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A CORRECTION SCHEME FOR THE MAGNET IMPERFECTION ON THE CEPC COLLIDER RING

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Abstract

This paper describes the error correction scheme for the CEPC CDR lattice in Higgs mode, which has a small beta function at the interaction point. The low emittance optics has an enhanced sensitivity to the magnet misalignments and field errors, especially for the final focus quadrupole misalignment. The magnet imperfection will cause the closed orbit distortion and optics distortion. The correction scheme for these magnet imperfections includes the closed orbit correction, the dispersion correction, the beta function correction and the betatron coupling correction. The resulting performance and the dynamic aperture for the corrected lattice are studied.

INTRODUCTION

The Circular Electron-Positron Collider (CEPC) is a 100 km circumference double-ring Collider [1], the luminosity at Higgs is $3 \times 10^{34}\ \mathrm{cm^{-2}s^{-1}}$ with 242 bunches. The L^* is 2.2 m and the strength of first quadrupole is 136 T/m. The CDR lattice has a small beta function at the interaction point, which is $\beta_x/\beta_y = 0.36/0.0015$ m. The low emittance optics which is $\epsilon_x/\epsilon_y = 1.21/0.0024$ nm has an enhanced sensitivity to the magnet misalignments and field errors. It contains thousands of magnets, the corresponding magnet imperfection will cause the closed orbit distortion (COD) and optics distortion. Especially the final focusing quadrupole magnets (FF) near the interaction point (IP), the lattice with the small beta function is very sensitive to the FF misalignments. In this paper, we present a correction scheme for the magnet imperfection on the CDR lattice at Higgs mode [1] and the corresponding correction results. We also perform the dynamic aperture (DA) tracking to the corrected lattice, where the DA requirement is $8\sigma_x \times 15\sigma_y \times 0.0135$.

MAGNET IMPERFECTION

Table 1 lists the magnet misalignment and the field errors used in this paper. All error sources follow a Gaussian distribution truncated at $\pm 3\sigma$. We generated 1000 random lattice seeds for testing the passing rate of the current error correction scheme.

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	
Sextupole	0.10	0.10	0.10	

CORRECTION SCHEME AND CORRECTION RESULTS

The correction is mainly based on SAD [2] and MATLAB-based [3] Accelerator Toolbox (AT) [4] and described in detail elsewhere [5]. The horizontal correctors and vertical correctors are placed beside focusing quadrupoles and defocusing quadrupoles, respectively. The total number of horizontal (or vertical) correctors is about 1500. The beam position monitors (BPM) are placed at quadrupoles with four per betatron wave. Firstly, we perform a COD correction with sextupole off, then we turn on the sextupole and perform the COD correction again. The COD correction is applied using the orbit response matrix and SVD (singular value decomposition) method [6]. Figure 1 shows the COD after correction for 955 converged seeds, the RMS values of both horizontal residual orbit and vertical residual orbit are lower than 50 µm.

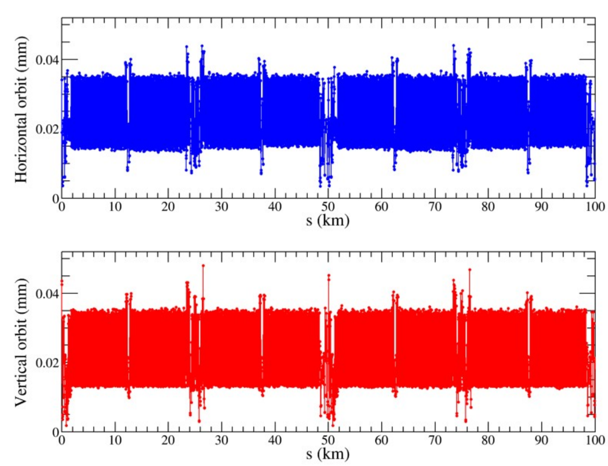

Figure 1: The RMS values of (upper) horizontal residual orbit and (lower) vertical residual orbit after COD correction.

The dispersion correction is performed for the converged seeds shown above. The dispersion free steering method [7] is used for dispersion correction. There are 724 converged lattice seeds after dispersion correction, the horizontal dispersion distortion and vertical dispersion distortion after dispersion correction are shown in Fig. 2. The RMS value of horizontal dispersion distortion is decreased from 31 mm

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to 2.2 mm. The RMS value of vertical dispersion distortion is decreased from 42.7 mm to 5.9 mm. There are about 14 times and 7 times improvement for horizontal and vertical dispersion after dispersion correction.

