MAGNET ERROR EFFECT ON DYNAMIC APERTURE 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 ($L \sim 10^{34}$ cm^{-2}s^{-1}) is becoming more popular in the accelerator world. The CEPC project in China is one of them. The performance of the machine can be influenced by the existence of every kind of inaccuracies of the magnets, such as misalignment errors and field errors, multipole errors etc on. In this paper, we reported the errors that used in the CEPC beam dynamic study, and the influence on dynamic aperture of the CEPC main ring when introducing these kinds of errors.

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. In order to achieve high luminosity ($L \sim 10^{34}$ cm^{-2}s^{-1}), the beam quality should be kept in the best level to reach the requirements. However, the manufacture of the magnets may be not perfect, thus many kinds of inaccuracies may exist in the magnet, such as the field errors and multipole errors etc. on. In addition, the installation of the magnets may also be not satisfied, in this case misalignment including the rotation errors in both the horizontal, vertical and longitudinal direction may destroy the beam orbit in the commissioning. These imperfections will degrade the beam quality and have influence on the machine performance.

In this paper, the errors that used in CEPC dynamic aperture study which is from LEP are first listed. And dynamic aperture due to the magnet strength errors and multipole errors are analysed and reported in both CEPC single ring and partial double ring.

IMPERFECTIONS IN THE MAGNETS

There are many kinds of inaccuracies of magnets, generally speaking because of two reasons. One is from the installation, which is generated from the alignment of the mangets (bending magnets, quadrupole magnets and sextupole magnets), so called the misalignment errors, including the misalignment in horizontal, vertical, and longitudinal directions and also the rotation errors in each dimension; the other is from the manufacture, which is generated from the manufacture of the magnets, such as the systematic magnets strengths errors which is not exactly the same as the designed one; the systematic field components in the lattice elements, and also the random field components errors in the lattice elements due to the differences between individuals; etc on. We choose the LEP errors in our error study of CEPC, below is the error list from LEP report [2]:

Table 1: LEP Magnet Error Parameters

	Dipole	Quadrupole	Sextupole
<y> mm	0.2	0.1	0.15
<x> mm	0.3	0.1	0.15
<tilt> mrad	0.1	0.1	0.5
B*L	5e-4	5e-4	4e-3
quadrupole(s)	8e-4		
sextupole(s)	2e-4	6e-4	
Octupole(s)	7e-5	5e-4	1.7e-3
Decapole(s)	1.3e-4	6.9e-4	3.4e-3
Dodecapole(s)	1.4e-4	1e-3	6.5e-3
18-pole			1.6e-2
Quadrupole(r)	2e-4		
Sextupole(r)	2.9e-4	1.2e-3	
Multipole(r)	2e-4	1e-3	2e-2

For the misalignment error, since we choose bending magnets, quadrupole magnets and sextupole magnets in both <x>, <y> and <tilt> errors which are shown in table 1; Magnet strengths errors of bending magnets, quadrupole magnets, and sextupole magnets are shown in the B*L line. These field errors are from the manufacture and it is random, so we generate in Gaussian distribution and cut in three sigmas, we deleted the ones beyond three sigmas; Multipole components are existed in every kind of magnets, e.g. bending magnets, quadrupole magnets, and sextupole magnets. These field components are systematic and intrinsic during the manufacture. They are shown in table suffixed with (s); Due to the differences between individuals, the field components in the lattice elements may have random errors, which are shown in quadrupole(r), sextupole(r), multipole(r).

MAGNET ERROR EFFECT ON DYNAMIC APERTURE IN CEPC SINGLE RING

The CEPC single ring with pretzel [3, 4] has a circumference of about 50km with more than two thousand quadrupoles, and several hundreds of bending magnets and sextupole magnets. The error effect in such a

large ring could be much more serious. We studied the error effect one by one seperately on the dynamic aperture in CEPC main ring, in order to find which the most important factor of DA reduction is.
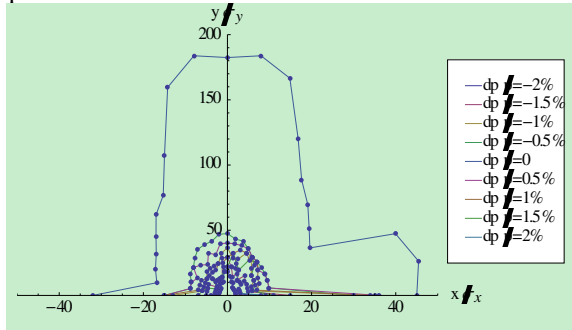

Figure 1: The dynamic aperture of CEPC main ring without error.

