ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPMF059

ERROR STUDY OF HEPS BOOSTER*

C. Meng†, D. H. Ji, J. Y. Li, Y. M. Peng,
Institute of High Energy Physics, 100049, Beijing, China

Abstract

The High Energy Photon Source (HEPS) is a 6-GeV, ultralow-emittance light source to be built in China. The injector is composed of a 500-MeV linac and a full energy booster with 1 Hz repetition frequency. The detailed error study of the booster will be presented, including misalignment errors and closed orbit correction, magnetic field errors and power supply errors. The effect of errors on closed orbit, tune, chromaticity and dynamic aperture will be discussed. The dynamic aperture with multipole errors will be presented also.

INTRODUCTION

The High Energy Photon Source (HEPS) is a 6-GeV, ultralow-emittance storage ring light source to be built in China. The HEPS is composed of a 500-MeV linac, a full energy booster with 1 Hz repetition frequency, 6-GeV storage ring and transport lines. The design progress of HEPS is proposed including linac [1], booster [2] and storage ring [3]. A FODO lattice design of the booster is chosen after iterations of lattice design. The lattice of the booster is four-fold symmetrical super-period structure with traditional FODO structure and the circumference is 453.5 m, where each super-period consists of 14 standard FODO cells and 2 match cells. Each super-period has 32 dipoles, 37 quadrupoles and 17 sextupoles. The optical functions and layout of one super-period lattice of the HEPS booster is shown in Fig. 1, which of the tunes are 16.83/10.73 (H/V).

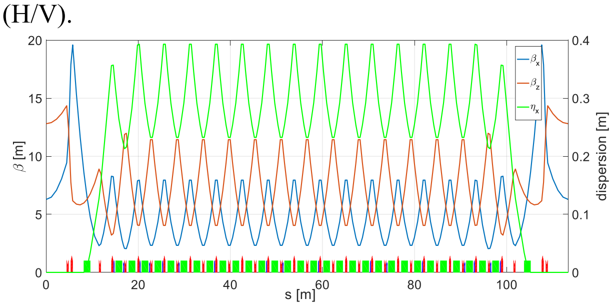

Figure 1: Optical functions and layout of one super-period lattice of the HEPS booster.

To investigate the error tolerance of the booster lattice, the error study is presented including static errors and dynamic errors. The static errors contain misalignments and field error of all magnetic elements and can be corrected. The dynamic errors mainly are power supply errors for magnetic element and cannot be corrected. The effect of errors on closed orbit, tune, chromaticity and dynamic aperture (DA) will be discussed in this paper. The DA with multipole errors is also presented. The used tools are elegant [4] and Pelegant [5] in the simulation. The radiation and RF are all included in the simulation.

STATIC ERRORS

The static error is independent of time or has very slow changes over a long period of time including misalignments and field error of all magnetic elements. The misalignments consist of displacement errors and rotation errors and affect all the magnetic elements. The field error and misalignments of dipoles have effect on closed orbit and dispersion. The field error and misalignment of quadrupoles have effect on tunes and closed orbit. The field error and misalignment of sextupoles have effect on chromaticity and tunes. The effect caused by static errors can be corrected with diagnostic system and correction elements. The misalignments and filed errors of the HEPS booster is shown in Table 1. The BPM noisy is dynamic error and can affect close orbit correction, so it's introduced in this section.

Table 1: Error Settings in Simulation (σ, Gaussian Distribution)

Element	Error	Units	Value
Dipole	Displacement (x/y)	mm	0.1
	Displacement (z)	mm	0.15
	Roll	mrad	0.2
	Field error	%	0.1
Quadrupole	Displacement (x/y)	mm	0.1
	Displacement (z)	mm	0.2
	Roll	mrad	0.2
	Field error	%	0.1
Sextupole	Displacement (x/y)	mm	0.1
	Displacement (z)	mm	0.2
	Roll	mrad	0.2
	Field error	%	0.1
BPM	uncertainty	mm	0.1

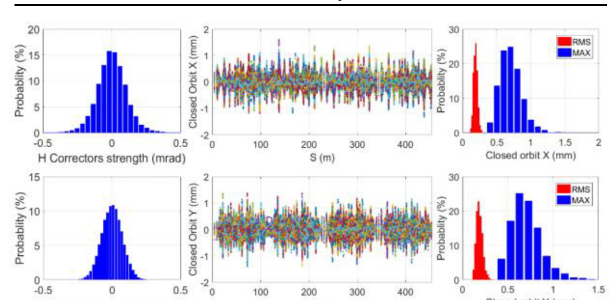

Figure 2: Closed orbit distortion after correction.

* Work supported by NSFC (11705214)
† mengc@ihep.ac.cn

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In the booster there are 72 BPMs, 48 horizontal correctors and 32 vertical correctors used for closed orbit correction. The simulation results with 1000 seeds are shown in Fig.2. The average of RMS closed orbit is 0.19 mm and the average of maximum closed orbit is 0.7 mm. The probability of maximum closed orbit larger than 1 mm is about 11% and the maximum closed orbit is smaller than 1.5 mm. The rms value of corrector strength is 0.11 mrad and maximum value is 0.5 mrad. The rms beta beating is about 2.2% and rms residual dispersion is about 10 mm, which is shown in Fig.3.

