STATUS OF CEPC LATTICE DESIGN

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Abstract

IHEP has proposed a circular electron and positron collider (CEPC) to study the properties of the Higgs boson. In the baseline design, the circumference of CEPC will be taken as 50km, and a sing ring scheme will be adopted, e.g., the electron and positron beam will share the beam pipes. This paper will show the latest design of the CEPC lattice, including the design of the main ring lattice and the pretzel scheme. Some critical issues that we encountered when designing the lattice will also be discussed.

INTRODUCTION

After the discovery of Higgs-like boson at CERN [1-3], many proposals have been raised to build a Higgs factory to explicitly study the properties of the particle. One of the most attractive proposals is the Circular Electron and Positron Collider (CEPC) project in China [4,5].

CEPC is a ring with a circumference of 50-70 km, which will be used as electron and positron collider at phase-I and will be upgraded to a Super proton-proton Collider (SppC) at phase-II. The designed beam energy for CEPC is 120 GeV, the main constraints in the design is the synchrotron radiation power, which should be limited to 50 MW, the target luminosity is ~$10^{34}cm^{-2}s^{-1}$.

As beam energy is high, CEPC favors more arcs which enables RF cavities to compensate the energy loss in the straight section, thus can reduce energy variation from synchrotron radiation. SppC needs long straight sections for collimators etc. To compromise between CEPC and SppC, the ring is decided to have 8 arcs and 8 straight sections, RF cavities will be distributed in each straight section.

In this paper, we will show the latest design of the CEPC lattice, including the design of the main ring lattice and the pretzel scheme. Some critical issues that we encountered when designing the lattice will also be discussed.

LATTICE DESIGN OF THE RING

The circumference of the ring is 54km with 8 arcs and 8 straight sections. The layout of the ring is shown in Fig. 1. 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 the IP section, the RF cavities will be symmetrically placed at the two ends of the section, at the other straight sections, the RF cavities can be located together at the middle of each straight section.

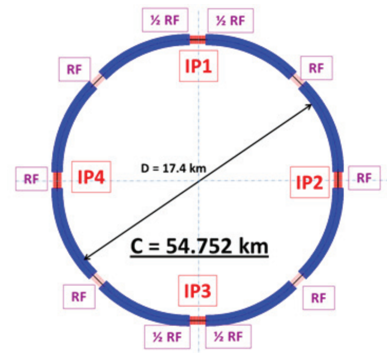

Figure 1: Layout of the CEPC ring.

FODO Cells

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, than the 90 degrees phase advance lattice cells.

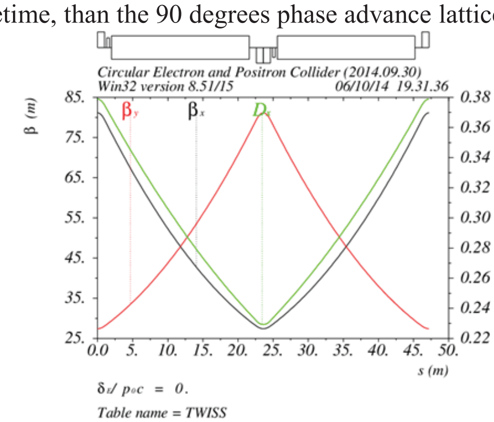

Figure 2: Beta functions and dispersion function of a standard FODO cell with 60/60 degrees phase advance in CEPC ring.

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.

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ISBN 978-3-95450-172-4

Dispersion Suppressors

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.

