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ORBIT CORRECTION IN CEPC*

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Abstract

With the discovery of the higgs boson at around 125GeV, a circular higgs factory design with high luminosity (L ~ 10^{34} $cm^{-2}s^{-1}$) is becoming more popular in the accelerator world. The CEPC project in China is one of them. To reduce the cost, pretzel scheme was considered in CEPC orbit design. The presence of every kind of errors and misalignments will destroy the pretzel orbit. In this paper, we correct the distorted pretzel orbit in the CEPC main ring using the dipole correctors and beam position monitors. The pretzel orbit was recovered and the maximum corrector strengths are got.

INTRODUCTION

With the discovery of a Higgs boson at about 125 GeV, the world high-energy physics community is investigating the feasibility of a Higgs Factory, a complement to the LHC for studying the Higgs [1]. There are two ideas now in the world to design a future higgs factory, a linear 125 × 125 GeV e^+e^- collider and a circular 125 GeV e^+e^- collider. From the accelerator point of view, the circular 125 GeV e^+e^- collider, due to its low budget and mature technology, is becoming the preferred choice to the accelerator group in China. To reduce the cost, only one tunnel may be digged. In this case, e+ and e- bunches will be travelled in the same tunnel and separated by several electrostatic sperators. This is so called the “pretzel” scheme [2] which has already been demonstrated in LEP. The position of the pretzel closed orbit in CEPC main ring is affected by the field errors and the alignment errors in the magnets. The orbit errors are mainly due to displaced quadrupoles. Deviations of the beam orbit from the ideal positions can be detected by the beam position monitors (BPM) located near each quadrupole. The closed orbit errors as measured by these monitors can be corrected by a series of dipole correctors near each quadrupole.

In this paper, the field errors and alignment errors of the magnets are first specified. The distorted closed orbit is then calculated and corrected by the approximately distributed dipole correctors. The maximum strengths of correctors are got for manufacture.

THEORY

The orbit correction vector $\overrightarrow{\Delta_c}$ at all the monitors is related to the beam bump $\vec{\theta}$ at all the correctors by [3]:

$$\overrightarrow{\Delta_c} = T\vec{\theta} \qquad (1)$$

Where T is a m x n matrix with m the number of monitors and n the number of correctors; the elements of T are

$$T_{ij} = \frac{\sqrt{\beta_i \beta_j}}{2\sin \pi\nu} \cos \nu(\pm\pi + \phi_i - \phi_j) \qquad (2)$$

Where ν is the betatron wave number, β is the betatron function; ν φ is the betatron phase. The plus sign in front of π is used for the case of $\varphi_i < \varphi_j$ and the minus sign for $\varphi_i > \varphi_j$. The orbit deviation is given by:

$$\vec{\Delta} = \overrightarrow{\Delta_0} + \overrightarrow{\Delta_c} \qquad (3)$$

Where $\overrightarrow{\Delta_0}$ is the orbit deviation measured before correction. The sum of the squares of the orbit deviation

$$S = \sum_{i=1}^{n} (\Delta_{0i} + \Delta_{ci})^2 \qquad (4)$$

We wish to find the vector $\overrightarrow{\theta_n}$ which minimizes the value of S, i.e., $\partial S / \partial \theta_n = 0$ for n=l, 2, ... N.

IMPERFECTIONS IN THE MAGNETS

The CEPC machine imperfections mainly consist of the field errors and misalignment errors of every kinds of magnets, bending magnets, quadrupoles and sextupoles. The largest contributions to the orbit distortions come from the misalignment of the quadrupoles. We choose the imperfections setting similar to LEP [4]:

Table 1: LEP Magnet Error Parameters

	Dipole	Quadrupole
<y> mm	0.2	0.1
<x> mm	0.3	0.1
<tilt> mrad	0.1	0.1
<△B/B> rms values	5e-4	
<△K/K> rms values		5e-4

