STUDY OF HEPS PERFORMANCE WITH ERROR MODEL AND SIMULATED CORRECTION*

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Abstract

As an important component of physics study on High Energy Photon Source (HEPS), error modelling and simulated correction will provide the guideline to restrict the manufacture redundancy of the hardware and estimate the real machine performance. In this paper, we present some work on error effect evaluation and simulated commissioning based on a recent lattice design.

INTRODUCTION

The High Energy Photon Source (HEPS), a kilometre-scale quasi-diffraction limited storage ring (DLSR) light source with the beam energy of 6 GeV, is to be built in Beijing area and now is under extensive design [1-2].

The storage ring baseline lattice, which consists of 48 identical hybrid 7BAs, is designed to provide a basic for the further studies to be based on. The natural emittance of the storage ring baseline lattice is ~60pm.rad. In order to achieve that, eight independent quadrupole magnets and three dipole-quadrupole combined magnets with very strong focusing are set per cell. It make the closed orbit very sensitive to the magnet misalignment. 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. And large orbit is conflicted with the small vacuum chamber, which is required by strong magnet strength. Therefore, the errors effect will be a more pressing issue on HEPS than the third generation light source. While various errors combine together, the effects become associated and difficult for estimations. Thus in this paper, we address on the single error effect meanwhile beam performance taking into account various errors after simulated correction procedure.

ERRORS MODEL EVALUATION AND SETTING

The effect of individual errors on accelerator performance are estimated and simulated to show the sensitivity between the beam performance and the error. And a preliminary error sheet used for developing systematic and procedural analysis is also based on these evaluation information.

Alignment Errors

In the real machine, the magnets are always positioned away from design locations. While the longitudinal alignment of one element is relative to adjacent element, the horizontal misalignment errors are serious and difficult to be avoided. The individual elements on the same girder have random independent misalignment. Meanwhile, the girder misalignments also act on all the elements on the girder. For random misalignment errors, the orbit and beta-beating could be estimated by:

$$\frac{x_{rms}}{\Delta x_{rms}} = \frac{\sqrt{N} K_1 L \beta_{x,max}}{2\sqrt{2}\sin(\pi \upsilon_x)} \quad (1)$$

$$\left(\frac{\Delta\beta_x}{\beta_x}\right)_{rms} \cong \beta_{x,ave}\left|K_2 L\right| \times N_s^{\frac{1}{2}} (\Delta x)_{rms} \quad (2)$$

N is amount of magnets, K is the strength of quadrupole and sextupole. Because of very strong quadrupole and sextupole magnets required in HEPS baseline design, the horizontal misalignment errors have inevitable huge consequences for orbit and optics. Figure 1 shows the simulated result from 100seeds and estimation by equation above. If we want the maximum of closed orbit not to exceed the vacuum chamber dimensions (~10mm) without correction, the random misalignment errors should be less than 10μm, which is infeasible technically and unreasonable economically. For preliminary error requirement, 30μm for most individual elements and 50μm for girder are request for the transverse misalignment errors. Which means the trajectory correction will need to be developed in order to find a closed orbit.

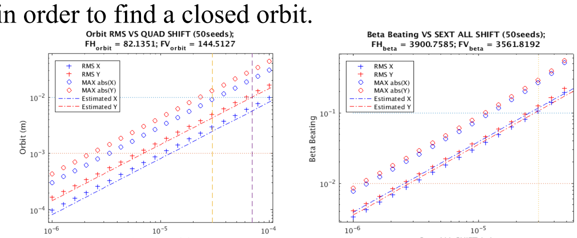

Figure 1: Left: Orbit shift for quadrupole magnets transverse misalignment. Right: Beta-beating for sextupole magnets transverse misalignment.

In addition, roll errors generate skew field components, which will induce spurious dispersion, coupling, and ultimately define the vertical emittance of the machine. The roll errors also are taken in the error model.

Field Error

The actually gradient dipoles and quadrupoles will contain gradient errors. The sextupole and octupole magnets also will show deviations between the actual and the designed strength. These errors have an effect on the linear optics, the nonlinear optics, chromaticity shifts and a reduction of the dynamic aperture.

