LATTICE AND ITS RELATED BEAM DYNAMICS ISSUES IN THE CEPC STORAGE RING*

H. Geng[#], G. Xu, Y. Zhang, Q. Qin, S. Bai, Y. Wang, D. Wang, Y. Peng, T. Yue, Z. Duan
Institute of High Energy Physics, Beijing, China

Abstract

CEPC was proposed as an electron and positron collider ring with a circumference of 50-100km to study the Higgs boson. Since the proposal was made, the lattice design for CEPC has been carried out and a preliminary conceptual design report has been written at the end of 2014. In this paper, we will describe the philosophy and results of our lattice design. The procedure of dynamic aperture optimization will be shown. A specific issue for CEPC, the pretzel orbit, which has been found distorting the linear lattice for a considerable amount, will be examined. The ways that we are trying to correct the pretzel orbit effect and the results will be shown.

INTRODUCTION

On 4th July, CERN announced that both the ATLAS and CMS experiments had discovered a new Higgs-like boson[1-3]. Since then, many proposals had been made to build a new collider to study this new particle in detail. The linear and circular electron and positron are considered to be the most feasible one. At the end of the year 2012, the candidates of a Higgs factory, their pros and cons were compared in detail at the ICFA workshop[4,5]. It was also at this workshop, the concept of CEPC and SPPC was raised[6].

CEPC (Circular Electron and Positron Collider) was proposed as an electron and positron collider ring with a circumference of 50-100km to study the Higgs boson. The lattice design for CEPC has been carried out since the end of 2013. In about one year time, a preliminary conceptual design report has been written at the end of 2014. In this paper, we will describe the philosophy and results of our lattice design. A specific issue for CEPC, the pretzel orbit, which has been found distorting the linear lattice for a considerable amount, will be examined. The ways that we are trying to correct the pretzel orbit effect and the result will be shown. We will also discuss the saw tooth effect on the linear lattice and dynamic aperture of the ring.

LINEAR LATTICE

The layout of the ring is shown in Fig. 1. The circumference of the ring is 54km with 8 arcs and 8 straight sections. There are four IPs in the ring, IP1 and IP3 will be used for CEPC, while IP2 and IP4 will be used for SPPC. The RF sections are distributed in each

straight section. At each straight section, the RF cavities will be symmetrically placed at the two ends of the section.
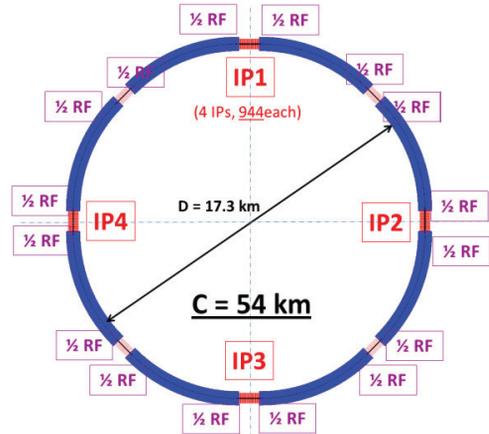

Figure 1: Layout of the CEPC storage ring.

The lattice for CEPC ring has been chosen to use the standard FODO cells with 60 degrees phase advances in both transverse planes. The FODO cell structure is chosen to have a maximum filling factor. The 60 degrees phase advance is chosen to have a relatively large beam emittance, so that a relatively longer beamstrahlung beam lifetime.

A standard FODO cell with 60 degrees phase advance is shown in Fig.2. The length of each bend is 19.6m, the length of each quadrupole is 2.0m. There is one sextupole, with a length of 0.4 m, next to each quadrupole for chromatic corrections. The distance between the sectupole and the adjacent magnet is 0.3 m, while the distance between each quadrupole and the adjacent bending magnet is 1.0 m. The total length of each cell is 47.2 m.
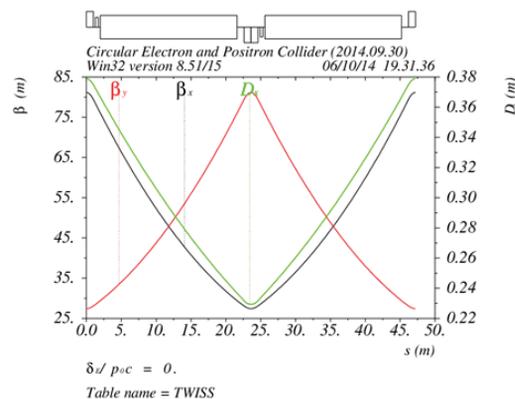

Figure 2: Beta functions and dispersion function of a standard FODO cell with 60/60 degrees phase advance in CEPC ring.