THE DISTORTED PRETZEL ORBIT WITH ALL ERRORS

With all the field and misalignment errors of the magnets given in the above table 1, which are distributed in Gaussian and cut at three sigma, the horizontal and vertical orbit deviation at all the BPMs before orbit correction, are shown in figure 1 and figure 2:

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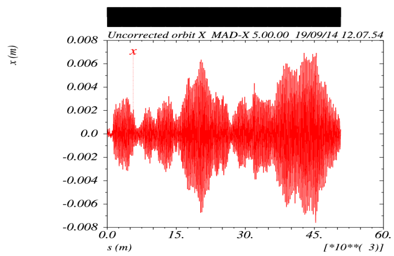

Figure 1: Horizontal orbit deviation before correction.

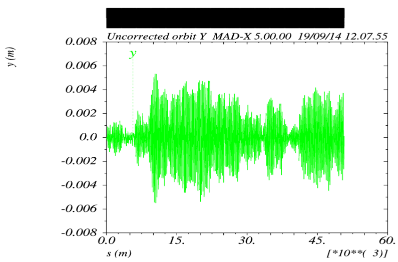

Figure 2: Vertical orbit deviation before correction.

Figure 1 and figure 2 show the horizontal and vertical orbit deviation before orbit correction respectively. The maximum horizontal and vertical orbit offset is about 8mm and 6mm.

ORBIT CORRECTION

Target Orbit

In the CEPC main ring, two pairs of electrostatic separators are put near each IP, and the beam separated at horizontal plane with orbit deviation is about $5\sigma_x \sim$ 3.5mm. The maximum bunch number is 96.

In an ideal lattice without any errors and misalignments, the orbit should be the pretzel orbit in horizontal and zero in vertical which is shown in fig. 3 and fig. 4.

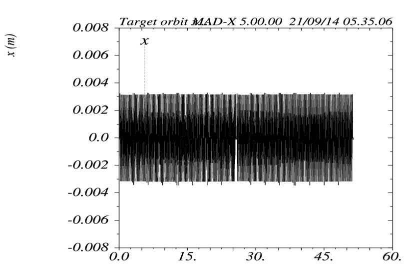

Figure 3: Target orbit in horizontal.

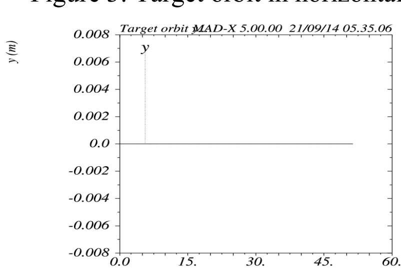

Figure 4: Target orbit in vertical.

To evaluate the effect of the orbit correction, the result after the orbit correction should be as much as similar to the result in figure 3 and 4.

Orbit Correction Result

Most of the many well-known correction methods are based on minimising the r.m.s orbit distortion. In this paper, we use the MICADO correction method. The MICADO method works as described in ref. [5]. It starts by examining all correctors and selects the one which yields the smallest residual r.m.s distortion. At every following iterate on MICADO selects only one new corrector, maintaining all correctors from previous iterations but recalculating their strengths. The number of iterations (i.e. number of correctors used) per correction can be set by the operator. The maximum strength of the correction coils is taken into account.

To correct the distorted orbit as shown in figure 1 and 2, we put a corrector and a BPM beside each quadrupole in the CEPC main ring. So the total number of the corrector or BPM is 2336 which is the same as the quadrupoles. Each of the corrector and BPM can execute the correction in both horizontal and vertical planes. The necessary correction of the orbit is obtained by adjusting the strengths of correcting dipoles, based on the information obtained in both planes from BPMs. The correction efficiency is restricted by the finite number of monitors and correctors, and by the input errors and misalignments.

After trying many times, we find that with 1800 correctors the results of the orbit correction is rather satisfactory. As shown in fig. 5 and fig. 6.