Figure 2 shows the simulation of the beta beating with the quadrupole magnet field errors. If the quadrupole field

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RMS error set as 2e-4, the beta beating could be limit to ~1%, which is much weaker than the the influence of sextupole misalignment errors. Further simulation show that the dynamic aperture reduction from sextupole and octupole magnet field also could be negligible compared to the reduction from misalignments.

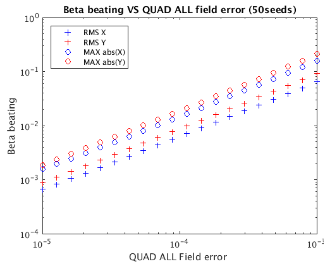

Figure 2: Beta-beating increasing with the quadrupole field errors.

Multipole error exist in each magnet, which should be studied in detail. As a preliminary study, random systematic multipole errors of 1e-4 were added to magnet by same type no matter with the bending, quadrupole or sextupole magnets. Further scan of higher-order magnetic field components effects is going.

Table 1 shows the preliminary error sheet for misalignment errors and magnet field errors taken in the follow simulations.

Table 1: Preliminary Error Sheet for Magnets

	Bend	Quad	Sext	Girder
Transverse misalignment (μm)	200	30	30	50
Longitudinal misalignment (μm)	150	150	150	200
Tilt about X/Y (mrad)	0.2	0.2	0.2	0.1
Tilt about Z (mrad)	0.1	0.2	0.2	0.1
Nominal field	3e-4	2e-4	3e-4	\
Multipole field	2e-4/ 3e-4	2e-4	3e-4	\

BPM Parameters

In consideration of technology capabilities and economic limit, we assume BPM resolution 0.5μm, which will not be bottleneck for closed orbit and optics correction. Because HEPS performance is sensitive to the misalignment error and close orbit correction result, we simulate the relation between BPM offset and close orbit correction result, as Figure 3 shown. When BPM offset better than 20μm, the closed orbit after correction will not be significantly affected.

Table 2 shows the preliminary error sheet for BPM errors set in follow correction procedure.

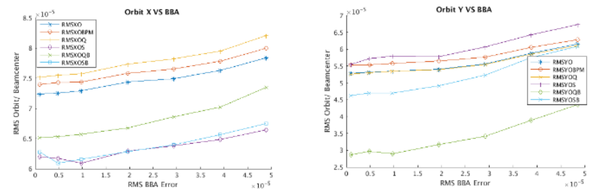

Figure 3: RMS orbit after correction with different BBA accuracy. Line type represent different position orbit.

Table 2: Preliminary Error Sheet for BPM

Accuracy (μm)	0.5
Tilt (mrad)	0.1
Gain	5%
Offset after BBA (μm)	20

SIMULATED COMMISSIONING PROCEDURE AND PERFORMANCE

Simulation shows that when magnet misalignment set as table which is difficult and expensive to improve, the closed orbit will exceeding the vacuum chamber dimensions. Therefore, the trajectory correction is needed to get a closed orbit at the first injection, which will be discussed in [3] .

With trajectory correction study, the follow simulation corrections assume the closed orbit found. The subsequent simulation procedure consists of closed orbit correction, linear optics correction, vertical dispersion and coupling correction. The 48 cells HEPS baseline storage ring set 13 BPMs and 8 H/V Corrector per cells. The average phase advance between BPMs is 23° in the vertical plane and 67° in the horizontal. 2 correctors with skew quadrupole are set at where horizontal dispersion design to zero. 2 independent correctors are placed closed to middle of the cell. Other 4 correctors are combined with defocusing sextupole magnets. Meanwhile, the other 2 skew quadrupole magnets for vertical dispersion correction are combined with focusing sextupole magnets where are maximum horizontal dispersion, as Figure 4 shown.

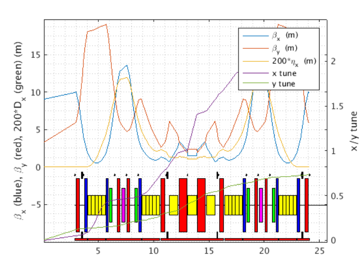

Figure 4: Layout and optical functions. Black point: BPM; Black block: Corrector.

