

MDI ISSUES IN CEPC DOUBLE RING*

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Abstract

With the discovery of the higgs boson at around 125GeV, a circular higgs factory design with high luminosity ($L \sim 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$) is becoming more popular in the accelerator world. The CEPC project in China is one of them. Machine Detector Interface (MDI) is the key research area in electron-positron colliders, especially in CEPC, it is one of the criteria to measure the accelerator and detector design performance. Because of the limitation from the existing tunnel, many equipment including magnets, beam diagnostic instruments, masks, vacuum pumps, and components of the detector must coexist in a very small region. In this paper, some important MDI issues will be reported for the Interaction Region (IR) design, e.g. the final doublet quadrupoles physics design parameters, beam-stay-clear region and beam pipe, synchrotron radiation power and critical energy are also calculated.

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 $125 \times 125 \text{ GeV } e^+e^-$ 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.

MDI is one of the most challenging field in CEPC design, it almost covered all the common problems in accelerator and detector. The Machine Detector Interface of CEPC double ring scheme is about $\pm 16\text{m}$ long from the IP, where many elements need to be installed. The two beams collide at the IP with a horizontal angle of 33mrad and the final focusing length is 2.2m [2]. The space is very tight.

The CEPC detector consists of a cylindrical drift chamber surrounded by an electromagnetic calorimeter, which is immersed in the superconducting solenoid with 3 T magnetic field and the length of 7.6m.

In this paper, some essential MDI design issues are reported: the final doublet quadrupoles physics design parameters which is the source of the MDI design; electron and positron beam stay clear region which is important input into the beam pipe shape design; synchrotron radiation power of the last bending magnet upstream of the Interaction Point (IP) to enter the IR region, and also the synchrotron radiation power of the

final doublet quadrupoles, critical energy are also calculated.

BEAM STAY CLEAR REGION

The beam stay clear region size is decided by the beam emittance, β function and beam quantum lifetime. According to the design experience of the large collider in world [3, 4, and 5], CEPC IR beam stay clear region are considered of the points below:

- 1) To satisfy the requirement of injection, beam stay clear region(BSC) is defined as 19σ
- 2) To satisfy the requirement of beam lifetime after collision: $BSC_x=20\sigma_x, BSC_y=40\sigma_y$
- 3) coupling=1%, including the coupling of circulating beam $\sim 0.3\%$ and blow up after beam-beam effect, also considering magnet errors.

Finally, we define the CEPC beam stay clear region:

$$BSC_x = \pm(20\sigma_x + 3\text{mm}), BSC_y = \pm(40\sigma_y + 3\text{mm})$$

Figure 1 shows the beam stay clear region of electron (blue line) and positron (red line) beam in the $\pm 6 \text{ m}$ interaction region.

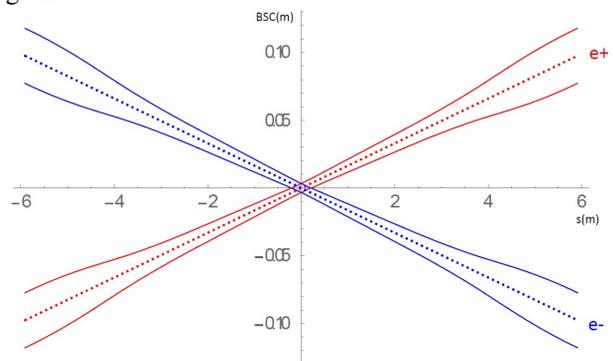


Figure 1: Beam stay clear region of CEPC double ring Interaction Region.

FINAL DOUBLET PHYSICS DESIGN PARAMETERS

On each side of the IP, a final doublet of quadrupoles on each beamline is used to provide the focusing optics needed at the IP. It allows the vertical beta function at the IP to be 2mm. The first vertical focusing quadrupole is a superconducting magnet, which is shared by both beams. To save space, the quadrupole coils are two-in-one aperture. The second element of the final doublet is horizontal focusing quadrupole. The distance from the last quadrupole is 0.5m.

