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ERROR CORRECTION FOR THE HIGH LUMINOSITY LATTICE OF THE CEPC

B. Wang*, Y. Y. Wei, Y. W. Wang, and C. H. Yu
Key Laboratory of Particle Acceleration Physics and Technology,
Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China

Abstract

This paper presents a study of the error correction for the lattice of the Higgs mode in the Circular Electron-Positron Collider technical design report, which is proposed for increasing the luminosity of the Higgs and Z modes by squeezing the vertical beta function at the interaction point. In the high luminosity lattice, the emittance of the Higgs mode is half lower that of the CEPC CDR, while the small beta function and emittance increase the difficulty of the error correction. The scheme of the correction and the resulting performance are discussed. The dynamic aperture tracking after correction satisfies the requirements of on-axis injection.

INTRODUCTION

The Circular Electron-Positron Collider (CEPC) is a double-ring collider with a circumference of 100 km and two interaction points (IP) [1, 2]. A high luminosity scheme has been proposed for the CEPC project, which aims to increase the luminosity mainly at the Higgs and Z modes by squeezing the vertical beta function at the IP [3,4]. The luminosities of the Higgs and Z modes will be up to 5×10^{34} cm^{-2}s^{-1} and 115×10^{34} cm^{-2}s^{-1}, respectively. The emittance optics of the Higgs and Z modes are ϵ_x/ϵ_y = 0.64 nm/1.3 pm and 0.27 nm/1.4 pm, respectively, The beta function at IP is β_x/β_y = 0.3 m/1 mm for the Higgs mode and 0.12 m/0.9 mm for the Z mode.

The correction study for the Higgs lattice in the CEPC CDR examined various scenarios involving magnet misalignments [5, 6]. Specially, the misalignment of quadrupoles in the interaction region was analyzed using 1000 random lattice seeds. However, the smaller emittance and more limited beta function of the high luminosity lattice dramatically increase the challenge of the current correction scheme, especially the beta beating correction. Therefore, some optimizations, which are described in the following text, are necessary for the correction to the high luminosity lattice. This paper describes the error correction for the Higgs mode of the high luminosity lattice, the correction results for the Z mode are comparable with those for the Higgs mode.

ERROR ASSUMPTIONS

Tables 1 list the misalignment errors and field errors of all magnets. All error sources follow a truncated Gaussian distribution with limits of $\pm 3\sigma$.

* corresponding author: wangbin@ihep.ac.cn

Table 1: Magnet misalignment RMS errors and field errors for the collider ring.

Component	Δx (mm)	Δy (mm)	$\Delta\theta_z$ (mrad)	Field error
Dipole	0.10	0.10	0.10	0.01%
Arc Quadrupole	0.10	0.10	0.10	0.02%
IR Quadrupole	0.10	0.10	0.10	0.02%
Sextupole	0.10	0.10	0.10	

CORRECTION SCHEME

The correction algorithms are mainly based on SAD [7] and Matlab-based accelerator toolbox (AT) software [8, 9]. Beam position monitors (BPM) and correctors are arranged to correct the closed orbit. One BPM and a pair of correctors (one each for horizontal and vertical) are installed in each cell. For the cells accommodating sextupoles, horizontal and vertical correctors are produced by the sextupole trims. For other cells, individual horizontal and vertical corrector magnets are located close to the focusing and defocusing quadrupoles respectively. Therefore, there are four BPMs and four corrector magnet pairs per betatron period. Firstly, we perform a closed orbit distortion (COD) correction with sextupoles off by using the orbit response matrix and SVD (singular value decomposition) method [10]; then we turn on the sextupoles and perform the COD correction again. The precision of the beam-based alignment (BBA) for sextupoles is assumed to be 10 μm. The dispersion correction and beta beating correction are also used for optics correction. Dispersion free steering (DFS) [11] and linear optics from closed orbits algorithm (LOCO) [12] are the corresponding methods. The coupling and vertical dispersion correction are used for decreasing the vertical emittance. The iteration of the above correction scheme is used until the emittance and tracking dynamics aperture satisfy the design requirements.

CORRECTION PERFORMANCE

To achieve the fully converged COD correction, we increase the iteration times, steps in response matrix calculation and the number of different error steps during the orbit correction for the high luminosity lattice. Figure 1 shows the RMS residual orbit after correction for all Higgs lattice seeds. The results show that both horizontal and vertical residual orbit are mostly lower than 50 μm, and the RMS orbits after correction are calculated to be lower than 40 μm.