Considering coupling factor κ=0.003 for vertical emittance and tracking with three times of damping time, without radiation damping and error of the magnets, the on-momentum dynamic aperture which is shown in Figure 1 is about $20\sigma_x$ in horizontal and $180\sigma_y$ in vertical, while the off-momentum DA is quite limited to $1\sigma_x$ and $7\sigma_y$ for energy spread 2%.

Magnet Strength Error

With all the magnets(bend, quadrupole, sextupole) strength errors given in table 1, which are distributed in Gaussian and cut at three sigma, tune has changed a lot to (.05, .15) while the original tune is set at (.08, .22). The dynamic aperture and horizontal/vertical orbit deviation at all the BPMs before orbit correction, are shown in Figure 2 and Figure 3:
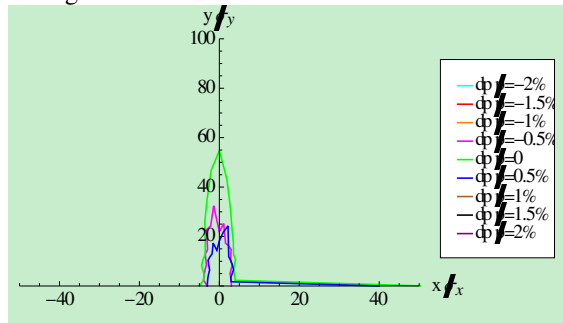

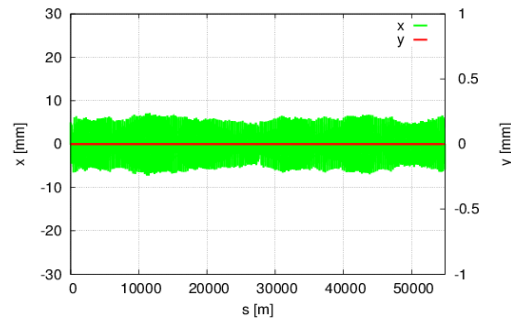Figure 2: Dynamic aperture with all magnet strength errors.

Figure 3: Horizontal and vertical orbit deviation with all magnet strength errors.

From Figure 2, we can see that the field errors reduced the on-momentum dynamic aperture observably. The vertical on-momentum DA is reduced by three times, and the horizontal DA is reduced to a quarter. While the off-momentum DA with energy spread 1% and 2% reduced to zero.

Figure 3 shows the horizontal and vertical orbit deviation before orbit correction respectively. The maximum horizontal orbit offset is about 8 mm.

Multipole Error

When introducing multipole errors to all magnets, the tune and orbit are still kept, and on-momentum dynamic aperture in vertical reduced to $100\sigma_y$ while horizontal still kept the same as before. The off-momentum dynamic aperture is not changed obviously with 2% at $1\sigma_x$ and $7\sigma_y$.
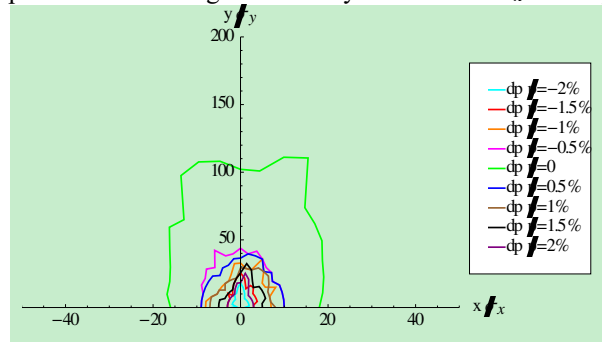

Figure 4: Dynamic aperture with all multipole errors.

MAGNET ERROR EFFECT ON DYNAMIC APERTURE IN CEPC PARTIAL DOUBLE RING

In the CEPC partial double ring scheme [5], all the bunches are distributed in average in the 3.2km partial double ring. The dynamic aperture without any error is shown in Figure 5:
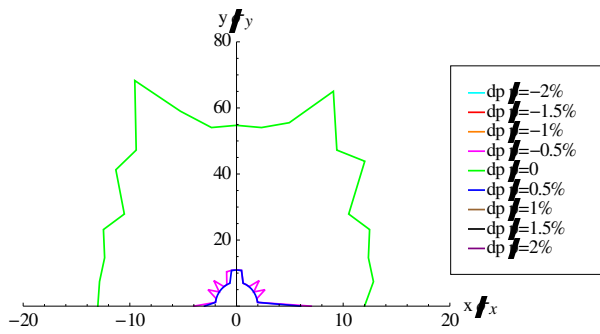
Figure 5: Dynamic aperture without error in CEPC partial double ring.