Orbit Correction

The response matrix method[4] is used for the closed orbit correction. The goal of the orbit correction is to bring the RMS orbit to the level of misalignment errors while keep the maximum of corrector strength under control. During orbit correction loop, the singular value in

SVD increase until maximum corrector strength reach the limit. The BPM offset and noise are taken into calculation by based on simplifying assumptions. The detail of offset precision from Beam based Alignment (BBA) simulation in ongoing.

After automatic orbit correction procedure, RMS orbit of ~90% seeds could be corrected smaller than 100μm, similar to misalignment errors (30 μm for elements & 50 μm for girders), shown in Figure 5. The other 10% seeds mostly break out in correction loops because the tune shift leads instability or singular value automatic chosen fail, which could be fixed by manual calculation or tune adjustment. And the reason of about 3% seeds fail in correction still not clear and need to study.

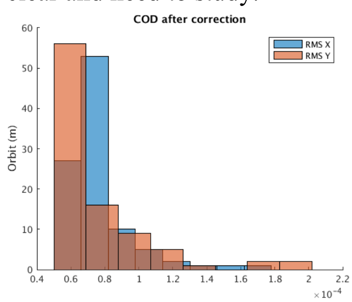

Figure 5: Distribution of rms orbit after correction (100 seeds).

Optics Correction

The residual orbit in sextupole magnet, the field errors of quadrupole magnet and other errors made the linear optics was deviated from design lattice. So after orbit correction, linear optics also needed to be corrected in simulation. A simulated response matrix made by lattice with error was fitted by the Linear Optics from Closed Orbits (LOCO) [5] code. Quadrupole strengths, BPM and corrector gains are fitted to correct beta function and horizontal dispersion. In order to save calculation time and memory, the coupling and vertical dispersion correction is not taken in this step. Results of the optics correction shown in Figure 6. This optics correction procedure make the beta beating smaller than 2% in most successful case, and horizontal dispersion errors smaller than 1mm. The horizontal emittance growth was below 10% when beta-beating smaller than 2% in 90% cases.

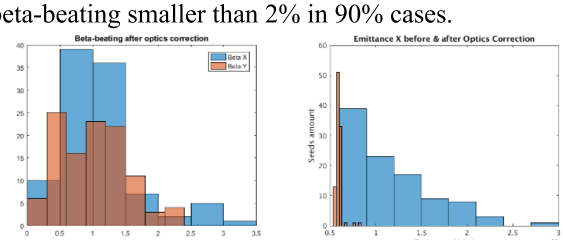

Figure 6: Left: Distribution of rms beta-beating after optics correction; Right: Distribution of horizontal emittance before and after Optics Correction.

Vertical Dispersion and Coupling Correction

After linear optics correction, four skew quadrupole used for vertical dispersion and coupling correction. While the BPM noise set as 500nm and tilt as 0.3mrad, simulation shows that RMS vertical dispersion could be corrected to about 1~2mm. Then the vertical emittance will be adjust with the coupling [6].

Figure 7 shows the DA change during all the correction procedure. DA reduction mostly could be more than 2 mm after optics correction, which was acceptable for on axis injection.

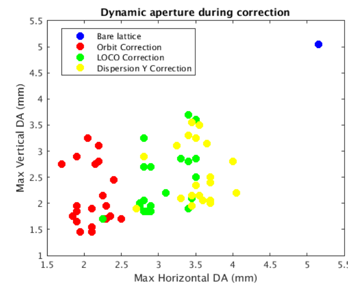

Figure 7: DA change during the correction procedure.

CONCLUSIONS

Up to now, we have modelled the alignment errors of magnets and girders, BPM errors, main field errors and multipole errors of magnets, and simulate the lattice calibration process, including correction of orbit, beta beating, dispersions and coupling. It is found that the misalignments of the focusing magnets have the most distinct influence on the optics. For present error setting and correction procedure, DA reduction mostly could be more than 2 mm after optics correction, which was acceptable for on axis injection. And horizontal emittance growth was below 10% in 90% cases. Further study will be done to obtain detailed tolerance budget table for various hardware systems.

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