DYNAMIC APERTURE OPTIMIZATION AT CEPC WITH PRETZEL ORBIT

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Abstract

A preliminary design of the CEPC ring with pretzel orbit will be presented. The ring and pretzel orbit will be designed for 50 bunches, as required in the CEPC Pre-CDR. The linear optics, as well as the non-linear chromaticity compensation with the presence of pretzel orbit will be described. Different phase advance difference between the long and short straight sections, have been tried to optimize the dynamic aperture, the results will be shown in this paper.

INTRODUCTION

After the discovery of Higgs-like boson at CERN [1,2], 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 [3].

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 on the order of 10^{34} $cm^{-2}s^{-1}$.

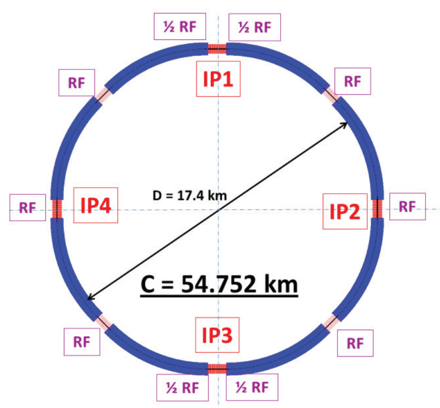

Figure 1: A schematic drawing of CEPC ring.

As beam energy is high, CEPC favors a lattice with more arcs which will enable 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. The layout of CEPC can be seen in Fig. 1.

The lattice design for CEPC has been carried out and a preliminary conceptual design report has been written at the end of 2014 [4]. Many work has been done since the publication of the Pre-CDR. In this paper, we will describe the principles of pretzel scheme design, which is one of the most important issues in CEPC lattice design. Then, we will show the modification of the lattice based on the lattice design shown in the Pre-CDR. The latest pretzel orbit design result will also be shown. Different phase advance difference between the long and short straight sections, have been tried to optimize the dynamic aperture, the results will be shown in this paper.

PRINCIPLES OF PRETZEL SCHEME

In single ring collider, the pretzel orbit is used to avoid the beam collision at positions except the IP.

For ideal pretzel orbit, the following relationship should be fulfilled: $\phi = N \cdot 2\pi$, where ϕ is the phase advance between the adjacent collision points, N is an integer. This relation guarantees that if the beam is properly separated at the first parasitic collision point, then it can be automatically properly separated at other parasitic collision points.

For our lattice, it is comprised of 60/60 degree FODO cells, every 6 cells have a phase advance of 2π, so the distance between the adjacent parasitic points L_{pc} can be written as: $L_{pc} = N \cdot 6 \cdot 47.2 = N \cdot 283.2$ m. For 50 bunches, there are 100 collision points in total, thus the ring circumference C must be $C = 100 \cdot L_{pc} = 28320 \cdot N$ m.

As the circumference of the CEPC ring is about 50 km, the integer number N has to be 2, which means the ring circumference has to be 56640 m and there will be one collision point every 4π phase advance.

MODIFICATION OF THE MAIN RING LATTICE

In our Pre-CDR, the ring circumference is 54752 m [4]. To make the pretzel scheme works for 50 bunches as required by the Pre-CDR, two options (assuming the phase advance per cell keeps constant) can be done to modify the ring lattice. First, the cell length can be changed. This will result in the change of the circumference and emittance etc. Second, the number of cells, or the length of the straight section can be changed. This will only change the circumference while keeping the emittance unchanged.

In the following, we take the easy way, i.e., we change the circumference of the ring to make the lattice works for

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the pretzel orbit of 50 bunches. We keep the arc length and short straight section length constant, while mke the long straight section length increased from 1132.8 m to 1604.8 m, or from 20 FODO cells to 34 FODO cells. After making this change, the circumference of the ring becomes 56640 m, which is suitable for the pretzel orbit of 50 bunches as shown in Section 2.

PRETZEL SCHEME DESIGN

To avoid big coupling between horizontal and vertical plane, we use horizontal separation scheme to generate the pretzel orbit here. Also, in order to avoid beam instability and High Order Mode in the RF cavities, we require that there is no off-center orbit in any RF sections. Thus, we use one pair of electrostatic separators for each arc.

