# DYNAMIC APERTURE STUDY OF THE CEPC MAIN RING WITH INTERACTION REGION *

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*Abstract*

CEPC is a Circular Electron and Positron Collider proposed by China to mainly study the Higgs boson. In order to achieve factory luminosity, a strong focusing system and low-emittance are required. A momentum acceptance as large as 2% is also required to get a reasonable beam lifetime. This is one of the key issues of the CEPC accelerator physics. In this paper, the optics design of the interaction region and the optimization of dynamic aperture for the whole ring (single ring scheme) will be presented.

## INTRODUCTION

CEPC is a Circular Electron and Positron Collider proposed by China to mainly study the Higgs boson. In order to achieve factory luminosity, a strong focusing system and low-emittance are required. A momentum acceptance as large as 2% is also required to get a reasonable beam lifetime. This is one of the key issues of the CEPC accelerator physics. In this paper, the optics design of the interaction region and the optimization of dynamic aperture(DA) for the whole ring (single ring scheme) will be presented.

We optimized dynamic aperture for the CEPC main ring by adding several additional sextupoles in the interaction region(IR). It's found that the additional sextupoles are very effective to increase the dynamic aperture for large off-momentum particles. This work is inspired by R. Brinkmann's idea on the final focus of linear colliders [1] (see Table 1).

Table 1: Key Parameters of the Interaction Region for CEPC Single Ring Scheme [2]

| Parameters | Unit | Value |
|---|---|---|
| Distance from QD0 to IP $L^*$ | m | 1.5 |
| Number of IPs $N_{IP}$ | - | 2 |
| Beam energy $E$ | GeV | 120 |
| Beta function at IP $\beta_x^*/\beta_y^*$ | mm | 800/3 |
| Horizontal emittance $\epsilon_x$ | nm · rad | 6.12 |
| Vertical emittance $\epsilon_y$ | nm · rad | 0.0184 |
| Bunch length SR $\sigma_z$ | mm | 2.14 |
| Energy spread SR $\sigma_E$ | % | 0.13 |
| Luminosity/IP $L$ | $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ | 2.04 |

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## INTERACTION REGION

The CEPC interaction region (IR) was designed with modular sections [2–4] including the final transformer(FT), chromaticity correction for vertical plane(CCY), chromaticity correction for horizontal plane(CCX) and matching transformer(MT). To achieve a momentum acceptance as large as 2%, local correction of the large chromaticity from final doublet (FD) is necessary. Two pairs of sextupoles separated with -I transportation are used to make the 1st order chromaticity correction. The optics of the IR starting from the interaction point(IP) are shown in Fig.1.

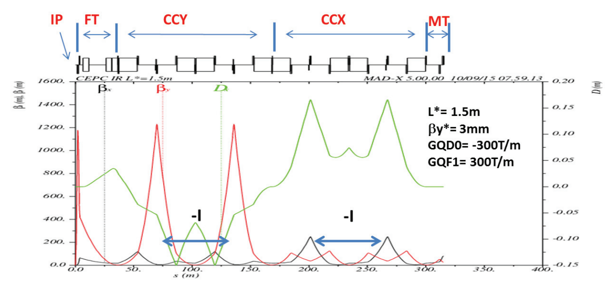


Figure 1: Optics of the interaction region (one side).

To correct the tune shift due to finite length of main sextupoles, two pairs of weak sextupoles are installed next to the main ones [5]. The 1st order tune shift terms are shown in Fig.2.

To reduce the 2nd order chromaticity, the phases of sextupoles are carefully tuned. To reduce the 3rd order chromaticity, only 2 quadrupoles are used in the final transformer [6, 7] and one additional sextupole are installed at 1st image point [1]. Chromatic functions for the IR are shown in Fig.3. The change of the vertical tune is small than 0.03 when energy deviation dp/p=±2%. The horizontal plane can be optimized further with more additional sextupoles.

