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SIMULATION OF MODEL INDEPENDENT ANALYSIS TO HEPS STORAGE RING*

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Abstract

Model Independent Analysis (MIA) is a beam analysis method applied for Turn-by-Turn (TBT) Beam Position Monitor (BPM) data. To develop the commissioning method of the HEPS storage ring, we simulate application of MIA on HEPS storage error model to measure and correct the optics parameters. Difficulties and limitations of the MIA method are also discussed.

INTRODUCTION

The High Energy Photon Source (HEPS) is a 6-GeV, 1.3-km, ultralow-emittance storage ring light source to be built in Beijing, China. The storage ring baseline lattice, which consists of 48 identical hybrid 7BAs, made the natural emittance to be about 34 pm.rad [1].

In order to get extremely low emittance, very strong focus force is set per cell, which makes the closed orbit quite sensitive to magnet misalignment error. Meanwhile, as a result of strong focusing, high linear chromaticity need to be corrected, in turn strong sextupole magnets are also required. And so that the large orbit in strong sextupole leads to the serious optics and coupling errors, which cause the beam performance, like emittance and DA, deteriorated. [2]

As the first step of commissioning, beam accumulated will be difficult issue as expected. Trajectory correction while the sextupole closed has been developed in recently study, which could be able to get beam circulate hundreds [3]. But strong optics distortion make beam have little prospect of storage. Beam life time will be so short that even by hundreds of turns which not enough for conventional optics correction such as response matrix measurement. Meanwhile BPM data quality will be bad because of low beam current and uncalibrated with beam.

Therefore, the commissioning process for HEPS need an effective optics measurement and correction method which could work in short time, low current and bad BPM data quality.

Table 1: HEPS Preliminary Error Sheet for BPM

BPM data type	Accuracy (μm)	Tilt (mrad)	Gain
turn-by-turn	1	10	5%
fast acquisition	0.3	10	5%
slow acquisition	0.1	10	5%

Turn-By-Turn (TBT) BPM data coherent betatron oscillation contain valuable information of the linear optics of the machine and requires only a few seconds to take data.

Although the accuracy of TBT BPM is 1 micron in the hardware design requirements, the beam intensity is very low due to the difficulty of beam accumulation in the initial commissioning stage, and the accuracy is far below the design requirements. It is estimated that the accuracy is about several hundred microns. In present design, HEPS storage ring is placed 574 digital broadband BPMs which make global optics measurement from TBT data available. The MIA method [4] is widely used for TBT data analysis for linear optics and coupling measurement and correction.

The rest of the paper will present the simulation of MIA application based on HEPS storage ring. Firstly, we present the condition of simulation data set. Afterwards, the measurement result about betatron parameter from MIA simulation is introduced. And we also make the effort to correction the optics error and give an introduction. Discussions will be given at the end.

SIMULATED OPTICS MEASUREMENT

Description of the Method and Simulation Set

To obtain optics parameters from TBT BPM, the beam must be stimulated first. In practice, injection kicker, feedback system and fast dipole magnet can be used as incentive means. In the simulation, the beam is stimulated in a way similar to that of injecting kicker, and a single excitation of 0.04 mrad is applied to the horizontal and vertical directions, resulting in betatron oscillations up to 0.5 mm (Peak-Peak) in the horizontal and vertical directions, respectively.

MIA uses PCA to process TBT BPM data matrix B:

$$B = USV^T = \sum \sigma_i \mu_i \upsilon_i^T, \tag{1}$$

Where $U_{P\times P} = [\mu_1, \cdots, \mu_P]$ and $V_{M\times M} = [\upsilon_1, \cdots, \upsilon_M]$ are orthogonal matrices containing the temporal vectors μ_i and spatial vectors υ_i. S is a diagonal matrix with non-negative $\sigma = \sqrt{\lambda}$ along the diagonal in decreasing order. Generally speaking, betatron mode has the greatest impact on beam oscillation. After PCA decomposition, the amplitude and phase shifts of betatron oscillation can be obtained by analysing the space vectors of the two main modes.

$$\begin{cases} \upsilon_+ = \frac{1}{\sqrt{\lambda_+}}\left\{\sqrt{\langle J\rangle \beta_m}\cos(\phi_0+\psi_m), m = 1,\cdots,M\right\}, \\ \upsilon_- = \frac{1}{\sqrt{\lambda_-}}\left\{\sqrt{\langle J\rangle \beta_m}\sin(\phi_0+\psi_m), m = 1,\cdots,M\right\}, \end{cases} \tag{2}$$

From the spatial vector we can get betatron the amplitude β and phaseψ:

$$\beta = \langle J\rangle^{-1}(\lambda_+\upsilon_+^2 + \lambda_-\upsilon_-^2), \tag{3}$$

$$\psi = \tan^{-1}\left(\frac{\sigma_-\upsilon_-}{\sigma_+\upsilon_+}\right) \tag{4}$$

In addition to the FFT analysis of betatron mode, the phase calculation of each BPM TBT data can be used to get the working point.