Based on the beam stay clear region, the final doublet quadrupoles physics design parameters are below in Table 1 and Table 2:

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Table 1: QD0 Physics Design Parameters

QD0	Horizontal BSC 2 (20 σ_x +3)	Vertical BSC 2 (40 σ_y +3)	e+e- beam center distance
entrance	13.73 mm	20.24 mm	72.61 mm
Half	18.06 mm	23.65 mm	101.45 mm
exit	25.94 mm	22.11 mm	130.33 mm
Good field region	Horizontal 25.94 mm; Vertical 23.74 mm		
Effective length	1.7489m		
Distance from IP	2.2000m		
Gradient	150 T/m		

Table 2: QF1 Physics Design Parameters

QF1	Horizontal BSC 2 (20 σ_x +3)	Vertical BSC 2 (40 σ_y +3)	e+e- beam center distance
entrance	31.84 mm	19.83 mm	146.83 mm
Half	38.46 mm	17.41 mm	170.99 mm
exit	40.54 mm	16.62 mm	195.11 mm
Good field region	Horizontal 40.55 mm; Vertical 19.83 mm		
Effective length	1.4636m		
Distance from IP	4.449m		
Gradient	106 T/m		

BEAM PIPE

To reduce the detector background and radiation dose due to beam loss, the IR vacuum chamber has to accommodate large beam stay clear region. In order to keep precise shaping, all chambers should be made by numerically controlled machine and carefully welded to avoid deformation.

In the present design, the inner diameter of the beryllium pipe was decided to be 28mm by considering both the mechanical assembly and beam background issues. The beam pipe between the detector beryllium pipe and the accelerator copper pipe which is the central part of the IP chamber has the same diameter 28mm with the length of ± 0.5 m. The connection from single pipe to double pipe is realized by flange CF35 at ± 0.7 m. From the flange to the entrance of the quadrupole, the beam pipe is cylindrical. See Fig. 2.

For the beam pipe within the final doublet quadrupoles, cold vacuum chamber has to be adopted for the sufficient coils space.

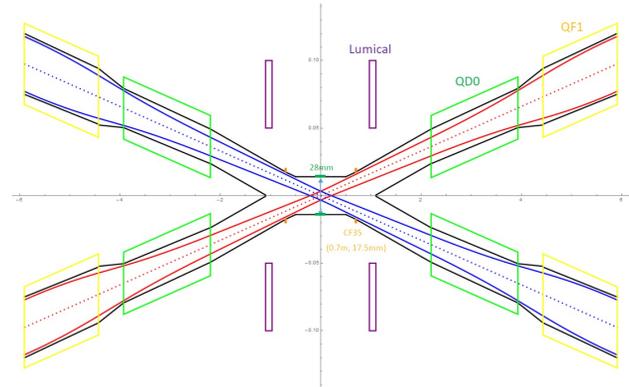


Figure 2: IR layout with beam pipes.

SYNCHROTRON RADIATION

Synchrotron radiation (SR) is produced when an electron (or positron) trajectory curves in the magnetic field of a dipole or quadrupole. Photons are emitted in a direction tangential to the particle instantaneous trajectory with differential power [6]:

$$dP[\text{kW}] = \frac{d\phi}{2\pi} \cdot 88.47 \cdot E_{\text{beam}}^4 [\text{GeV}] \cdot I[\text{A}] / \rho[\text{m}] \quad (1)$$

Where ρ is the local radius of curvature and $d\phi$ is the deflection angle.

The critical energy is [7]:

$$E_c = 0.665 E^2 [\text{GeV}] B[\text{T}] \quad (2)$$

where E is the electron energy and B the peak bending magnet field.

The synchrotron radiation will contribute the heat load to the beam pipe and cause the photon background to the experiments. Furthermore, the radiation dose can damage the detector components. Thus the beam optics should be carefully designed in order to prevent the SR photons from directly hitting or once-scattering to the detector beam pipe.

SR from Bending Magnets

For the CEPC double ring, the maximum designed current of single beam is 19.2mA and the maximum energy is 120GeV. The synchrotron radiation fans in the IR are mainly generated from the final bending magnet before the IR section and from the IR quadrupole magnets due to the eccentric particles. Figure 3 shows the SR fans in the IR, which are produced by positron beam.

As the positron beam travels through the final bending magnet upstream of the IP, which is located at 102.33m from the IP and enters the IR, it generates a fan of SR with the total power 47W. The critical energy of photons is about 55keV. In the proposed design, 47W of SR power contributed by e+ within 10 σ_x will go through the IP. And no SR hits directly on the detector beryllium pipe. The synchrotron radiation generated by electron beam is symmetric with positron beam.