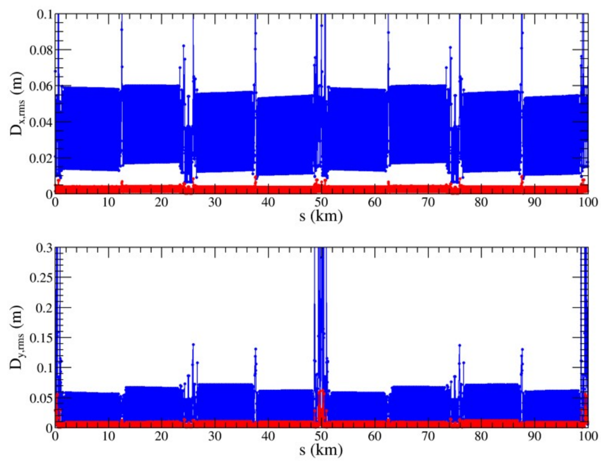

Figure 2: The RMS values of (upper) horizontal dispersion and (lower) vertical dispersion after dispersion correction, where the blue curves are the dispersion distortion before dispersion correction and the red curves are the dispersion distortion after dispersion correction.

We then performed the beta beating correction for the lattice seeds passing through the dispersion correction by using AT-based LOCO (Linear optics from closed orbits algorithm [8]). The dispersion distortion is also reduced by fitting the response matrix during the beta beating correction. Figure 3 shows the beta beating before and after the correction. There are 724 converged lattices seeds after the beta beating correction. The RMS value of horizontal beta beating is decreased from 37.7% to 11.2% (factor of 3 improvement). The RMS value of vertical beta beating is decreased from 11.7% to 5.1% (factor of 2 improvements).

In order to minimize the emittance due to coupling, the skew coils on sextupoles and some independent skew quadrupoles are used to minimize the coupling. The trim coils of the sextupoles which can provide a skew-quadrupole field are used to do the emittance tuning, as shown in Fig. 4. The emittance is calculated to be $\epsilon_x = 1.2131 \pm 0.0040$ nm and $\epsilon_y = 0.0777 \pm 0.0023$ pm. Thus, the emittance ratio is $\epsilon_y/\epsilon_x = (0.0064 \pm 0.0002)\%$, which satisfies our design requirement.

We track the DA over 145 turns corresponding to one damping time for above converged lattice seeds with errors. Figure 5 shows the DA results of all selected lattice seeds, the statistical results are also shown in Fig. 5. The DA of the lattice with errors is calculated to be $9\sigma_x \times 20\sigma_y \times 0.014$. The DA requirement with on-axis injection is $8\sigma_x \times 15\sigma_y \times 0.0135$, so the DA after error correction satisfies the requirement of on-axis injection.

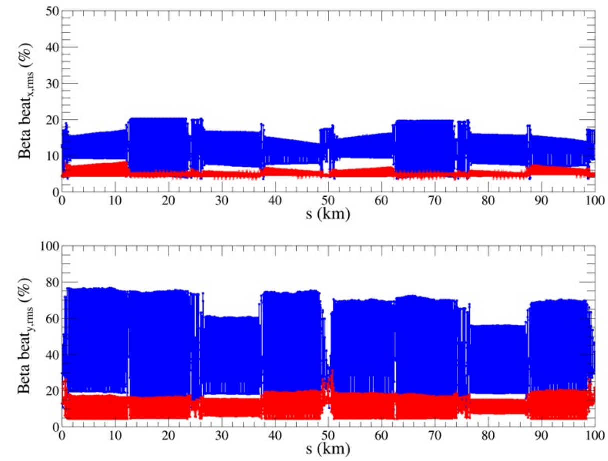

Figure 3: The RMS values of (upper) horizontal relative beta beating and (lower) vertical beta beating after beta beating correction, where the blue curves are the beta beating distribution before correction and the red curves are the beta beating distribution after correction.