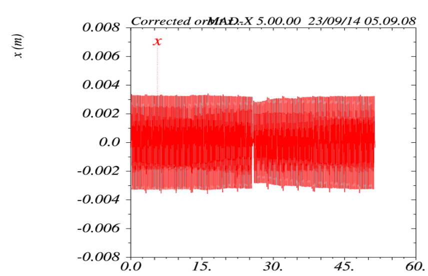

Figure 5: The horizontal orbit after orbit correction.

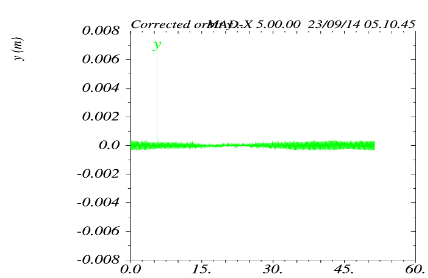

Figure 6: The vertical orbit after orbit correction.

Correctors and BPM Readings Statistic

The r.m.s of BPM readings in horizontal before orbit correction is about 2.02mm. And after orbit correction, this number reduced to 9.7um. For the vertical plane, this

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number is improved from 1.52mm to 6.2um. The statistic of r.m.s BPM readings after orbit correction is shown in fig. 7 and fig. 8.

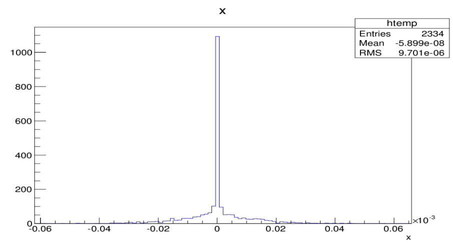

Figure 7: The horizontal r.m.s BPM readings after orbit correction.

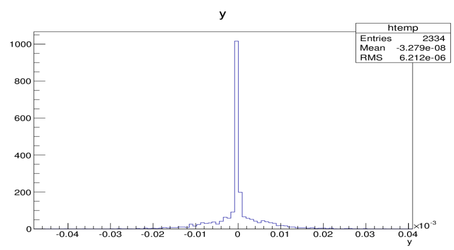

Figure 8: The vertical r.m.s BPM readings after orbit correction.

Among the 1800 correctors which are used in the orbit correction, the maximum strength for the horizontal is about 43urad. While the r.m.s of the horizontal corrector strengths is around 3.9 urad. In the vertical plane, the maximum strength is about 16 urad, and the r.m.s is 3.7 urad. The maximum strength of the correctors is at 10% scale of the bending magnets designed in the CEPC main ring, which is about 3mrad.

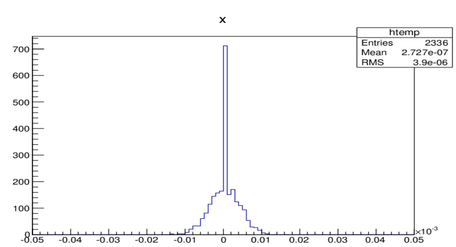

Figure 9: The horizontal correctors' statistic after orbit correction.

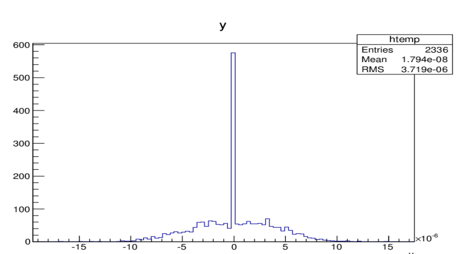

Figure 10: The vertical correctors' statistic after orbit correction.

CONCLUSION

The presence of every kind of field errors and misalignments in the magnets will destroy the pretzel orbit in the CEPC main ring. We start the orbit correction study by introducing the LEP scale tolerance. The optimal corrector magnet deflections calculated by a relatively quick linear approximation method. It was found that it is advantageous to have 1800 corrector magnets for the orbit correction. Average corrector magnet strengths rise with the level of magnet misalignments. The maximum corrector deflection angle found is about 43urad, which is at 10% scale of the bending magnet in the CEPC main ring. Increasing the number of correctors does not reduce the maximum deflection required.

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