CEPC BOOSTER LATTICE DESIGN *

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Abstract

In September 2012, Chinese scientists proposed a Circular Electron Positron Collider(CEPC) at 240 GeV centre of mass for Higgs studies. The CEPC booster(CEPCB) provides 120 GeV electron and positron beams to the CEPC collider for top-up injection. We foucus on the beam dynamic study for CEPCB and analyse the key point of CEPCB lattice design. In this paper, a lattice design with good dynamic aperture is proposed.

INTRODUCTION

As the Higgs boson has been discovered, so voices are being raised building a Higgs factory for further study. CEPC (Circular Electron and Positron Collider) was proposed by China as an electron and positron collider ring with a circumference of 50–100km [1]. Meanwhile, CERN also proposed FCC(Future Circular Collider) as next generation super collider [2]. In this paper, we talk about the CEPC booster(CEPCB) lattice design.

In the second section, the requirements for CEPC booster lattice disign are analysed. The third section will show the details of lattice design, including linear optics and nonlinear dynamics. Design results are shown in the fourth section.

LATTICE DESIGN REQUIREMENTS

At present, the emittance of CEPC is about $1.3 \times 10^{-9} m * rad$, it is much lower than the Pre-CDR because of the crab waist scheme. That makes the CEPCB harder to design because emittance of CEPCB at high energy is also reduced, which makes the chromaticity and resonance much stronger and pose challenges to our design at the same time. Asume that the dynamic aperture of CEPC mainring at 0.5% energy spread is 15 times of sigma and the β function is about 200m.

Then the lattice design requirements of CEPCB are proposed:

1. The emittance of CEPCB at 120Gev is about $3.0 \times 10^{-9} m * rad$.

2. 1% energy acceptance for enough quantum life time.

3. The dynamic aperture results must better than 5 sigma (sigma is defined by beam emittance from linac, which is $3 * 10^{-7} m \cdot rad$) for both on-momentum and off-momentum(0.5%) particles.

LATTICE DESIGN FOR CEPCB

The CEPCB is made up by FODO strucures and has four folds and bypass the CEPC and future SPPC detectors, as shown in Fig. 1. The total length is 100 km and the two RF stations are arranged at two side, same as the CEPC arrangement.

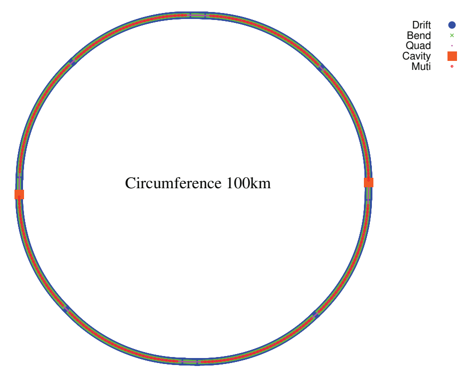

Figure 1: Layout of CEPCB.

Linear Optics for CEPCB

The lattice for CEPCB has been chosen to use the standard FODO cells with 90 degrees phase advances in both transverse planes, which give us smaller emittance and clear phase relationship between sextupoles. The length of each bend is 54.31 m, the length of each quadrupole is 1.00 m, while the distance between each quadrupole and the adjacent bending magnet is 1.6 m. The total length of each FODO structure is 110.92 m. 99 FODO structures make up one eighth of the booster ring. At the two side of each cell, there are de-dispersion sections and straight sections.

Sextupole Scheme for CEPCB

In CEPCB, the twiss functions are smooth, unlike the final focus system with extreme big twiss function and strong sextupoles, so the chromaticity and detuning terms are not very big. The key point of CEPCB lattice design is find out how to cancel the off-momentum resonance terms. In another word, if a lattice cell generate some resonance terms, we should find a way to cancel them in another lattice cell.

In Fig. 2, FODO structures are shown. "qfh" and "qd" are focus and defocus quadrupoles. Red rectangle denote sextupole, "sf" and "sd" are focus and defocus sextupoles. Different combination of i, j, k means different sextupole families. For convenience, we will use "FODO", "FODOSFi" and "FODOSDi" stand for the lattice cells respectively.

Figure. 3 shows a macro cell of CEPCB lattice. It is made up by two tiny cell apart by 90°(one FODO structure). Although the two tiny cells are apart by 90°, but the tiny cells have another 90° phase advance itselves, so the total phase advance is 180°. Figure. 4 shows the resonance lines and we plot the weak resonance lines with dash lines. In

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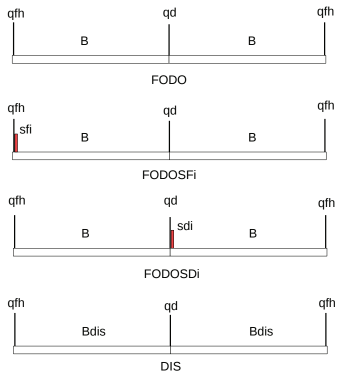

Figure 2: FODO structures in CEPCB.

this macro cell, some of the second order, third order, fourth order and fifth order resonance lines are weaken.