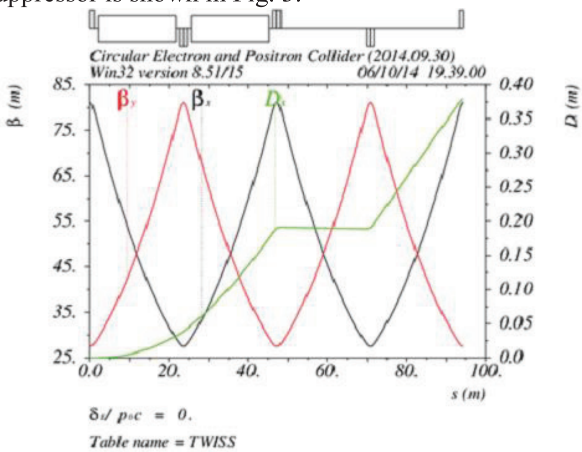

Figure 3: The beta functions and dispersion function of a dispersion suppressor in CEPC ring.

Straight Sections

The straight sections have two different lengths, the four straight sections which have the IPs have a length of 1132.8 m, and the other straight sections have a length of 849.6 m. The first four FODO cells at each end of every straight sections are used for matching and working point adjustment. The beta functions and dispersion function of a short straight section in CEPC ring is shown in Fig. 4.

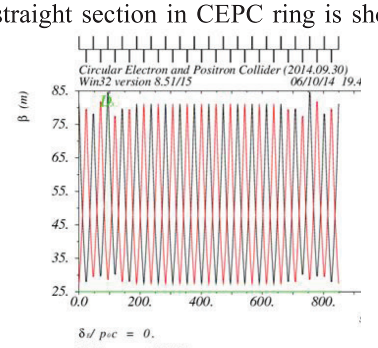

Figure 4: The beta functions and dispersion function of a short straight section in CEPC ring.

Dynamic Aperture

We use the code SAD to track the dynamic aperture of the ring. Three transverse damping times were tracked to characterize the dynamic aperture size. Momentum spread from +2% to -2% were tracked. The tracking result is shown in Fig. 5. The dynamic aperture shown in Fig. 5 has been normalized to transverse beam sizes. No coupling and full coupling has been assumed to calculate the horizontal and vertical beam sizes. From Fig. 5 we can that the dynamic aperture is ~60 times beam sizes in both horizontal and vertical planes.

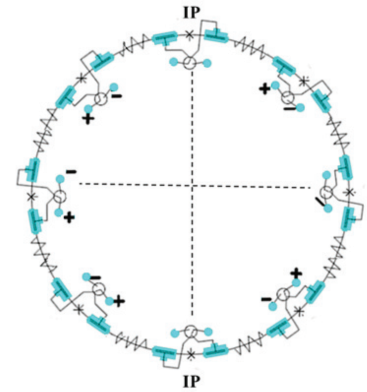

Figure 5: The beta functions and dispersion function of a short straight section in CEPC ring.

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 inFig.6.

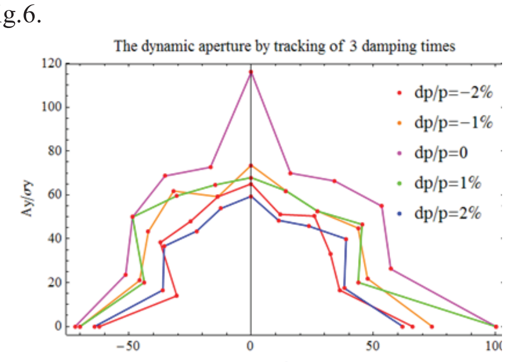

Figure 6: The beta functions and dispersion function of a short straight section in CEPC ring.

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

ISBN 978-3-95450-172-4

it can easily induce big coupling between horizontal and vertical planes. As the coupling factor in CEPC is strictly limited to a small value 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. 7.

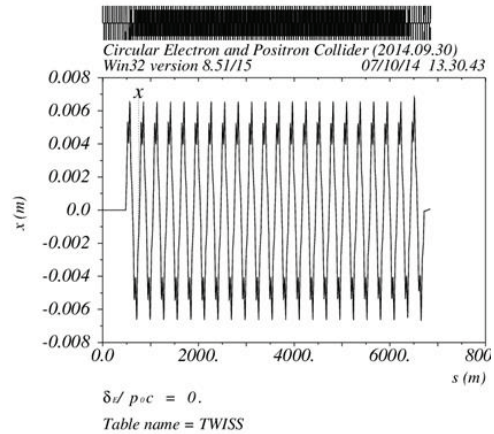

Figure 7: Pretzel orbit of electron beam in one arc section of CEPC ring.

