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PROGRESS OF THE FIRST-TURN COMMISSIONING SIMULATIONS FOR HEPS*

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Abstract

This paper describes the progress of the first-turn commissioning simulation for the High Energy Photon Source. We develop and update the simulation algorithm for achieving the first-turn commissioning based on the latest HEPS storage ring lattice. The accelerator toolbox (AT)-based program is updated for automatically optimizating the first-turn commissioning. There is no significant difference compared to the results for previous lattice version. The 4D simulation results and the sensitivities of accumulation rate are also considered. The accumulation rates are higher than 65% with the corrector strength limit higher than 500 µrad and the quadrupole shift lower than 30 µm.

INTRODUCTION

The High Energy Photon Source (HEPS) [1] is a 6 GeV, kilometer-scale, 4th generation storage ring light source. The lattice has an ultralow emittance and strong focusing such that the beam dynamics is very sensitive to the magnet misalignments and other error sources. Getting the first-turn is essential for accelerator commissioning.

In 2017, we reported the algorithm and 4D simulation results based on previous lattice version (V2.4) [2]. The results show that the current algorithm and simulation process are valid for commissioning simulation, we update the algorithm for the latest version lattice as well as the furth commissioning simulations.

This paper describes the simulation processes and the corresponding 4D simulation results for the first-turn commissioning based on the latest HEPS storage ring lattice (V3.0) [3]. All accelerator-related simulations are performed using the MATLAB-based [4] Accelerator Toolbox (AT) [5]. An automatic optimization program for the first-turn commissioning is developed. The sensitivity of accumulation rate is also considered in this paper.

ERROR DEFINITION

Table 1 lists the field and alignment errors of the quadrupole and dipole magnets in addition to the beam position monitor (BPM) errors. All of these error sources follow a Gaussian distribution truncated at $\pm 3\sigma$. The physical aperture and up to 20th order multipole field errors of the quadrupole and dipole magnets are also included in this simulation. In order to achieve the first-turn commissioning, we turn off the nonlinear element, such as sextupole, octupole and RF cavities. The synchrotron radiation effects are not included in this stage. The simulation is performed for 100 random error seeds for each error cases. Throughout this paper, all statistical results are based on the simulation of 100 random error seeds unless explicitly stated.

Table 1: Field and Alignment Errors of the Quadrupole and Dipole Magnets in Addition to the Beam Position Monitor (BPM) Errors

Quadrupole Δx	30 µm
Quadrupole Δz	150 µm
Quadrupole $\Delta \Phi$	200 µrad
Quadrupole $\Delta G/G$	2×10^{-4}
Dipole Δx	200 µm
Dipole Δz	150 µm
Dipole $\Delta \Phi$	100 µrad
Dipole $\Delta G/G$	3×10^{-4}
BPM Noise/Shift	100 µm/100 µm

OPTIMIZATION METHOD

The optimization method of the first-turn commissioning is described in detail elsewhere [2]. Figure 1 shows a sketch of the optimization method. A certain number of BPMs and correctors are combined as a section, we optimize the lattice section by section using the response matrix of bare lattice and the singular value decomposition (SVD) [6].

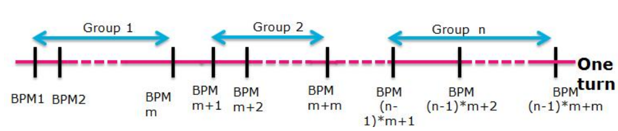

Figure 1: Sketch of the first-turn optimization [2].

The corrector strength θ is calculated as

$$\theta_i = -\sum_{j=1}^{n_B} (A_{ij}^{-1}) R_j, \tag{1}$$

where R is BPM reading, the subscript i and j are the index of correctors and BPMs, respectively. n_B is the number of BPM. A is response matrix of single turn for the bare lattice and can be expressed by

$$A_{n_B \times n_C} = U_{n_B \times n_B} S_{n_B \times n_C} V^*_{n_C \times n_C}, \tag{2}$$

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where the diagonal entry of matrix S are singular values of A, n_C is the number of correctors. We can truncate different number of SVD modes to minimize the affection of errors. A 'kick factor' (κ) is used for adjusting the corrector strength, all corrector strengths are

$$\theta_i^{(1)} = \kappa^{(1)}\theta_i. \tag{3}$$

We scan the kick factor (0~1.7) and SVD mode number (from 1/10 of its rank to its rank) for searching the best setting such that the beam can survive the longest distance. We select the settings with smallest BPM reading if there are more than one setting have the same transmission distance.