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MIA method itself does not depend on the accelerator model. But it can match the accelerator model by fitting optics measurement result as correction. In the simulation calculation, the R_{12} parameter in the transfer matrix is selected as the matching target.

$$R_{12ij} = \frac{1}{\langle J\rangle}\left(\sigma_+\upsilon_{+j}\sigma_-\upsilon_{-i} - \sigma_-\upsilon_{-j}\sigma_+\upsilon_{+i}\right), \quad (5)$$

The MIA method is sensitive to the data gain of BPM, so the BPM gain is considered in the fitting besides the strength of some quadrupole magnets. Then the BPM gain results will form iteration in the optics parameter calculation process and improve the matching accuracy.

Simulation Based on Ideal Model

Some results of calculating optics parameters using MIA method under relative ideal model are given in figure below. In this case, a 1% error is added to one quadrupole, while random errors (with RMS error of 5e-4) are added to all other quadrupoles. The BPM noise is 0.002 mm rms. While kicker excitation of 0.04 mrad, signal-to-noise ratio between the beam amplitude and the noise of BPM after excitation is about 50, and the TBT data of 3000 cycles are simulated and collected. The fitting lattice parameters include 480 quadrupole parameters and all the BPM gains.

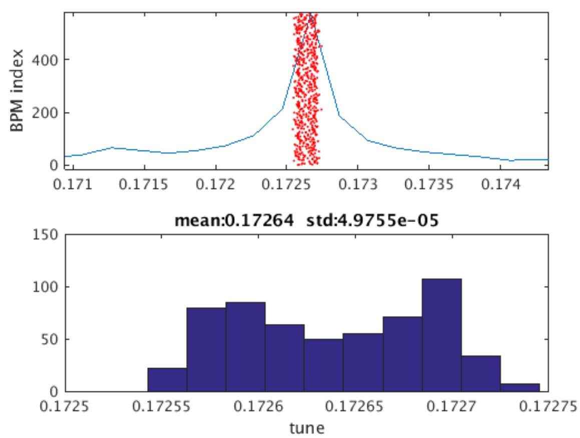

Figure 1: Tune calculation result. Red dots are phase accumulation results from each BPMs; blue line is FFT of temporal vectors; the histogram is the statistical result of red dot.

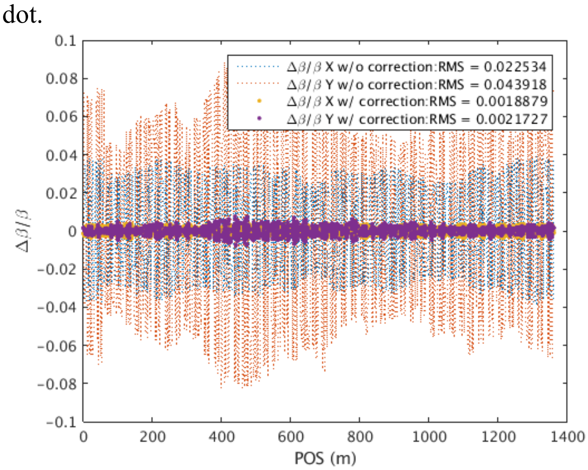

Figure 2: Beta function simulated measurement result. Lines are before correction; dots are after correction.

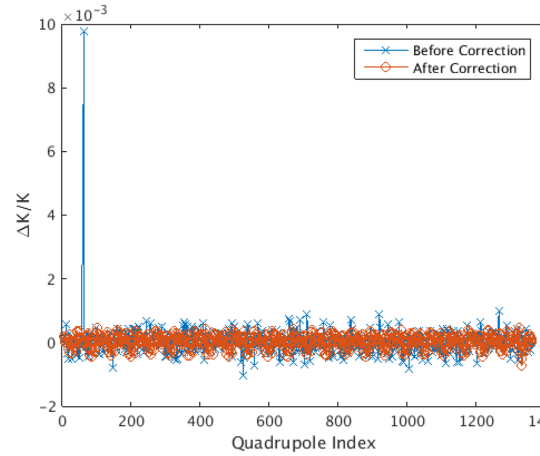

Figure 3: Quadrupole strength error fitting result. Blue lines and crosses are quadrupole strength error before correction, a 1% error is added to one quadrupole while the other is 5e-4 rand error. Red is after correction result.

The results show that in this case, the tune measurement accuracy (Figure 1) reach to 5e-5. And after lattice correction, the strength of the quadrupole magnet cannot be restored completely because the number of error quadrupole magnets is more than that of matched quadrupole magnets, but the beta function restores very well (Figure 2, Figure 3). The RMS beta beating reduce from 2.2% horizontal and 4.5% vertical to 0.2% horizontal and vertical, respectively.

Simulation Based on Initial Commissioning Model

At the first stage of beam commissioning, the BPM quality could not be test with beam. In simulation we assume that some BPMs have the problem below to test the robustness of programs.

- No response.
- Noise is too large.
- The data between BPM is not synchronized due to the fault of timing system.
- The data errors may be caused by the absence of pole signal.

BPM with high noise and no response can be judged by matching results of working points. The problem of data asynchronization caused by timing system is more troublesome. The MIA method can be judged by calculating the phase shift between adjacent BPM (Figure 4).