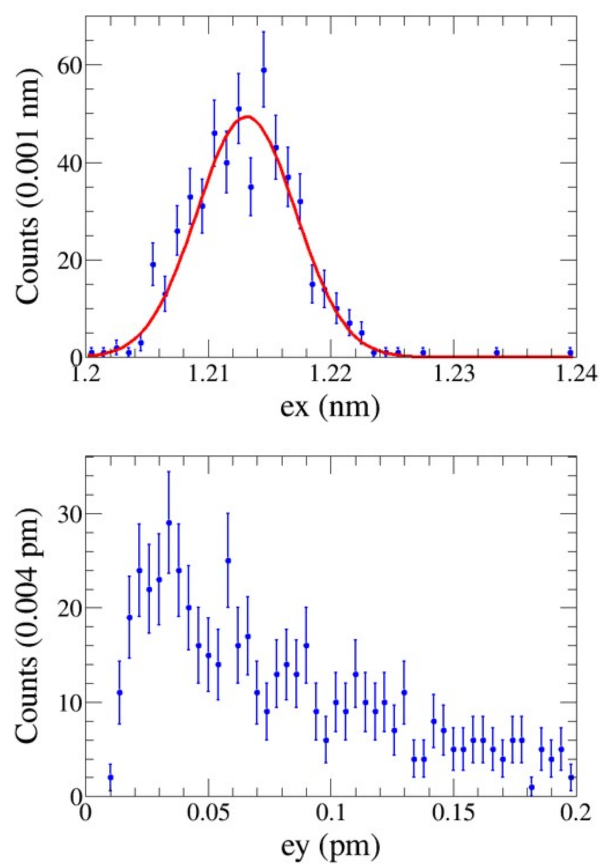

Figure 4: The RMS values of (upper) horizontal emittance and (lower) vertical emittance after coupling correction, where the red curve is the fit to the horizontal emittance distribution by using a Gaussian function.

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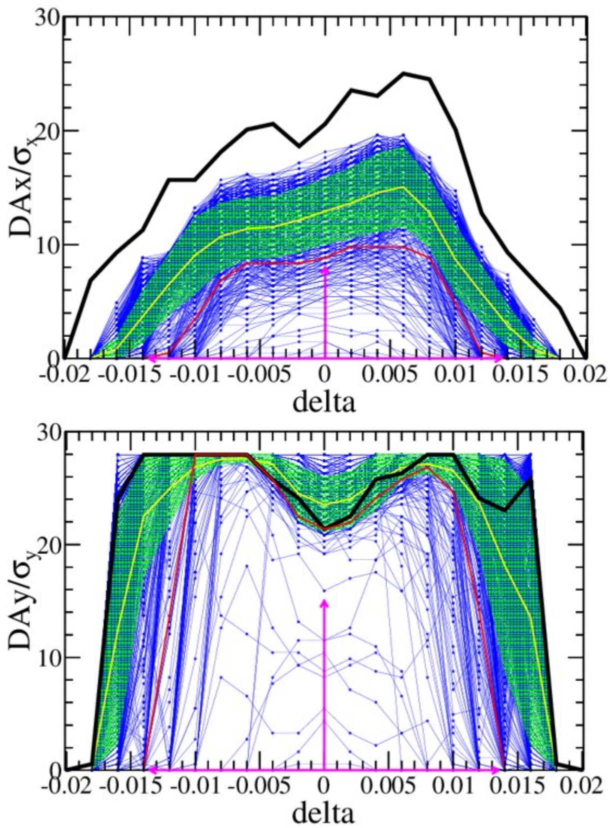

Figure 5: The tracking (upper) horizontal DA and (lower) vertical DA, where the black curves are the DA result with bare lattice, The blue curves are the DA results of all lattice seeds, the yellow curves and green bands are the statistical mean DA and the corresponding statistical error bands, respectively. The pink curves are the lower limit of DA with 90% confidence level.

SUMMARY

In this paper, we perform an error correction for the CEPC CDR lattice with magnet imperfections which includes 100 µm for all magnet misalignment, 100 µrad for all magnet tilt, 0.01% for all dipole magnet field error and 0.02% for all arc quadrupole magnet. The passing rate is evaluated to be 72.4%. The tracking DA is evaluated to be $9\sigma_x \times 20\sigma_y \times 0.014$, which satisfies the on-axis DA design requirement.

REFERENCES

[1] The CEPC Study Group, "CEPC Conceptual Design Report Volume I-Accelerator", CEPC, China, Rep. IHEP-CEPC-DR-2018-01, Sep. 2018.

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

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

[4] A. Terebilo, "Accelerator toolbox for MATLAB", SLAC, Stanford, CA, United States, Rep. SLAC-PUB-8732, May 2001.

[5] Bin Wang, "Imperfection and correction for CEPC, in The IAS program on high energy physics", presented at The IAS Program on High Energy Physics (HEP 2021), Jan. 2021.

[6] W. H. Press, *Numerical recipes 3rd edition: The art of scientific computing*, Cambridge, England: Cambridge University Press, 2007.

[7] R. Assmann *et al.*, "Emittance optimization with dispersion free steering at LEP", *Phys. Rev. ST Accel. Beams*, vol. 3, p. 121001, Dec. 2000. doi:10.1103/PhysRevSTAB.3.121001

[8] J. Safranek, "Experimental determination of storage ring optics using orbit response measurements", *Nucl. Instrum. Meth. A*, vol. 388, pp. 27-36, 1997. doi:10.1016/S0168-9002(97)00309-4