FODOSF1 FODO FODOSF1		FODOSF1 FODO FODOSF1
FODOSF2 FODO FODOSF2		FODOSF2 FODO FODOSF2
FODOSF3 FODO FODOSF3		FODOSF3 FODO FODOSF3
FODOSF4 FODO FODOSF4		FODOSF4 FODO FODOSF4
FODOSD1 FODO FODOSD1		FODOSD1 FODO FODOSD1
FODOSD2 FODO FODOSD2		FODOSD2 FODO FODOSD2
FODOSD3 FODO FODOSD3		FODOSD3 FODO FODOSD3
FODOSD4 FODO FODOSD4		FODOSD4 FODO FODOSD4
FODO	FODO	FODO
FODOSF1 FODO FODOSF1		FODOSF1 FODO FODOSF1
FODOSF2 FODO FODOSF2		FODOSF2 FODO FODOSF2
FODOSF3 FODO FODOSF3		FODOSF3 FODO FODOSF3
FODOSF4 FODO FODOSF4		FODOSF4 FODO FODOSF4
FODOSD1 FODO FODOSD1		FODOSD1 FODO FODOSD1
FODOSD2 FODO FODOSD2		FODOSD2 FODO FODOSD2
FODOSD3 FODO FODOSD3		FODOSD3 FODO FODOSD3
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Figure 3: A macro cell of CEPCB lattice.

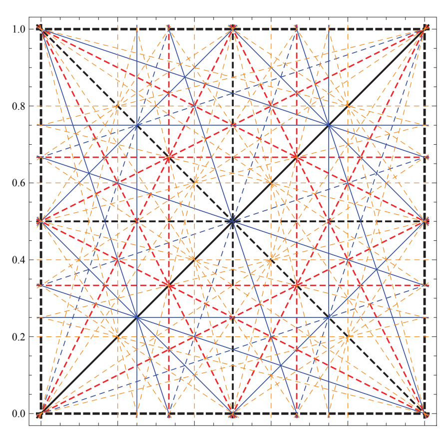

Figure 4: Resonance lines for a macro cell.

Two macro cell and a 315° phase-matching section makes up a quarter cell. The macro cells have 270° phase advance itselves, so the total phase advance is $-315° - 270° = -180° - 360° - 45°$. Figure. 5 shows the resonance lines and we plot the weak resonance lines with dash lines. In this quarter cell, some of the fouth order resonance lines are weaken. Now we have weaken most low order resonance lines(from first order to fifth order).

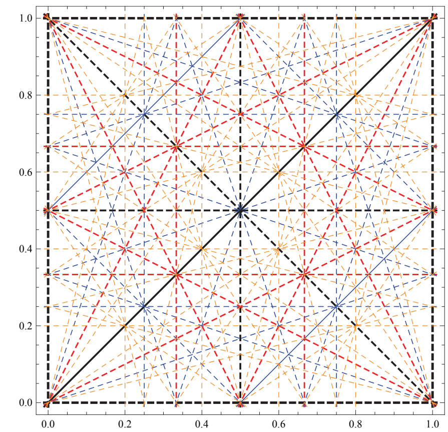

Figure 5: Resonance lines for quarter cell.

DESIGN RESULTS

We adopt a sextupole scheme which makes most low order resonance lines became weak. To find out a better tune, we implement the tune scan, match the tune and conculate the size of dynamic aperture. Figure. 6 show us the result. In this plot, we can clearly see how resonance lines affect the beam dynamic performence. With the help of tune scan result, we can pick out severval tunes with good dynamic aperture and finally we fix the tune at (0.053,0.821).

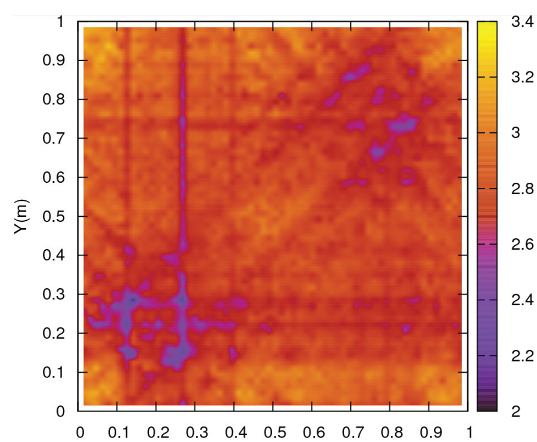

Figure 6: Tune scan.