At the first stage the beam lift time will be so short even not able be storage that the TBT data length will be limited. Ideally, the accuracy of MIA phase measurement is proportional to$1/\sqrt{P}$, where P is the length of beam history. Different data length is set from hundreds to 500 turns to get the P-dependence. And because of low beam current, the accuracy of TBT data will be bad compared with operation current. Figure 5 and Figure 6 show the beta function and phase calculation result under different S/N and data length. Under the beam oscillations up to 0.5 mm (Peak-Peak) in both plane, 0.1mm BPM noise (S/N = 5) and 500 turns data, the beta measurement results with a precision of 1% and phase with 0.01 rad can be obtained.

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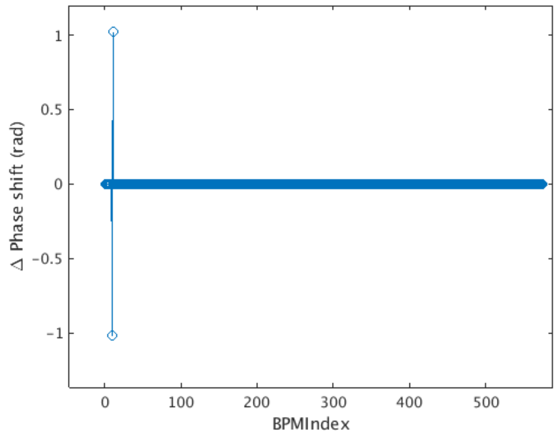

Figure 4: Phase calculation result. One of the BPM is not synchronized which make phase shift error obvious.

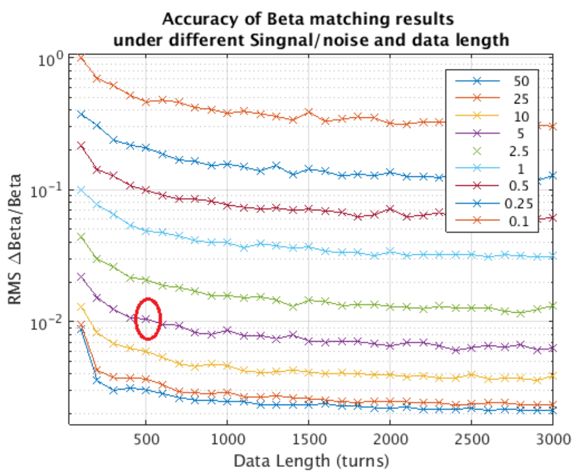

Figure 5: Accuracy of Beta matching results under different Signal/Noise and data length. Legend is S/N.

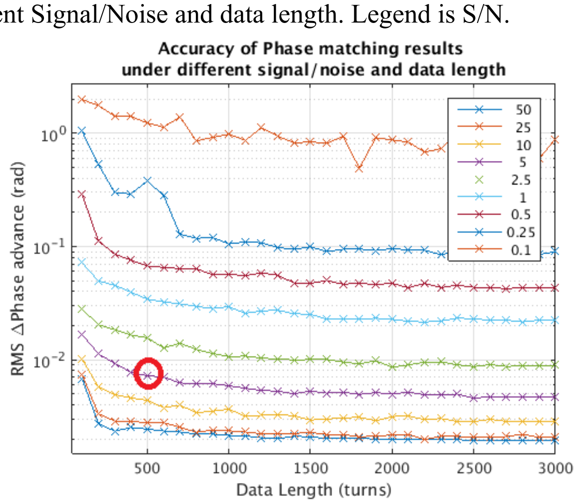

Figure 6: Accuracy of phase matching results under different Signal/Noise and data length. Legend is S/N.

CONCLUSION

We simulate the MIA method to measure and correct linear optics for HEPS storage ring. Using TBT BPM data, MIA method can effectively obtain Optics parameters and correct the lattice containing errors. The simulation results show that MIA method can effectively improve the data quality and reduce the impact of noise, and obtain reliable optics parameters when the initial commissioning stage is characterized by low current intensity, low life and unreliable BPM quality. Further improvements may include x-y coupling as well as more realistic estimation of measurement errors. And other optics measurement method based on TBT data, such as ICA, will be test recently.

REFERENCES

[1] Y. Jiao *et al.,* “Beam Dynamics Study in the HEPS Storage Ring”, presented at the 10th Int. Particle Accelerator Conf. (IPAC'19), Melbourne, Australia, May 2019, paper TUZPLS2, this conference.

[2] D. Ji. X. Cui, Z. Duan, Y. Jiao, Y. Wei, and Y. L. Zhao, “Beam Performance Simulation with Error Effects and Correction on HEPS Design”, *in Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, Canada, Apr.-May 2018, pp. 4186-4188.

[3] Y. L. Zhao *et al.*, “First Turns around strategy for HEPS”, in Proc. IPAC’17, MOPIK081, Copenhagen, Denmark, 2017.

[4] C. Wang et al.,” Model-Independent Analysis of beam dynamics in accelerators,” SLAC-PUB-7909, 1999.