The dispersion suppressors are formed by pulling out the bending magnets in the second last FODO cell on each side of every arc section in CEPC ring. The beta functions and dispersion function of one dispersion suppressor is shown in Fig. 3.
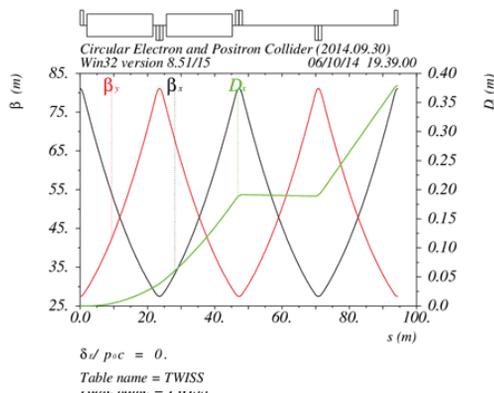

Figure 3: The beta functions and dispersion function of a dispersion suppressor in CEPC ring.

All the straight sections have the same length, which is 944m or 20 standard FODO cells. The first four FODO cells at each end of every straight sections are used for matching and working point adjustment.

PRETZEL ORBIT

In order to allow both electron and positron travel in the same beam pipe, the two beams have to be properly separated at the parasitic crossing points. A so called pretzel orbit is the normal way to separate the two beams. For CEPC, there are 50 bunches for each beam , thus there are 100 crossing or collision points. The two beams have to be separated at all the crossing points except for IP1 and IP3.

We use one pair of electrostatic separators to separate the beams at each arc section. One separator will be placed $\pi/2$ phase advance before the first crossing point in the arc section, the other separator will be placed $\pi/2$ phase advance after the last crossing point in this arc section. With these 8 pairs of separators, all the crossing points in the arc section can be well separated. At IP2 and IP4, we need extra pairs of electrostatic separators to avoid beam collision. Two more pairs of separators will be placed $\pi/2$ phase advance before and after IP2 and IP4 to separate the beams in these two collision points. In total, ten pairs of electrostatic separators will be used in CEPC ring to avoid all the parasitic crossing points. The layout of the electrostatic separators and its orbit is shown in Fig. 4.

Beams can be separated in either horizontal or vertical plane. With horizontal separation, the separation distance is bigger as the beam size is bigger than vertical. With vertical separation, the separation distance is smaller, but it can easily induce big coupling between horizontal and vertical planes. As the coupling factor in CEPC is strictly limited to a small value (0.3%) to have a big luminosity, thus we choose horizontal separation scheme for CEPC.

The maximum separation distance between the two beams has a big effect on the beam lifetime. To allow for a reasonable beam lifetime, a maximum separation distance of $5\sigma_x$ is considered for CEPC. The resulted pretzel orbit in one arc section is shown in Fig. 5.
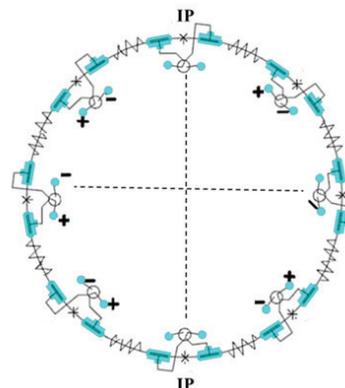

Figure 4: The beta functions and dispersion function of a short straight section in CEPC ring.
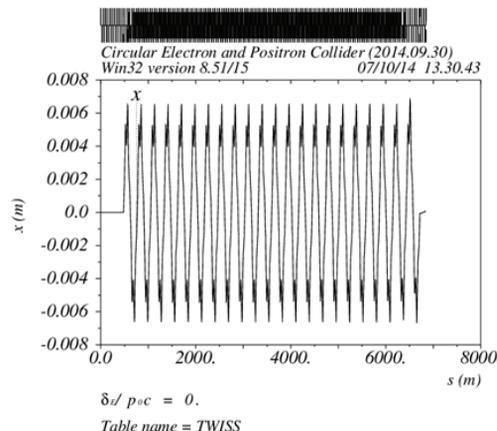

Figure 5: Pretzel orbit of electron beam in one arc section of CEPC ring.

LATTICE DISTORTIONS DUE TO PRETZEL ORBIT

When the beam is off centre, it sees additional fields in quadrupoles and sextupoles. We can estimate the field intensity assuming the maximum off center pretzel orbit is $5\sigma_x$ or 5 mm, the results are shown in Table 1.