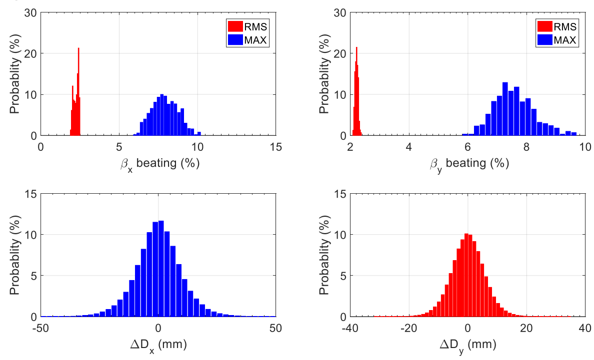

Figure 3: Beta beating (top) and residual dispersion distribution (down) with errors and closed orbit correction.

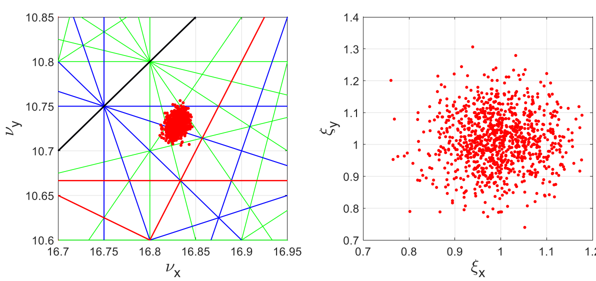

Figure 4: Tune and chromaticity distribution with errors and closed orbit correction.

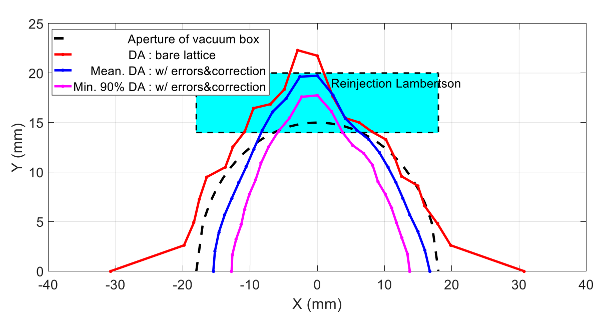

Figure 5: Dynamic aperture of bare lattice (red), average DA (blue) and minimum case of 90% confidence DA (purplish red) with errors and correction and aperture of vacuum box (black).

Because of the feed down effect of sextupole with COD and field errors of quadrupole and sextupole the tune and chromaticity have spread and distribution shown in Fig.4. The tune spread and chromaticity spread is large and can be correct by two family quadrupole and sextupole. Figure 5 shows the dynamic aperture at the middle point of long drift with errors and closed orbit correction. According to the simulation results, the dynamic aperture with errors and correction can meet the requirements for injection. The emittance distribution is shown in Fig.6.

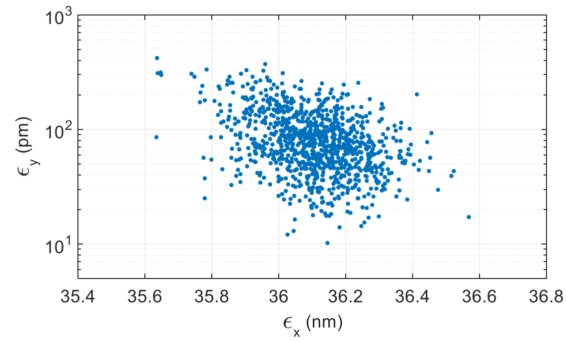

Figure 6: Emittance distribution with errors and correction.

Another one important static error is multipole fields of magnets, including dipoles, quadrupoles, and sextupoles. The multipole field of corrector will be included in the future. These multipole fields have influence on the dynamic aperture. Multipole errors can be divided into two types, namely, systematic multipole error and random multipole error. The systematic multipole is part of the magnet design and is unavoidable because the pole profile must be truncated to build a physical magnet, which should be the same for magnets of the same family and only have specific multipoles for one type magnet. The random multipoles represent the effects of construction errors. In the simulation the multipole errors settings are shown in Table 2 and dynamic aperture is shown in Fig.7, which can meet the requirements.