## ARC REGION

For the Arc region, the FODO cell structure is chosen to provide a large filling factor. The 60/60 degrees phase advances is selected due to its property of resonance cancellation [8, 9]. The 3rd and 4th order resonance driving terms (RDT) due to sextupoles in 24 cells is computed with Bengtsson's formular [11]. With only two families of sextupoles, all the 3rd and 4th order RDT except $2Q_x - 2Q_y$ are cancelled out within one betatron unit, i.e. 6 cells. However, as Yunhai Cai pointed out that the tune shift accumulate along the arc cells and reach a very large number with the ring [8], see Fig.6. The negative tune shift make the tune of

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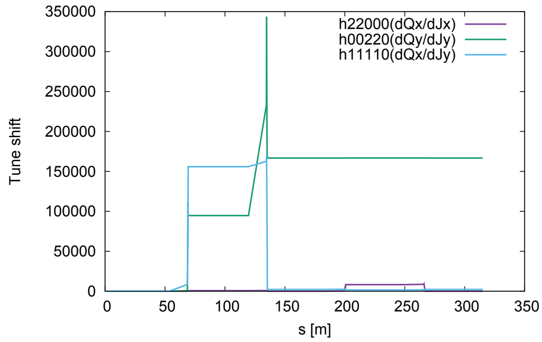


Figure 2: Tune shift correction in IR.

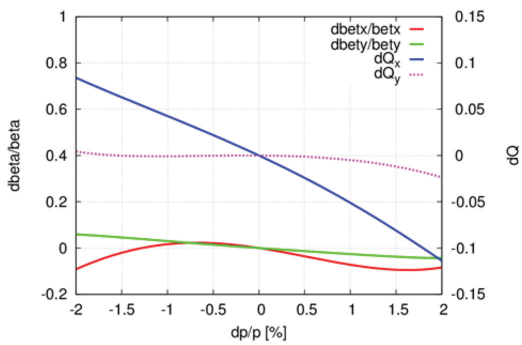


Figure 3: Chromatic functions at IP with the IR only (one side).

CEPC (0.08/0.22) go to the integer resonance line thus limit the on-momentum dynamic aperture (Figures 4 and 5).

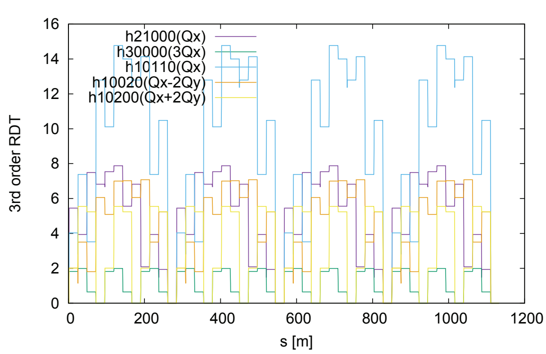


Figure 4: 3rd order resonance driving terms due to sextupoles in ARC (24cells).

## DYNAMIC APERTURE

### *Additional Sextupoles of CEPC IR*

In the previous CEPC IR lattice, many attemps have been tried to increased the the dynamic aperture for off-

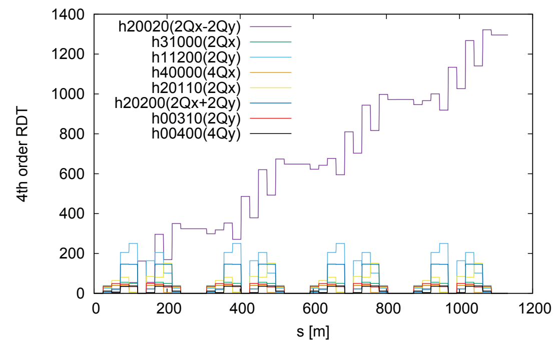


Figure 5: 4rd order resonance driving terms due to sextupoles in ARC (24cells).

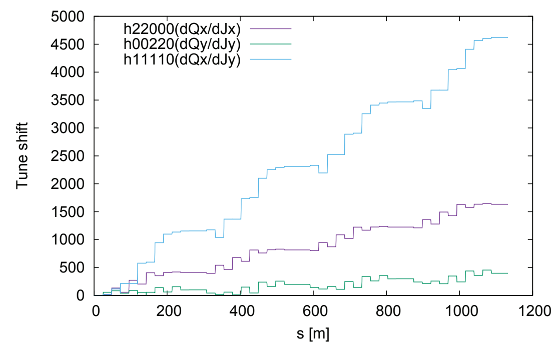


Figure 6: Tune shift due to sextupoles in ARC (24cells).

momentum particles. With two pairs of main sextupoles separated by -I transportation, 2 pairs of weak sextupoles and one additional sextupole, the dynamic aperture of $3\sigma_x \times 20\sigma_y$ are achieved for dp/p=±2%, see Fig. 7. However, it's still not enough to keep a reasonable beam lifetime and luminosity which require $20\sigma$ for on momentum particles and $5\sigma$ for off momentum particles [10]. This section will show the further optimization of the DA for large off-momentum particles.