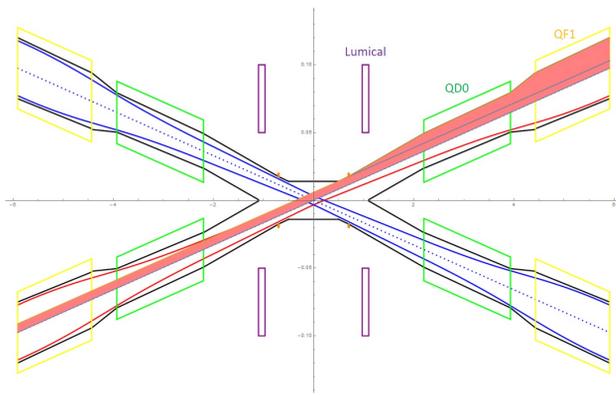


Figure 3: SR fans in the CEPC IR.

For the final bending magnet downstream of the IP, which is located at 73.88m from the IP, it generates a fan of SR with the total power 629.4W. The critical energy of photons is about 520keV.

SR in IR Cold Vacuum Chamber

Cold vacuum chamber has to be adopted within the final doublet superconducting magnet for the sufficient coils space. The design has been accepted by cryogenic system. The synchrotron radiation power within QD0 is 1.8W along 1.73m, on QF1 is 2.6W along 1.48m. The region between QD0 and QF1 is 66 W (0.5m) where has special cooling structure (Fig. 4).

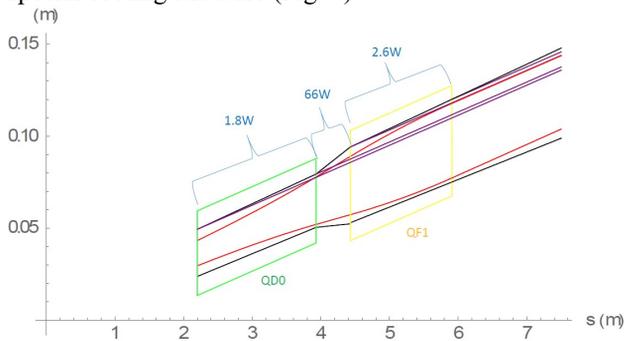


Figure 4: SR fans in the IR cold vacuum chamber.

SR from Final Doublet Quadrupoles

In sequence there are two quadrupole magnets in the section between the final bending magnet and the IP. They are the final doublet quadrupoles QD0 and QF1. The largest radiation source of which magnet depends on if it is installed off-axis with the beams.

Since in the Gaussian distribution beam, particles in 3σ occupies 99.7% of the total amount, 1σ occupies 68.7%, and 2σ occupies 95.5%. The total SR power generated by the QD0 magnet is 202W. The critical energy of photons is about 207keV. For the QF1 which is focusing in horizontal plane, the total SR power generated by the QF1 magnet is 2166W. The critical energy of photons is about 951keV. The photons generated by the quadrupoles are almost along the beam, and most of the photons will hit on the beam pipe downstream, so the effects on detector

is not serious, but when the quadrupoles are installed off-axis with the beams, the SR will be much serious.

CONCLUSION

The design of the interaction region (IR) has to accommodate competing and conflicting requirements from the accelerator and the detector. Because the limitation from the existing tunnel, many equipment including magnets, beam diagnostic instruments, masks, vacuum pumps, and components of the CEPC detector must coexist in a very small region. So one of the most difficult parts of the design of a new collider is that of the IR. The IR design poses a challenge both to the accelerator and technology.

The beam stay clear region is first clarified considering the requirements of injection, beam life time after collision and coupling. Final doublet quadrupoles physics design parameters are calculated based on the beam stay clear region. The QD0 should be two-in-one aperture due to the tight space. Beam pipes are designed which can accommodate the beam stay clear region and for the beam pipe within the final doublet, cold vacuum chamber has to be adopted for the sufficient coil space. Synchrotron radiation power from the last bending magnet upstream in the IR, of which 47W contributed by e^+ within $10\sigma_x$ will go through the IP, and no SR hit directly on beryllium pipe.

ACKNOWLEDGMENT

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