We then perform the dispersion correction for these lattice seeds. The iteration of COD correction and dispersion correction are necessary to get a converged result. Figure 2

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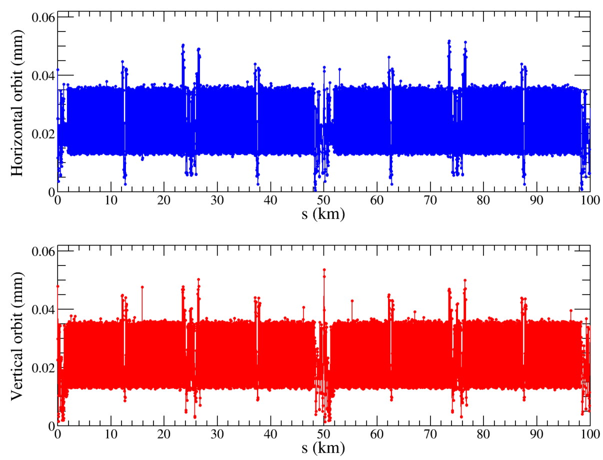

Figure 1: The RMS values of (upper) horizontal and (lower) vertical residual orbit for all 1000 lattice seeds after COD correction.

shows the RMS dispersion after correction, where the RMS horizontal dispersion decreased from 23.1 mm to 1.8 mm, and the RMS vertical dispersion decreased from 31.9 mm to 0.9 mm. There are about 12.8 times and 35.4 times improvement for horizontal and vertical dispersion after correction.

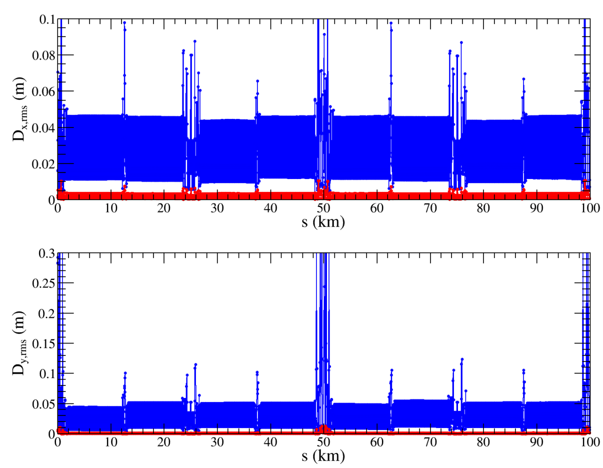

Figure 2: The RMS values of (upper) horizontal dispersion and (lower) vertical dispersion after dispersion correction, where the blue curves are the dispersion distortion before dispersion correction and the red curves are the dispersion distortion after dispersion correction.

The beta beating correction is performed for lattice seeds with passing through the above dispersion correction. Compared with the beta beating correction in the CEPC CDR, we scan the numbers of BPM, correctors and quadrupole magnets during the fit in the LOCO, the coupling correction is also optimized accordingly. Figure 3 shows the RMS relative beta beating distortion after correction for all lattice seeds, where the RMS horizontal beta beating decreased from 5.2% to 1.0% (about 5 times) and the RMS vertical beta beating decreased from 83.2% to 2.8% (about 30 times) There are about 5.2 times and 29.7 times improvement for horizontal and vertical beta beating after correction.

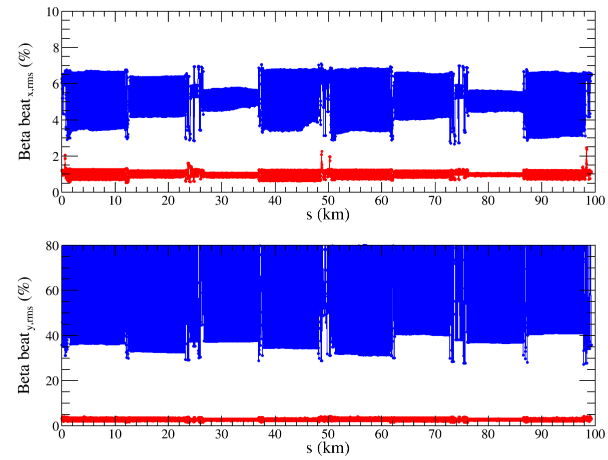

Figure 3: The RMS values of (upper) horizontal relative beta beating and (lower) vertical beta beating after beta beating correction, where the blue curves are the beta beating distribution before correction and the red curves are the beta beating distribution after correction.

The dynamic aperture in Higgs mode is tracked over 145 turns, about one damping time. All lattice seeds in the Higgs mode with the above error correction are used to track the dynamic aperture, as shown in Fig. 4. The results show that the dynamic aperture in the Higgs lattice after error correction satisfy the requirement of dynamic aperture for on-axis injection, which is $7\sigma_x \times 15\sigma_y \times 0.016$.