Saw Tooth Orbit

The beam energy of CEPC is very high, 120 GeV. At this beam energy, the synchrotron radiation effect is very strong. For CEPC, the synchrotron radiation loss per turn is 3 GeV for both beams, which means the energy difference at the entrance and exit of one arc section is

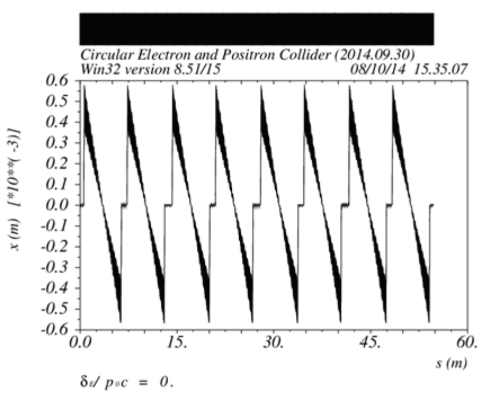

Figure 8: Saw tooth orbit in CEPC ring.

~0.3%, and at the following straight section, the energy loss will be compensated by RF cavities, and then the beam will loss energy from synchrotron radiation when entering the next arc section. Looking at the whole ring, the beam energy has a saw tooth structure. This energy saw tooth from the synchrotron radiation effect will in turn result in a beam orbit saw tooth because of the change of the beam centre energy.

In CEPC, the saw tooth orbit is calculated with MAD and is shown in Fig. 8.

We can see from Fig. 8 that the maximum sawtooth orbit is ~0.6 mm, which is one order smaller than the maximum pretzel orbit.

DISCUSSIONS

When designing the CEPC lattice, we found two issues which is very critical. First, the pretzel orbit has a big distortion on the original beta functions and dispersion functions, which in turn will result in change of tune and beam emittance. The distortion comes from the extra field seen by the beam when it is not on axis. The beam sees a dispole field in quadrupoles, the maximum strength of the dipole field is only slightly weaker than the field in the main bending magnets. At sextupoles, the beam sees both dipole and quadrupole field, but the strength is one order smaller than the nominal dipole and quadrupole field in the ring. The total effect from the off axis field from the quadrupole and sextupole distorts the periodicity of beta functions and dispersion functions, which have a significant effect on dynamic aperture reduction.

Another effect from the pretzel orbit is it enables the coupling of sextupole strength and the working point. This makes the chromatic correction and the working point adjustment inseparable.

The saw tooth orbit is a common behaviour at all rings at such a high energy. It has been proved the feasibility to correct the saw tooth orbit at double rings [6]. But, for CEPC, it is a single ring machine, both electron and positron beams share the same vacuum pipe, the correction method used in double rings could not be applied here. It seems that this orbit is uncorrectable at CEPC, if it is tolerable or not shall be clarified later.

SUMMARY

We have introduced the status of CEPC lattice design. The detailed lattice design principle and results have been showed. As the CEPC ring is a single ring machine, we also described our pretzel orbit design method and results. The critical issues such as distortion effect on beta functions and dispersion from pretzel orbit and the saw tooth effect has also been introduced.

The main topics in CEPC lattice design have been investigated, but the lattice distortion from pretzel orbit and the correction scheme of saw tooth orbit has not been fully solved. More work need to be done for CEPC lattice design.

ACKNOWLEDEMENT

The authors would like to thank th Yunhai Cai, Richard Talman, Dave Rice, Yoshihiro Funakoshi, Dmitry Shatilov , Kazuhito Ohmi , Yuhong Zhang, and those who are not mentioned here, for their help and useful discussions.

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ISBN 978-3-95450-172-4