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BEAM PERFORMANCE SIMULATION WITH ERROR EFFECTS AND CORRECTION ON HEPS DESIGN*

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Abstract

The High Energy Photon Source (HEPS) is a 6-GeV, ultralow-emittance kilometre-scale storage ring light source to be built in China. In this paper, the progress of the error and correction effect study on HEPS over the past one year will be presented, including error requirement and correction progress update. And beam performance evaluation with static error and correction on orbit, optics, emittance and dynamic aperture will be presented.

INTRODUCTION

The High Energy Photon Source (HEPS) is a 6-GeV, 1.3 km, ultralow-emittance storage ring light source to be built in the Huairou District, northeast suburb of Beijing, China.

Precious error study based on a based line 58-pm lattice. A new hybrid 7BA lattice with superbends and anti-bends, promising a lower natural emittance, i.e., 34 pm, and a higher brightness, is proposed for the HEPS project [1]. The lattice has 24 cells, each of which has 2 symmetric 7BA. The layout of half-cell is shown in Figure 1. The correctors (black block) and BPM (black dot) position is shown in figure too. There are 12 TBT BPMs in each 7BA. And 10 correctors per 7BA are used in orbit correction and response matrix measurement. 4 of them are windings supply H/V orbit correction and fast orbit feedback. 4 of them are auxiliary windings on SD sextupole magnets for orbit correction. 2 of them are auxiliary windings on quadrupole magnets Q7. Another quadrupole Q1 also has auxiliary winding to enable transfer of the DC components of nearby faster corrector rather than orbit correction. 4 skew quadrupoles are set in each 7BA. 2 are in dispersion free region, 2 are windings on octupoles in dispersion region.

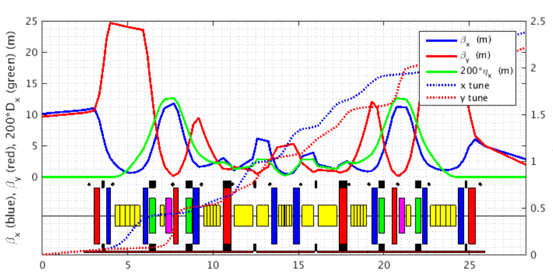

Figure 1:Optical functions and layout of half period (one 7BA) of the 34-pm lattice.

ERRORS SETTING

The effects of individual errors on accelerator performance are estimated and simulated to show the sensitivity between the beam performance and the error in previous study [2]. Because of very large lattice amplification factor of orbit/β-beat as a function of quad/sext misalignment error, the beam performance is very sensitive to the transverse shift error. Taken cost and hardware opinion into account, an error sheet is provide in Table 1 and 2.

Table 1: Error Sheet for Magnets

	Bend	Quad	Sext& Octu	Girder
Transverse shift X/Y (μm)	200	30	30	50
Longitudinal shift Z (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	\

Table 2: Preliminary Error Sheet for BPM

Accuracy 10Hz/22kHz/TBT(μm)	0.1/0.3/1
Tilt (mrad)	10
Gain	5%
Offset before/after BBA (μm)	100~600/30

SIMULATED COMMISSIONING PROCEDURE AND PERFORMANCE

Simulation show 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 has been discussed in [3]

Orbit Correction

The response matrix method 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.

After automatic orbit correction procedure, RMS orbit is corrected to 50μm/60μm (H/V), similar to misalignment errors (30 μm for elements & 50 μm for girders). The max of global orbit is smaller than 300μm/400μm (H/V) as shown in Figure 2.

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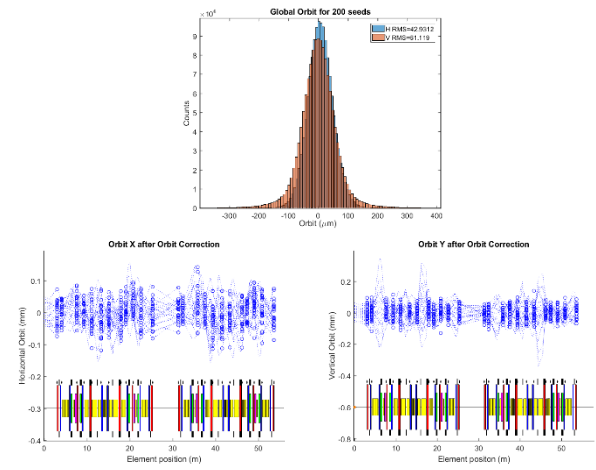

Figure 2: Orbit after orbit correction. Top: closed orbit around ring for 196 seeds. Bottom: Orbit distribution in cells. Left: X, Right: Y.