CONCLUSION

The error correction to the Higgs lattice in the CEPC TDR is studied, 1000 lattice seeds with 100 mm IR quadrupole misalignment are generated for correction. The results showed that compared to tighter error assumptions, corrections for these assumptions resulted in comparable closed orbit, dispersion, beta beating, emittance and dynamic aperture values but required longer correction durations and more iterations. The correcting results show a high passing rate (>90%) for both orbit correction and optics correction. The dynamic aperture after correction satisfies the requirements of on-axis injection. Correction for other three modes are also included in the coming CEPC TDR.

REFERENCES

[1] The CEPC Study Group, "CEPC Conceptual Design Report Volume I-Accelerator", arXiv:1890.00285, 2018.

[2] The CEPC Accelerator Study Group, "Snowmass2021 White Paper AF3-CEPC", arXiv:2203.09451, 2022.

[3] Y.W. Wang *et al.*, "Lattice Design of The CEPC Collider Ring for a High Luminosity Scheme", in *Proc. IPAC'21*, Campinas, SP, Brazil, May 2021, pp. 2679–2682.

[4] C. Yu, "High luminosity scheme at Higgs energy", presented at The 2020 Int. Workshop on the High Energy Circular

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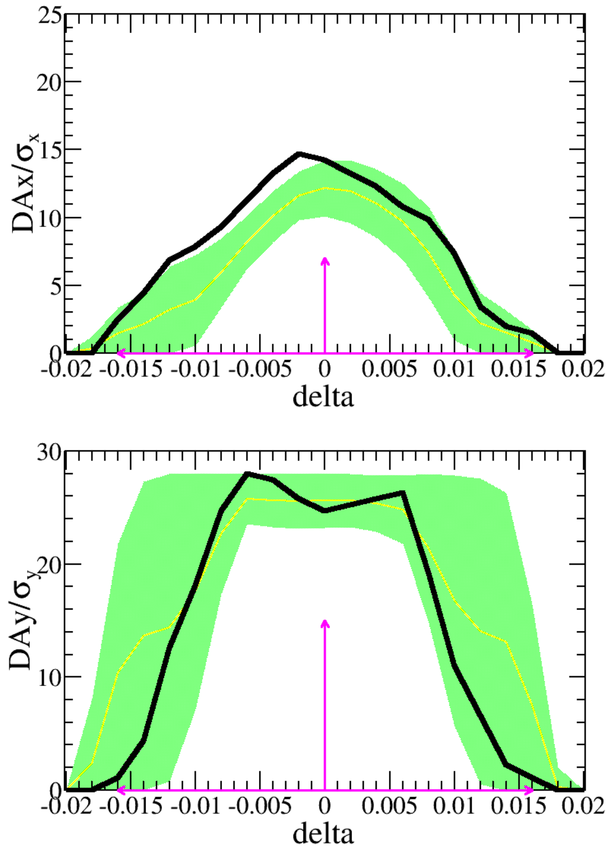

Figure 4: Dynamic aperture for the Higgs lattice with error correction, where the yellow lines and green bands are the mean value and its corresponding statistical errors. The black line is the dynamic aperture of bare lattice. The pink arrows are the dynamic aperture requirement.

Electron Positron Collider, Shanghai, China, Oct. 2020, unpublished.

[5] B. Wang, *et al.*, "A correction scheme for the magnet imperfection on the cepc collider ring", *Proc. IPAC'21*, Campinas, SP, Brazil, May 2021, pp. 1346–1348.

[6] B. Wang, *et al.*, "Imperfection and error correction for the CEPC CDR lattice", *International Journal of Modern Physics A* (2022) 2246005 (6 pages).

[7] SAD, Website and software repository. `http://acc-physics.kek.jp/SAD/index.html`; `https://github.com/KatsOide/SAD`

[8] MATLAB, R2015b. The MathWorks Inc., Natick, Massachusetts, 2015.

[9] A. Terebilo, "Accelerator toolbox for MATLAB", SLAC-PUB-8732, 2001.

[10] H. William, *Numerical recipes 3rd edition: The art of scientific computing*, Cambridge university Press, 2007.

[11] R. Assmann, *et al.*, "Emittance optimization with dispersion free steering at LEP", *Phys. Rev. ST Accel. Beams* vol. 3, p. 121001, (2000).

[12] J. Safranek, "Experimental determination of storage ring optics using orbit response measurements", *Nucl. Instr. Meth.*, vol. 388, pp. 27–236, 1997.