The beam can transfer the first turn after above optimization, while it is still difficult to be stored. In addition, the corrector strengths could easily exceed the limits, so another global optimization is performed. We adjust all corrector strengths and BPM readings by repeating above optimization if there is residual orbit larger than 1mm. The final corrector strength settings are calculated by

$$\theta_i^{(3)} = \theta_i^{(1)} + \kappa^{(2)}\theta_i^{(2)}. \tag{4}$$

4D SIMULATION RESULT

Figure 2 shows the 4D simulation result of one seed, where the corrector strength limit is 500 µrad (We set the corrector strength to the limit value if the corrector strength exceeds the limit). During the simulation, we assume that the beam injected strictly on axis. In the simulation of this seed, the beam can transfer to the position of the 48th BPM before the optimization, and can transfer about 1000 turns after optimization if we do not consider the synchrotron radiation and RF cavity effects. For the simulation of the latest version of lattice, the first-turn transmission is achieved based on this optimization algorithm.

The corrector strength settings and the corresponding distribution are shown in Fig. 3, we can find there is no significant difference compared to the results for previous lattice version [2]. In the distribution of the corrector strength settings, almost all corrector strengths are satisfied with their limits, about 70% of corrector strengths is lower than 20% of the limit. We also check this distribution of other error cases, the results show that almost all scanning error cases have the same distribution of corrector strength settings.

SIMULATION SENSITIVITY

To study the sensitivity of the simulation, we scan the corrector strength limits from 400 µrad to 900 µrad, the BPM noise and BPM shift from 100 µm to 600 µm, and the quadrupole shift from 30 µm to 100 µm. The physical aperture requirement is also studied in this paper, as shown in Fig. 4. To decrease the statistical fluctuation, we generated 100 random seeds for each scanning cases, the accumulation rate (AR, we do not perform additional manual optimization for each failed seeds) is calculated for further analysis.

Figures 4 and 5 shows the AR results of each scanning cases, the AR is decreased due to stricter physical aperture

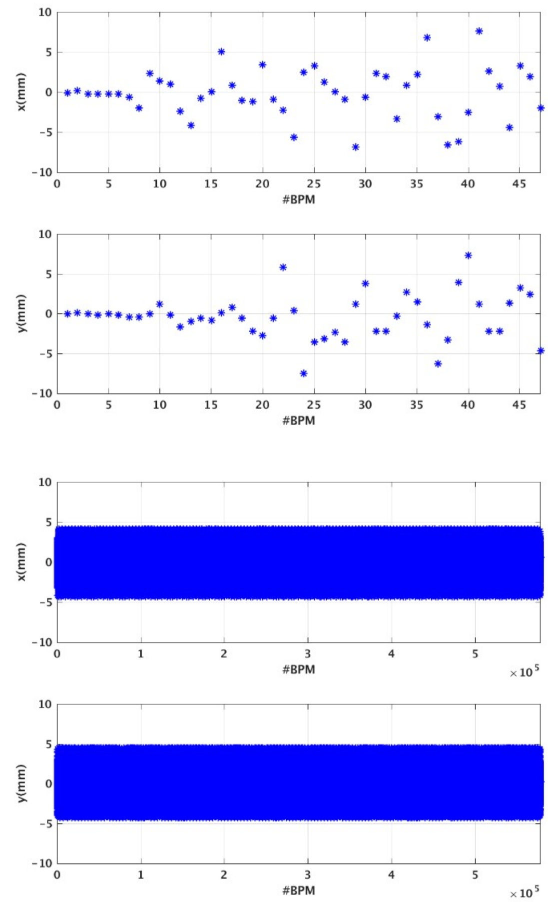

Figure 2: horizontal and vertical BPM readings before (upper) and after (lower) the optimization. The synchrotron radiation and RF cavity effects are not considered.

requirement, while the variation tendency of AR is similar to those of the constant physical aperture requirements. If the corrector strength limit is higher than 500 µrad and the quadrupole shift is lower than 30 µm, the AR is higher than 65% for real physical aperture requirement and 80% for constant physical aperture requirement. By analyzing all scanning cases, the AR is sensitive with the corrector strength limits, BPM noise/shift and quadrupole shift when the corrector strength limit lower than 700 µrad. The AR is higher than 70% (90% for constant physical aperture) if the corrector strength limit is higher than 700 µrad.

