FIRST TURNS AROUND STRATEGY FOR HEPS

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Abstract

The High Energy Photon Source (HEPS) is a 6-GeV, kilometer-scale, quasi-diffraction limited storage ring light source to be built in China[0]. Getting the first turn and approaching the closed orbit is very important in accelerator commissioning. In order to make first turn beam commissioning efficiently, we develop a MATLAB tool based on AT for automatic beam correction and closed orbit searching. The algorithm and simulation results are presented in this paper.

INTRODUCTION

HEPS is kilometer-scale, quasi-diffraction limited storage ring light source. Its emittance is very small, and correspondingly, its focusing is very strong. Unknown error sources may be introduced to cause large orbit distortion even beam loss when magnet manufacture and installation. It is questioned whether the beam can be survived and accumulated with such a low emittance and strong focusing when the HEPS project is being on beam commissioning for the first time. For the sake of safety and efficiency, we develop a first-turns correction code.

In this code, we turn off all of the nonlinear devices firstly. As to the first one turn beam searching, we take certain number of BPMs and correctors as a section and optimize the lattice section by section, during which process single turn response matrix is used to find corrector setting as initial value. Then, on this basis, we scan the SVD mode number and 'kick factor' to find the kick angle that make the beam transfer as far as possible, at the same time, the orbit is smallest. This function is described in the 'Main Step 1' section of 'METHOD' part.

As to the closed orbit searching, we think there is no difference to making the beam transfer multi-turns, like 20 turns. So, we take similar way like the last step, but all of the BPMs and correctors are used. The details are shown in 'Main Step 2' of 'METHOD' part.

METHOD

The goal of the first turns around strategy is to get the first beam when the machine is just completed. All the sextupoles, octupoles and cavities are off. Then, two main steps are used to steer the lattice and get the closed orbit.

Main Step 1

Take certain number of BPMS and correctors as a group and optimize the lattice group by group until we get the first turn orbit, as shown in Fig. 1.

The optimizing goal is to get the corrector setting that make the beam transfer as far as possible and the orbit be smallest. The response matrix of single turn and the SVD method are used to this goal.

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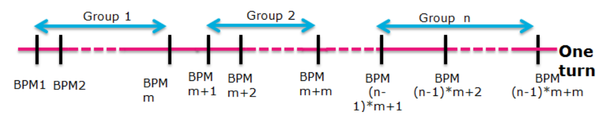

Figure 1: Outline of the main step 1.

The Response Matrix of Single Turn It is different to the normal meaning of response matrix which is based on the conception of closed orbit. For our case, the corrector value will just affect the orbit and BPM reading behind this corrector. And so, the format of the response matrix seems like

$$A = \begin{pmatrix} A_{11} & 0 & 0 & 0 \\ A_{21} & A_{22} & 0 & 0 \\ A_{31} & A_{32} & A_{33} & 0 \\ A_{41} & A_{42} & A_{43} & A_{44} \end{pmatrix} \tag{1}$$

The corrector strength θ and BPM reading changes R has the relationship as Eq. 2. It means the kick at j-th location on the orbit of i-th location[0].

$$\begin{aligned} R_i &= A_{ij}\theta_j \\ &= \frac{1}{2\sin\pi\nu}\sum_{j=1}^{n}\theta_j\sqrt{\beta_j}\cos\nu(\varphi_i-\varphi_j-\pi) \end{aligned} \tag{2}$$

Because the number of BPMs and correctors may be not equal, with the concept of generalized inverse matrix and SVD method, we can get the corrector setting θ, as shown in the Eq.3. Where A is the 'response matrix' of single turn and is gotten with the ideal lattice. R is BPM reading. The subscript 'i' and 'j' are the index of BPMs and correctors, n is the number of BPM.

$$\theta_i = -\sum_{j=1}^{n}(A_{ij}^{-1})R_j \tag{3}$$

SVD Method and Kick Factor The Single Value Decomposition[0] method is used to get the corrector strength. With this method, the single turn response matrix can be expressed as Eq. 4, where the diagonal entry of matrix S is the singular value of A. Every singular value represents one optimizing mode, or one combination type of correctors. We can truncate different number of SVD modes and discard the modes with small singular values to minimize the affection the errors.