Figure. 7 and Fig. 8 show the dynamic aperture as a function of energy spread in X and Y direction. Figure. 9, Fig. 10 show the Frequency map analysis and the tune scatter, and we can see how the resonance lines affect the dynamic aperture. Figure. 11 shows the phase space of several particles, and we can see that even the phase space of fringe particles are close to circles.

SUMMARY

In this paper, a lattice design for CEPCB is proposed. The emittance of booster at 120 Gev is $3.1 \cdot 10^{-9}$ m. With the phase shift optimization, the lattice shows good dynamic performance. Though tune scan, we have several tunes with good dynamic aperture.

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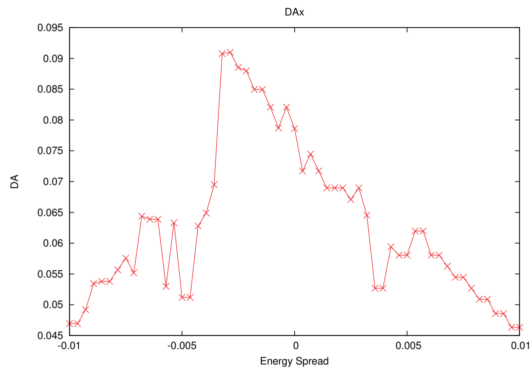

Figure 7: Dynamic aperture as a function of energy spread in X direction.

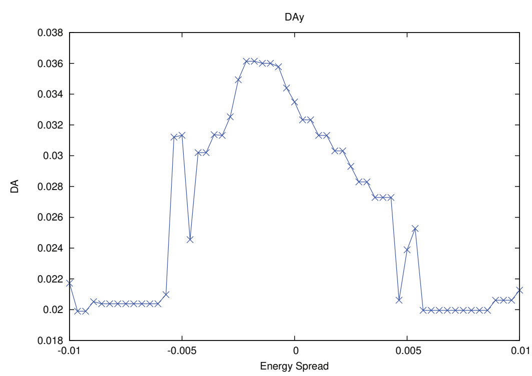

Figure 8: Dynamic aperture as a function of energy spread in Y direction.

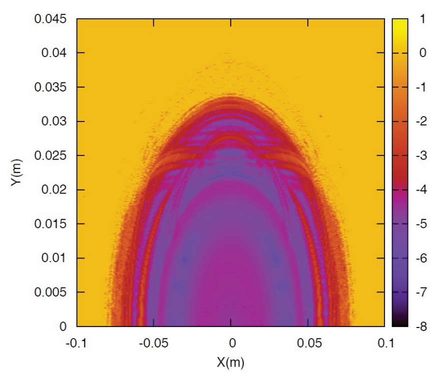

Figure 9: Frequency map analysis for on-momentum particles.

If we use tune (0.053,0.821) as an example:
1.X direction dynamic aperture is 11.32 sigma, Y direction

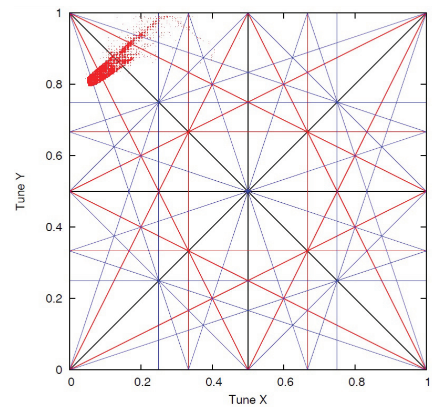

Figure 10: Tune scatter for on-momentum particles.

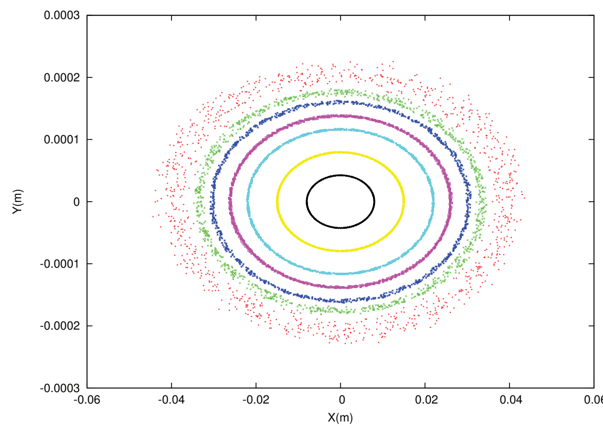

Figure 11: Phase space

dynamic aperture is 11.45 sigma@dp=0%.
2.X direction dynamic aperture is 6.92 sigma, Y direction dynamic aperture is 8.20 sigma@dp=0.5%.

Contrast with the design goal we have proposed in third section, the lattice design of CEPCB is reasonable and meet requirements.

REFERENCES

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[2] Benedikt Michael, "Towards future circular colliders.", *Journal of the Korean Physical Society*, 69.6(2016):893-902.