CONCLUSIONS

We develop the algorithm and simulation of the first turn commissioning for the latest HEPS lattice version. The 4D simulation results show that the first-turn transmission can be achieved in the current error tolerance. The simulation sensitivity of corrector strength limit, the BPM noise and BPM shift, and the quadrupole shift are studied in this paper. By ignoring the synchrotron radiation and RF cavity effects, the beam can transfer about 1000 turns after optimization. The further first-turn comissioning simulations with more

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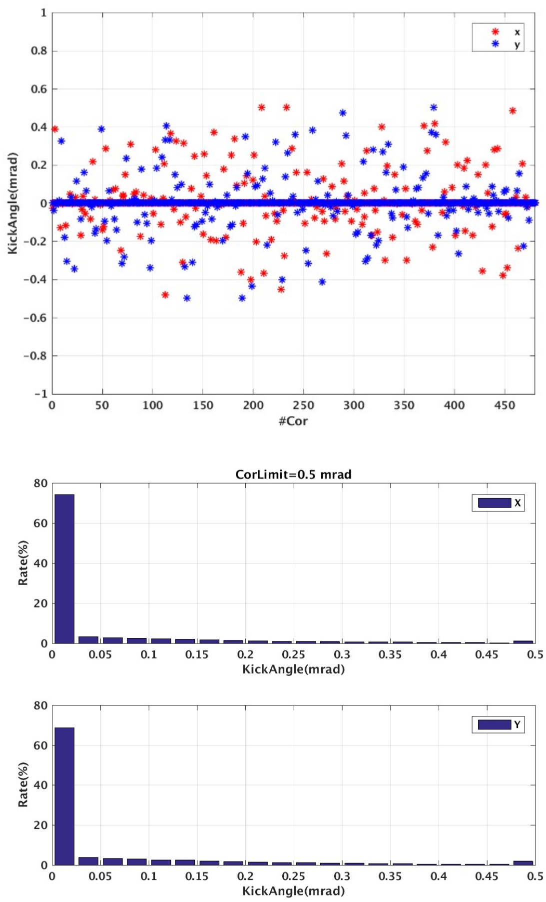

Figure 3: Corrector strength settings (upper) and the corresponding distributions (lower).

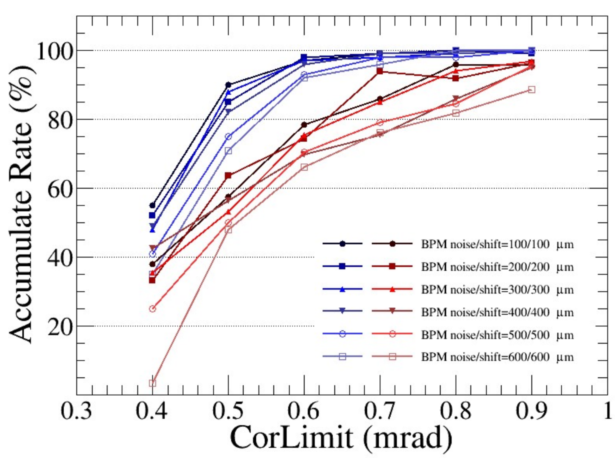

Figure 4: Accumulation distributions for different BPM noise/shift, corrector strength limits and different physical aperture requirements, where the blue curves are results for constant physical aperture, the red curves are results for real physical aperture. The quadrupole shift is set to 30 µm.

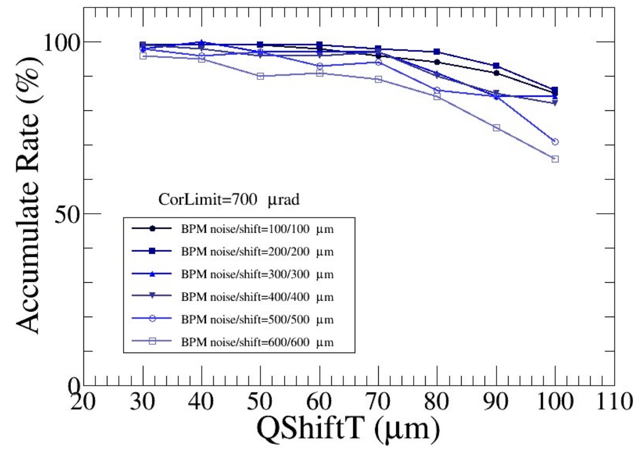

Figure 5: Accumulation distributions for different BPM noise/shift and different quadrupole shift, The corrector strength limit is set to 700 µrad.

practical conditions, such as the synchrotron radiation and RF cavity effects, are ongoing.

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