Table 1: Additional Fields in Magnets seen by Beams with Maximum Off Center Pretzel Orbit and compared to the Ideal Case

Field\Magnet	Dipole(T)	Quadrupole	Sextupole
Original field	0.066	0.022	0.38
Additional Dipole field (T)	-	0.05	0.0019
Additional Quadrupole	-	-	0.0019

We can see from Table 1 that the additional dipole field seen by the beam is almost as strong as the bending magnet in the ring. The additional quadrupole field is one order smaller than the one in the main ring. So we could expect the distortion on dispersion function is bigger than on the betatron functions. The results of the simulation results from mad when pretzel orbit is shown in Fig.6. It agrees with our expectation.
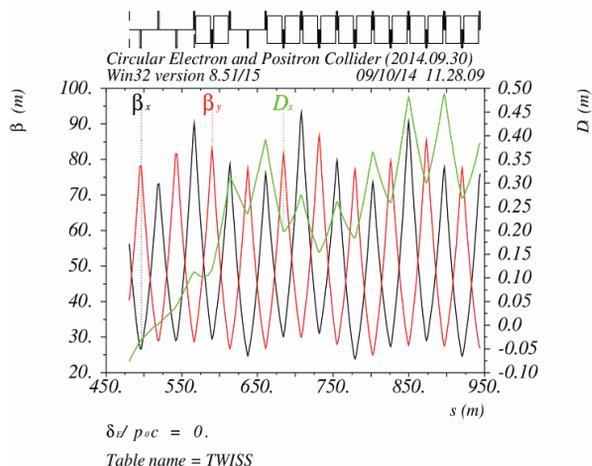

Figure 6: Distortion on lattice from the additional fields seen by the off center pretzel orbit beam.

CORRECTION OF LATTICE DISTORTIONS

To correct the distortion on lattice and restore the periodicity, we use 6 FODO cells to form a new period, and adjust the quadrupole strength to find the solution with the pretzel orbit. The new period in the arc section is shown in Fig. 7.
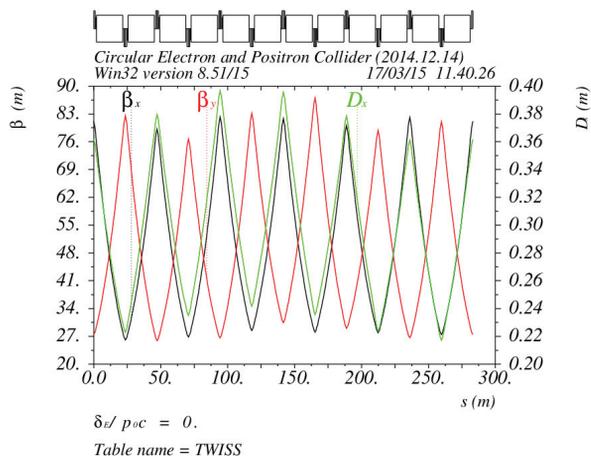

Figure 7: New period after the correction of off center pretzel orbit distortion on lattice.

After restoring the periodicity, the achromatic condition and the phase advance condition between the electrostatic separators can be adjusted accordingly. The price of correction of the lattice distortion from pretzel orbit is that, there will be more freely adjustable quadrupoles needed. We will make the quadrupoles freely adjustable by adding shunts on the quadrupoles. This method has been proven to be handy and cheap.

The betatron and dispersion function after correction of pretzel orbit effect is shown in Fig. 8.
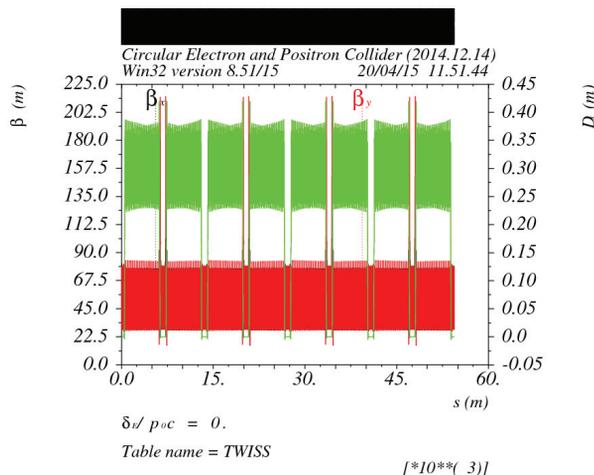

Figure 8: Betatron and dispersion functions after correction of pretzel orbit effect.

SUMMARY

We have shown the lattice design results of CEPC. The effect of pretzel orbit on the optics has been investaged, the correction scheme and correction results of the pretzel orbit effect have also been shown. We see that the effect on the optics from the pretzel orbit could be corrected. The partition number, emittance and the dynamic aperture etc. have not been studied yet, and will be investigated soon.

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