Optics Correction

The optics correction start based on orbit corrected lattice. Because the sextupole magnet is very strong, the non-zero offset in sextupoles provides more than 90% quadrupole field effect and is main contributors of DA reduction[4]. A response matrix measurement was simulated with BPMs and correctors errors to correct optics.

As conventional optics correction, the quadrupole magnets field strength is used to fit response matrix to correct the optics error. In our precious test by the Linear Optics from Closed Orbits (LOCO), this method could make betabeating rms~1.5%/3% (H/V) and horizontal emittance growth smaller than 10% in 90% cases. However there is significant dynamic aperture deterioration with errors and not recovered after correction.

The present correction procedure uses the beam based sextupole alignment for the optics correction. There are independent sextupole online movers in HEPS design which enable X/Y offset adjustment with 5 μm accuracy rms. The latest correction procedure is as follow:

- Orbit correction with sextupoles and octupoles turned off
- Measure response matrix and correct optics with quadrupoles using the LOCO algorithm
- Turn on sextupoles and octupoles, measure again response matrix, calculate the required offset adjustment for sextupoles with a modified LOCO algorithm, and apply the adjustment using the movers
- Iterate the RM measurement and sextupole adjustment several times.

Results of the optics correction are shown in Figure 3. These optics corrections make the betabeating rms~0.5% in both planes, horizontal dispersion errors rms~0.7mm and vertical dispersion rms~2.7mm.

From the simulated result, shown in Figure 4, the offset of sextupole reduce from 100μm to 20μm in horizontal, and from 80μm to 50μm in vertical. Vertical correction less effective is due to the worse S/N ratio in cross-plane RM measurement. The horizontal emittance is below 10% in 90% cases. Vertical emittance without coupling and vertical dispersion correction is smaller than 10% of horizontal emittance in some cases, which is shown in Figure 5. After sextupole alignment, the DA recovers to 3mm/2mm (H/V), which is obvious better than conventional method, as shown in Figure 6.

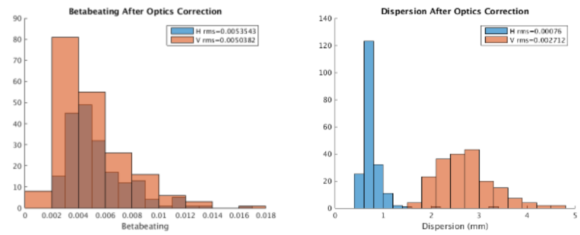

Figure 3: Beta beating and residual dispersion distribution after optics correction procedure.

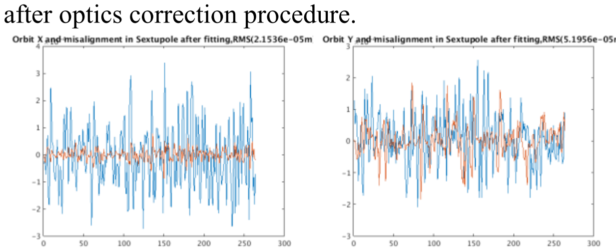
Figure 4: Residual offset of sextupoles before and after optics correction.

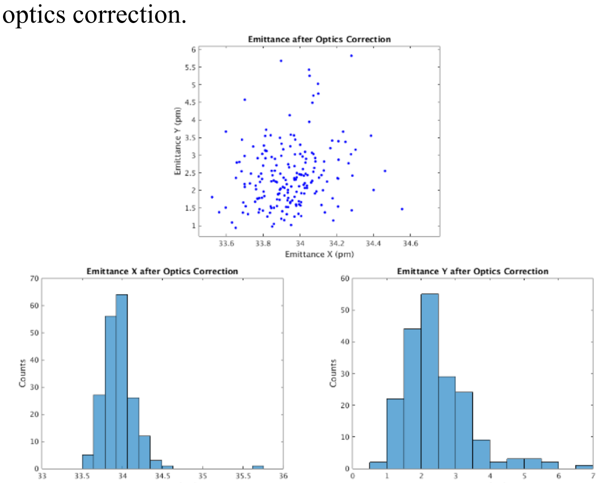

Figure 5: Emittance after correction. Top: Emittance distribution. Bottom left: x. Bottom right: y.