For each pair, the position of the first electrostatic separator is chosen such that it is $\pi/2$ phase advance before the first parasitic crossing point, and the position of the second electrostatic separator is chosen such that it is $\pi/2$ phase advance after the last parasitic crossing point in this arc. A schematic drawing is shown in Fig.2.

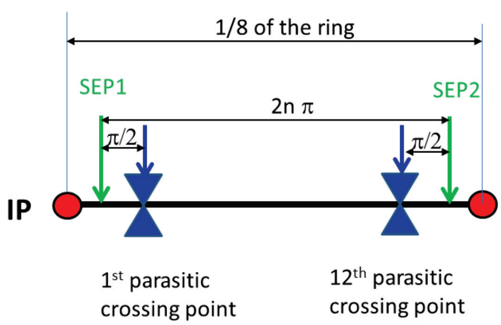

Figure 2: A schematic drawing of the positions of the electrostatic separators for 1/8th of the ring. SEP1 and SEP2 in the drawing means the first and second electrostatic separators.

The separation distance between the two beams is about $10\sigma_x$, which is a empirical number, to allow for a reasonable beam lifetime. The final orbit of the beam is shown in Fig.3.

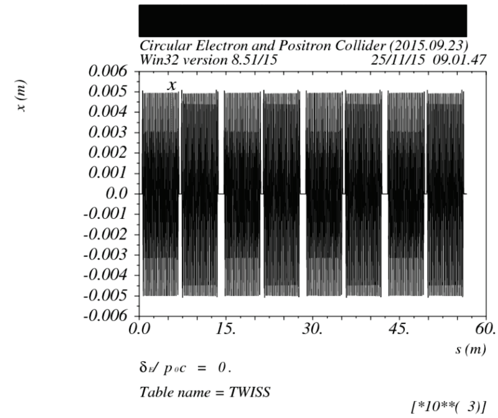

Figure 3: The pretzel orbit in the ring for one beam. The separation distance between the two beams is about $10\sigma_x$ in the horizontal plane.

DYNAMIC APERTURE OPTIMIZATION WITH PRETZEL ORBIT

When there is an off-center orbit, the beam will experience extra fields in magnets. To be specific, in quadrupole magnets, the beam will see an extra dipole filed when it is off-centered. The dipole strength can be estimated with a simple formula: $\Delta B = K_1 \cdot B\rho \cdot \Delta x$, where K_1 is the normalized quadrupole strength, $B\rho$ is the magnetic rigidity of the beam, and Δx is the orbit of the beam. With a simple calculation, we can see that the extra dipole field seen by the off-center beam has a strength that is comparable to the strength of the main bending magnets.

In sextupole magnets, the beam will experience extra dipole and quadrupole fields. The field strength can be estimated similarly. These extra fields (dipole field in quadrupole, and both dipole and qudrupole fields in sextupole) will break the periodicity and achromatic condition of the lattice, and this effect has to be corrected.

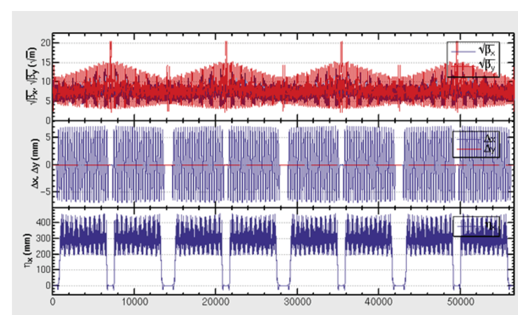

Figure 4: The beta function, dispersion function and orbit distribution along the ring after the correction of the pretzel orbit distortion on the lattice.

The distortion of pretzel orbit effects on beta functions and dispersion function has to be corrected to have a reasonable dynamic aperture. Also, since the sextupoles are now coupled with quadrupoles, the chromoticity correction and the tune are coupled together, so linear lattice and nonlinear chromaticity has to be corrected at the same time. We try to find a new lattice period by taking 12 FODO cells, with symmetrically placed magnets, and require the phase advance to be 4π and the chromaticity to be zero at the the same time. There is no detailed phase advance requirement in each FODO cell in this case. A new lattice can be found accordingly, the new lattice and the chromaticity correction result is shown in Fig. 4 and Fig. 5.