$$A_{m\times n} = \mathrm{U}_{m\times m}\mathrm{S}_{m\times n}\mathrm{V}^{*}{}_{n\times n} \tag{4}$$

Because of the difference between the ideal lattice and the lattice with errors, the corrector setting from Eq.4 is not always the best one. I define the 'kick factor' as the factor multiplied before the corrector strength. As shown in Eq. 5, κ is the kick factor. All the correctors have the same κ for single optimizing process.

$$\theta_{\mathrm{n}}^{(1)} = \kappa^{(1)}\,\theta_n; \tag{5}$$

In order to find the best kick angle and SVD mode number, I choose two optimizing goals and scan the kick factor from 0 to 1.7, SVD mode number from about one-tenth of its rank to the rank value. With this step, I successfully avoid the backward appearance. Here, the 'best' setting means the values make the beam transfer as far as possible and BPM reading is smallest if the transfer distance is the same.

Main Step 2

With the main step 1, the beam can transfer one turn. But it still can't be stored. Then, I re-optimize the kick angle with all of the correctors and BPM Reading of the first turn. In this step, only the orbit larger than 1mm will be optimized. With similar process like main step 1, I can get new corrector setting that make the beam stored and achieve the closed orbit. The $\theta^{(3)}$ in Eq. 5 is the final solution, where $\theta^{(1)}$ is from main step one, $\kappa^{(2)}$ is the best kick angle in main step 2, and $\theta^{(2)}$ is the kick angle from response matrix in main step 2.

$$\theta^{(3)} = \theta^{(1)} + \kappa^{(2)}\theta^{(2)} \tag{6}$$

RESULTS

The field and alignment errors and their strength used in this paper are shown in Tab.1. All of the errors are 3σ Gaussian distribution. To model the real situation, I also add system and random multipole field errors, whose order is 20, to the quadrupoles and bends.

Table 1: Error Tolerance Table

Error	value
Quadrupole Δx	30um
Quadrupole Δz	150um
Quadrupole ΔΦ	200urad
Quadrupole ΔG/G	2e-4
Dipole Δx	200um
Dipole Δz	150um
Dipole ΔΦ	100urad
Dipole ΔB/B	3e-4
BPM Noise/Shift	100um/100um

The Fig. 2, Fig. 3, and Fig. 4 is one optimizing example. The quadrupole error is 100um. Fig. 1 is the BPM reading before correction and it shows that the beam gets lost because of aperture limitation after it transfer along about 58 BPMs. Fig. 3 is the BPM reading of 1000 turns after correction and the beam getting stored. Fig. 4 is the correction strength in x and y direction. With our code, the beam could be stored and the closed orbit is achieved.

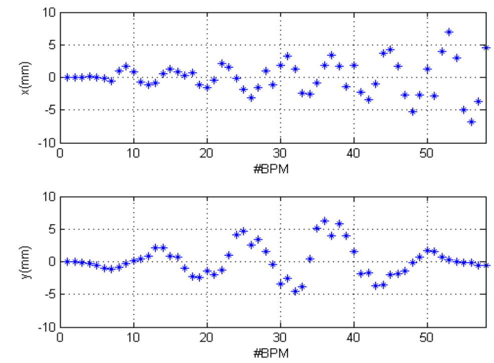

Figure 2: BPM data before correction.

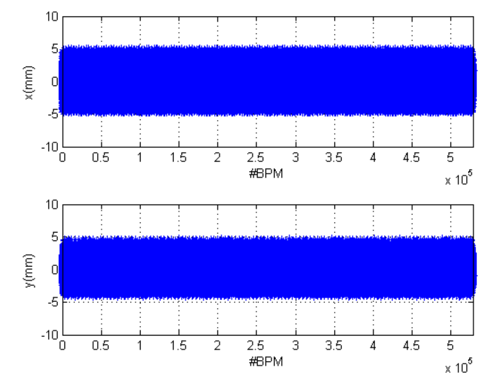

Figure 3: BPM data of 1000 turns.