The previous DA result shown that DA drops quickly with momentum deviation even just ±0.5%. This is because of the breakdown of -I transportation. To correct this effect, a simple way is to correct the tiny chromaticity within the -I transportation. Thus we respectively put three sextupoles for the vertical and horizontal chromaticity correction section, i.e. the position (3,4,5) and (8,9,10). And three more sextupoles (2,6,7) help to correct the second order dispersion and so on. The position of additional sextupoles are shown in Fig. 8. 1 denotes the sextupole we have added in previous IR lattice.

### *Optimise DA with Additional Sextupoles in IR*

It's difficult to correct a high order aberration while not increase other aberration. Similar to final focus of linear

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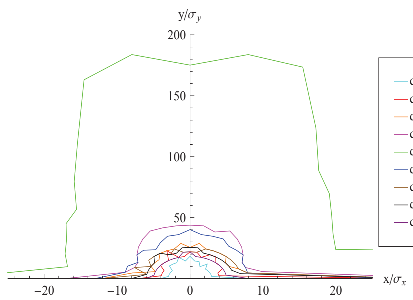


Figure 7: Dynamic aperture.

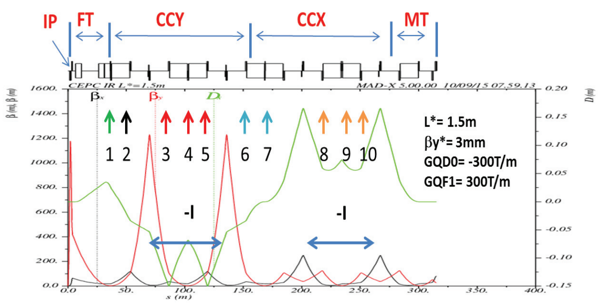


Figure 8: Optics of the interaction region with Brinkmann sextupoles.

collider, we optimise the momentum acceptance directly in the following way [12]: In the plane of "DA vs. DP/P", the area of dynamic aperture with $|dP/P| \leq 2\%$ was got by tracking. A small coupling factor of 0.1% used to mainly optimise the horizontal DA. To avoid DA cut-in shape with small step of momentum deviation, as large as 19 points within $|dP/P| \leq 2\%$ were used. Four cases of initial phases, i.e. (0,0), ($\pi/2$,$\pi/2$), (0,$\pi/2$), ($\pi/2$,0) are considered. We maximize the area of four cases with Downhill Simplex algorithm [12]. The tracking was done with 100 turns which corresponding to around one damping time.

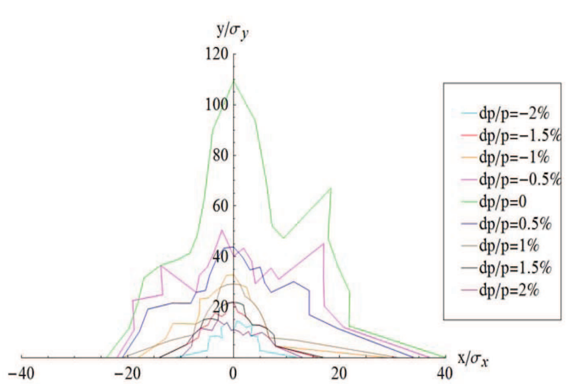


Figure 9: Dynamic aperture with Brinkmann sextupoles.

Fig. 9 show the optimised dynamic aperture with Brinkmann sextupoles including synchrotron motion but without radiation damping and errors. The horizontal DA no longer drop quickly with momentum deviation. With $dP/P = \pm 0.5\%$, the DA is still the same with on-momentum one, i.e. $20\sigma_x$. The horizontal DA for $dP/P = \pm 2\%$ are significantly increased to around $6.5\sigma_x$ though the vertical one decreased to $10\sigma_y$. This result has met the DA requirement we mentioned.

Though thin sexptupoles are used in this study, there will be no significant finite length effect due to the weak sextupole strength.

## CONCLUSION

We optimized dynamic aperture for the CEPC main ring by adding several additional sextupoles in the interaction region. It's found that the additional sextupoles are very effective to increase the dynamic aperture for large off-momentum particles. Including synchrotron motion but without radiation damping and errors, the optimised DA is $(6.5\sigma_x \times 10\sigma_y)$ for $dP/P = \pm 2\%$. This result has met the DA requirement with analytical estimation.

For further work, we'll try to find out the residual aberration and reduce the critical energy due to the bends in IR.

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