The dynamic aperture of the ring after correction of the pretzel orbit distortion on the lattice has been checked before the insertion of the Final Focus System (FFS). The result is shown in Fig. 6.The working point used here is (.79,.15) in horizontal and vertical planes. The plot shows that the dynamic aperture is $\sim 10\sigma_x \times 110\sigma_y$ in horizontal and

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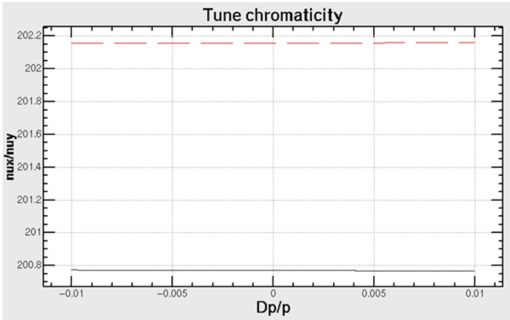

Figure 5: The tune v.s. momentum spread after the global correction of the pretzel orbit distortion on the lattice.

vertical planes. The tracking has been done with 240 turns, which corresponds to 3 transverse damping times.

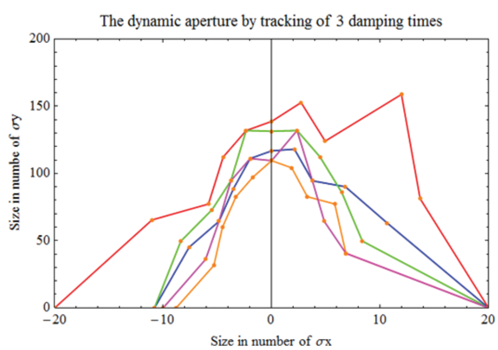

Figure 6: The dynamic aperture of the ring after correction of the pretzel orbit distortion on the lattice has been and before the insertion of the Final Focus System (FFS), the working point used here is (.79,.15) in horizontal and vertical planes.

We can that even before the insertion of FFS, the dynamic aperture of the lattice with pretzel scheme is not big enough. So we try to look at and optimize the dynamic aperture of the ring even before turn the pretzel orbit on. The latest result is shown in the following section.

DIFFERENT COMBINATIONS OF LENGTHS OF STRAIGHT SECTIONS IN THE MAIN RING

During the study of the main ring lattice, we found that the lengths of the straight sections have a big effect on dynamic aperture. So the most straight forward way is to keep the ring circumference and change the lengths of the short and long straight sections simultaneously, meanwhile, the arc section is kept constant. We start with an equal length of all straight

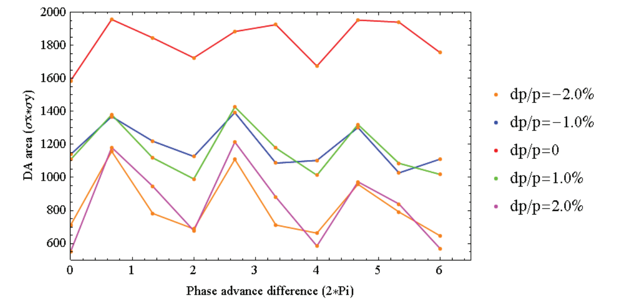

Figure 7: The dynamic aperture of the ring with different combinations of straight section lengths. The horizontal ordinate is the phase advance difference of the long and short straight sections. The vertical ordinate is the integrated dynamic aperture area in the transverse planes.

sections, and increase the length of the long straight section by 2*FODO cells each time to keep the symmetric layout of the straight section, and compare the dynamic aperture of all possible combinations. The result is shown in Fig 7.

In Fig 7, the dynamic aperture has been integrated as the area in the transverse planes. And the horizontal ordinate is the phase advance difference of the long and short straight sections. We can see that the dynamic aperture has a maximum value at certain phase advance difference. And a periodic variation of the dynamic aperture is clearly seen. More detailed phase advance scan is being carried out.

SUMMARY

In this paper, we have described how the pretzel orbit of 50 bunches has been designed. The distortion of lattice due to pretzel orbit has also been explained. We have also shown how the pretzel orbit distortion effect on the lattice can be compensated and the chromaticity been corrected. Different combinations of the straight sections has been tried to optimize the dynamic aperture, and a periodic variation of dynamic aperture is found. The work to achieve a reasonable dynamic aperture result is still ongoing.

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