Table 2: Multipole Errors Settings

Element	Error	Multipole	Value
Dipole	Total	4~14	$\pm 5\times10^{-4}$
Quadru-pole	Systematic	12, 20	$\pm 5\times10^{-4}$
	Random	6, 8, 10	$\pm 5\times10^{-4}$
Sextupole	Systematic	18, 30	$\pm 2\times10^{-3}$
	Random	8, 10, 12, 14	$\pm 2\times10^{-3}$

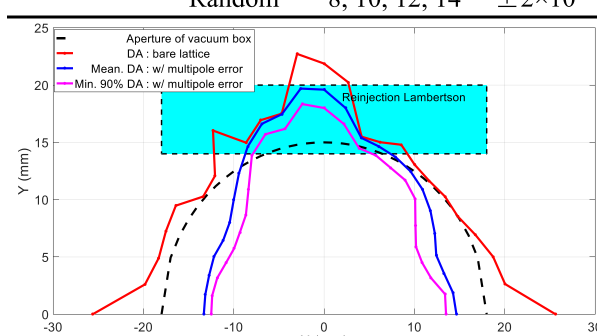

Figure 7: Dynamic aperture of bare lattice (red), average DA (blue) and minimum case of 90% confidence DA (purplish red) with multipole errors and aperture of vacuum box (black).

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DYNAMIC ERRORS

Dynamic error depends on time. It contains field jitter of the magnets caused by power supply current jitter including dipole, quadrupole, sextupole and corrector. Compared with static error, the effect of field jitter caused by dynamic error cannot be corrected and series power supply is adopted that means each power supply jitter can affect one family magnets. Considering the ramping of booster, the dynamic errors contain ripple, tracking accuracy, stability, drift and accuracy. In the simulation it doesn't distinguish different errors. The tune and chromaticity spread have been studied with different error level in dipole, quadrupole and sextupole, which is shown in Fig.8 and Fig.9. According to the simulation results, comprehensive consideration on technology and physical dynamic results, the total dynamic errors should be controlled within 300 ppm.

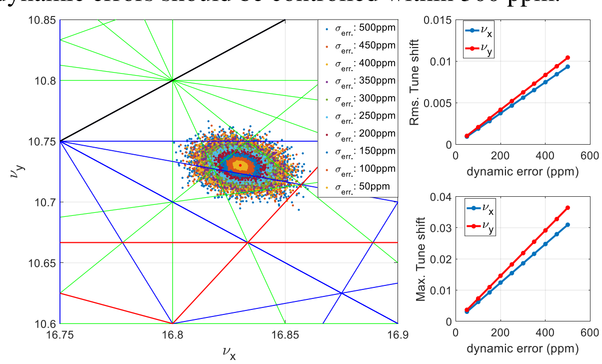

Figure 8: Tune spread with different dynamic errors.

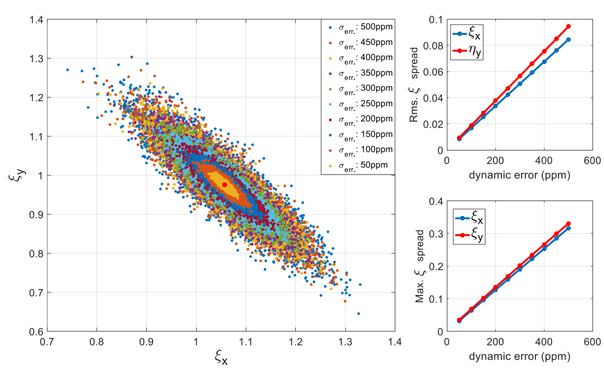

Figure 9: Chromaticity spread with different dynamic errors.

Because the energy ratio of booster is 12, the magnetic field jitter in low energy should be paid more attention to. The corrector current (power supply) jitter have been studied. If we take the power supply current corresponding to 0.5 mrad at 6 GeV as the reference current, the simulation results of closed orbit at 500 MeV with different current jitter are shown in Fig.10. According to the simulation results, the average of rms closed orbit would be controlled within 0.2 mm (same as the value of closed orbit with static errors and correction in above section), the corrector current jitter should be smaller than 0.1%.

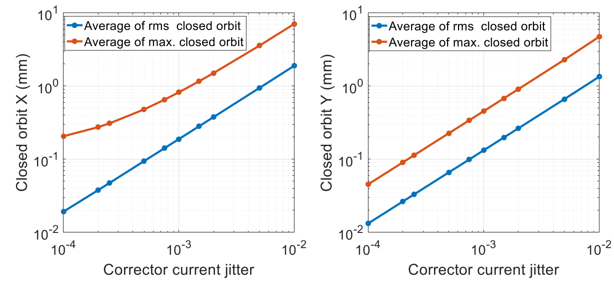

Figure 10: Closed orbit with different corrector current jitter.

CONCLUSION

The HEPS booster has a four-fold symmetrical super-period structure lattice with energy ramping from 500 MeV to 6 GeV in 1 Hz repetition frequency. The detailed error study of the booster is presented in this paper including misalignment, field error of magnet and power supply dynamic errors. The misalignment and field error requirement of magnet is proposed. The total power supply current jitter of dipole, quadrupole and sextupole should be controlled within 300 ppm. The corrector current jitter should be controlled within 0.1% of the reference current. Detailed simulation results on closed orbit, tune spread, chromaticity spread and dynamic aperture are presented in this paper.

ACKNOWLEDGEMENTS

The authors would like to thank all the HEPS group members for their valuable suggestions and comments.

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