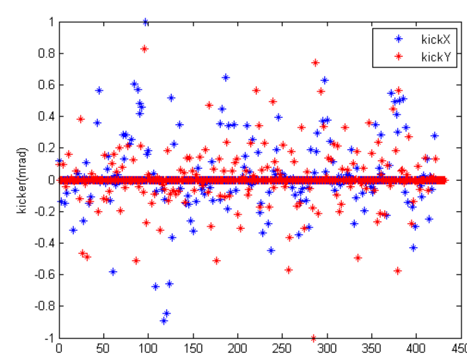

Figure 4: Corrector strength distribution

To find the feasibility of the code, I tested 100 cases to obtain the accumulation rate under different error level and corrector strength limit. The results show that the accumulation rate is only sensitive to the quadrupole shift and BPM errors in transverse direction. The relationship of the accumulation rate and the quadrupole misalignment are shown in Fig. 5. If the quadrupole misalignment is not larger than 80um and the corrector strength limit is greater than 0.4mrad, the beam will be accumulated 100%. At the same time, if the quadrupole misalignment reaches 100um, the maximum accumulation rate is about 97%,

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and will not increase along with the corrector limit. What can we do for the failed cases should be studied further.

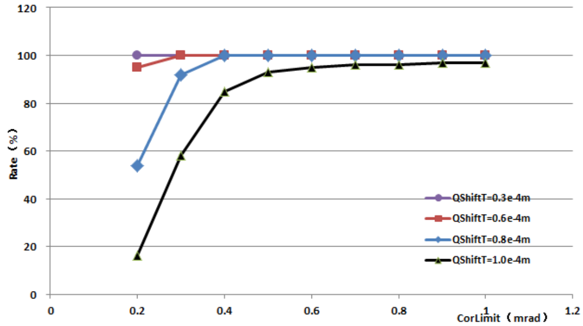

Figure 5: accumulation rate trends with different quadrupole shift in transverse. The x axis is the corrector strength limit and the y axis is the rate with 100 cases. Different colors means different quad shift in transverse and the other kinds of errors are set according to Tab. 1.

As to the correctors value, about 60%~70% are in the level of less than 20 percent of the corrector limit. This value doesn't change a lot along with the BPM errors, corrector strength limit, or quadrupole misalignment. Fig. 6 shows the averaged statistic result over 100 cases with all of the correctors.

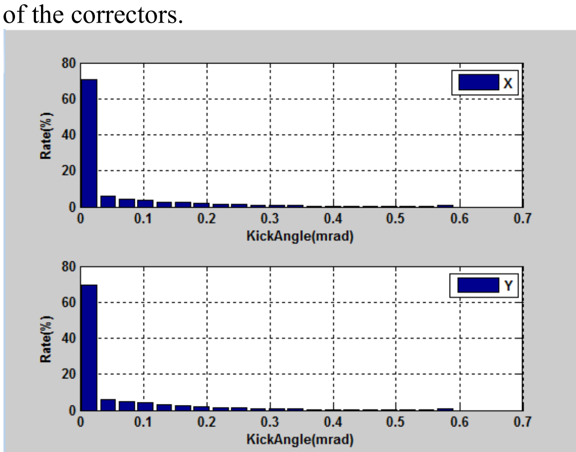

Figure 6: Corrector strength distribution. The quadrupole misalignment is 60um and BPM noise/shift error is 200/200um. The x axis is the corrector strength.

CONCLUSION

It is questioned whether the beam can be survived and accumulated with such a low emittance and strong focusing when the HEPS project is being on beam commissioning for the first time. To this end, we developed a program to simulate the operational scenario, in which the beam orbit is corrected based on the analysis of the response matrix. The simulation indicates that with the predetermined errors, we can succeed to storing the beam in the ring up to a few hundred turns. Next, we will study the commissioning of the first few turns, in several special cases, e.g., some BPMs or correctors are fault or have extremely large errors.

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