Magnet Strength Error

With only the quadrupole strength error respectively, orbit has no change, but tune changed a little bit to (.08, .27). The on-momentum dynamic aperture reduced, but off-momentum ones seems no obvious change which is shown in figure 6:
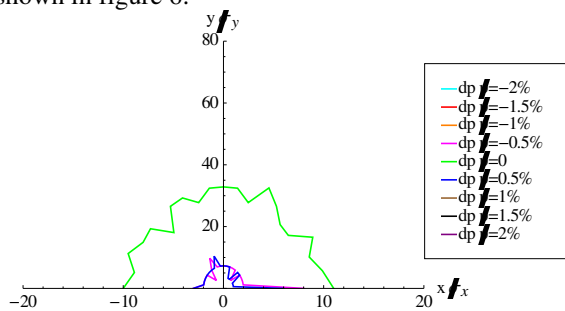

Figure 6: Dynamic aperture with quadrupole strength error.

While with only the sextupole strength errors, the orbit and tune are both not changed. And the dynamic aperture seems also no change. The situation is quite different when introducing bending magnet strength errors, the horizontal orbit changed a lot which is shown in figure 7, and tune has changed to be an integer resonance, beam is not stable. The dynamic aperture reduced to zero of both on-momentum and off-momentum ones.
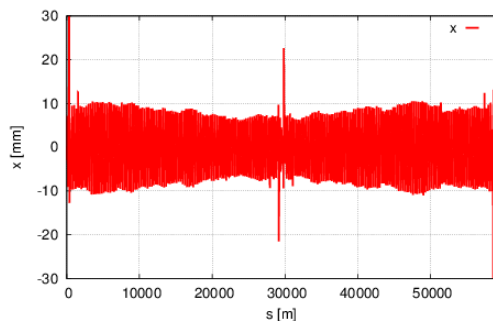

Figure 7: Horizontal orbit before correction with bending magnet strength errors.

Multipole Error

The multipole errors have two parts: one is the systematic field components in lattice elements which is produced by the imperfection during magnet manufacture; the other is the random field components in lattice elements which is due to the difference of individuals during magnet manufacture. The second part due to its random option, is introduced in Gaussian distribution and cut in three sigmas.
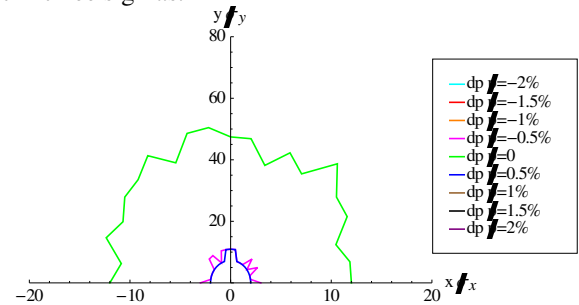

Figure 8: Dynamic aperture with all multipole error.

When introducing all multipole errors to bending magnets, quadrupole and sextupole. The orbit has no change to remain in zero. And also tune has no change. The dynamic aperture which is shown in figure 8 reduced a little bit but not much. It seems that the multipole errors has not much effect on the dynamic aperture, especially the off-momentum ones.

CONCLUSION

The dynamic aperture when introducing each kind of magnet errors is reported in this paper. From the error study, we can conclude that the multipole errors in the main ring have not much effect on dynamic aperture especially the off-momentum ones. However, the magnet strength errors seems to have a large effect on the dynamic aperture. Especially in the partial double ring design, the bending magnet strength errors cause an integer resonance to make the beam unstable.

There are two ways to cure the degradation of DA due to errors of magnets. One is to optimize the DA, such as to do orbit correction to cure the misalignment errors, to correct the tune to cure the B*L errors, and also we can do FMA analysis in addition to add some high order multipoles, ocutpoles, decapoles, dodecapoles...etc on. But the precondition is that the DA without any magnet errors is optimized to a satisfactory level. The other way is to reduce errors level to the DA that reach the requirement, however this may require the magnet manufacture more precisely.

ACKNOWLEDGMENT

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