than 20 m. Since the betatron function of SPring-8-II is smaller than SPring-8, improving the BBA accuracy under small betatron function conditions will be a subject of future work.

CONCLUSIONS

Efficient commissioning of the SPring-8-II storage ring necessitates a rapid and precise BBA procedure. In this study, we have successfully demonstrated the feasibility of such a method. An experiment conducted at the current SPring-8 storage ring, utilizing new MTCA.4-based BPM electronics with a 10 kHz data acquisition rate, achieved a BBA precision of approximately 10 µm. This result meets the stringent accuracy requirement for SPring-8-II. For implementation in SPring-8-II, we will use dedicated fast power supplies for steering magnets integrated in octupoles. Remote-controlled shunt resistors will be used for the target quadrupoles that do not have auxiliary power supplies for individual modulation. While the achieved precision is promising, further improvements are required. Future work will focus on investigating the source of outliers and mitigating the degradation of accuracy observed under specific conditions, such as a quadrupole with a small betatron function. Addressing these issues will be crucial for the successful and timely commissioning of SPring-8-II.

Table 1: Fast BBA Results at SPring-8

BPM	Quadrupole	Horizontal [µm]	Vertical [µm]
C08-3	C08-5	−119.9 ± 4.2	−346.2 ± 11.2
C24-5	C24-8	+423.5 ± 5.1	−55.6 ± 10.9
C24-5	C24-9	+529.2 ± 2.8	−140.9 ± 78.7

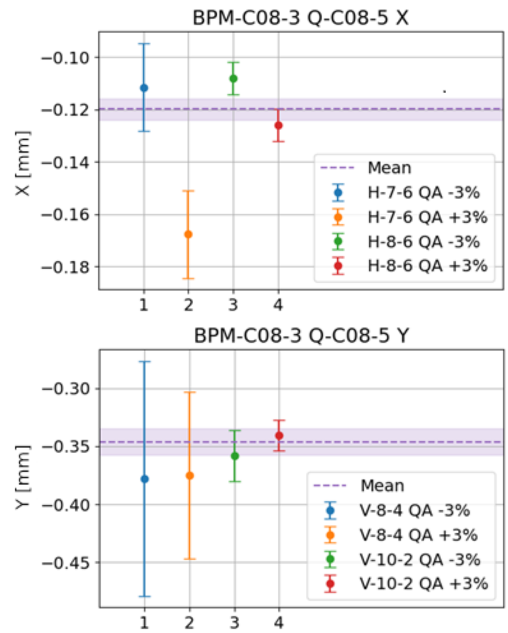

Figure 5: BBA results for BPM-C08-3 in the horizontal (top) and vertical (bottom) planes. Each data point represents a measurement under a different condition (i.e., varied quadrupole strength or steering magnet). The dashed line and the shaded area indicate the weighted mean of all data points and its corresponding error, respectively.

REFERENCES

[1] H. Tanaka *et al.*, "Green upgrading of SPring-8 to produce stable, ultrabrilliant hard X-ray beams", *J. Synchrotron Radiat.*, vol. 31, no. 6, pp. 1420–1437, Nov. 2024. doi:10.1107/S1600577524008348

[2] H. Maesaka *et al.*, "Development status of the BPM system for the SPring-8-II storage ring", in *Proc. IBIC'24*, Beijing, China, Sep. 2024, pp. 71–75. doi:10.18429/JACoW-IBIC2024-TUP16

[3] Z. Martí, G. Benedetti, U. Iriso, and A. Franchi, "Fast beam-based alignment using ac excitations", *Phys. Rev. Accel. Beams*, vol. 23, no. 1, p. 012802, Jan. 2020. doi:10.1103/PhysRevAccelBeams.23.012802

[4] H. Maesaka *et al.*, "Development of MTCA.4-Based BPM Electronics for SPring-8 Upgrade", in *Proc. IBIC'19*, Malmö, Sweden, Sep. 2019, pp. 471–474. doi:10.18429/JACoW-IBIC2019-WEBO03