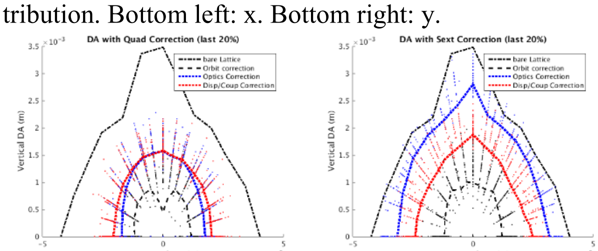

Figure 6: DA after optics correction. Left: corrected by quadupole. Right: corrected by sextupole alignment.

Multipole error

Multipole errors are added in simulation to evaluate the DA reduction. The effects of different types of magnets multipole errors are tracked separately to evaluate the

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requirements, which proved that the multipole in quadrupoles have the most severe effect on DA.

After discussion with the magnet design group, the HEPS magnets multipole errors are modeled as follow rules:

- Reference radius is 10mm
- Systematic multipole error is about 30% of random errors at same order.
- Random multipoles are generated with decreasing order by order when n>3
- Random errors for different magnet types follow a scaling ratio: BQ:Q:BLG:Multi~7:5:5:10
- The magnets divided into four types: dipoles, quadrupoles, bend_quad and multipole magnets which include the sextupole, octupole and correctors. The dipole magnets' multipole error is described by total field deviate in model.
- Each type magnets multipole is described by a coefficient, which equal to order 2~3 multipole field factors.

Figure 7 shows that DA tracking result with multipole error result. Table 3 shows multipole errors settings.

Table 3: Multipole Errors Settings

Element	Error	coefficient
Dipole	total	3.5e-3
Quad	Systematic	1.7e-4
	Random	5e-4
Bend_Quad	Systematic	2.3e-4
	Random	7e-4
Sext&Octu	Systematic	3.3e-4
	Random	1e-3

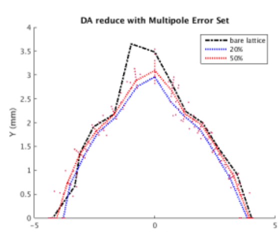

Figure 7: Dynamic aperture of bare lattice (Black), minimum case of 80% confidence DA (blue) and 50% confidence DA (red) with multipole errors.

ID Effect

Dynamic effects of 14 ID-beamlines on storage ring are under investigated. Two correctors with the maximum strength of 400 μrad near each ID with two feed-forward coils are introduced to adjust the close orbit distortion cause by the ID integral field errors. The additional electron energy loss per turn caused by IDs is 1.5 Mev. Horizontal emittance can be reduced to 27.5pm when the IDs are included in the 34-pm lattice. It is found that the 14 IDs can cause a vertical tune shift of totally 0.03 and a vertical beta beating of 0.3% without error. In addition 100Gs/m random quadrupole errors are added to ID model. These effect can be corrected by the nearby quadrupoles. Figure 8 show that after correction, the residual betabeating ~ 0.1%/0.3% (H/V), and primarily located in ID sections.

Figure 9 and Figure 10 shows that the emittance and DA change in correction procedure. The DA reduction after optics correction is not appreciably affected by the IDs and multipole errors.

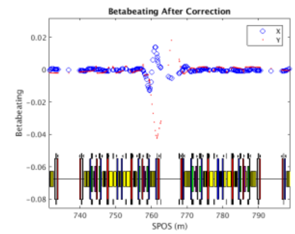

Figure 8: Betabeating after correction w/ IDs.

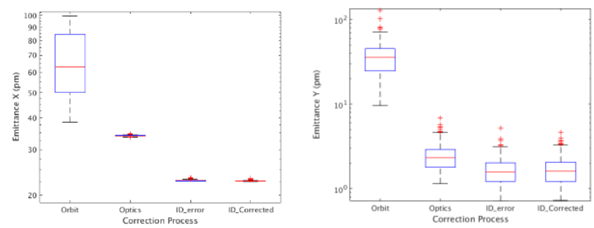

Figure 9: Emittance in correction procedure. Left: X. Right: Y

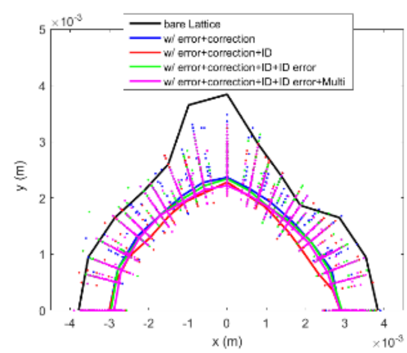

Figure 10: DA of error and correction

CONCLUSIONS

In the presence of typical alignment, magnetic field, ID, and BPM errors, we have simulated the correction procedure. Beam based sextupole alignment make the optics correction much more effective and better DA recover. The multipole error and IDs effect is also taken into simulation.

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