Final focus superconducting magnets for CEPC

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Abstract: Final focus high gradient quadrupole doublet magnets QD0 and QF1 are key devices of the Proposed Circular Electron Positron Collider (CEPC). They are both double aperture superconducting quadrupoles with field gradients of 136 T/m and 110 T/m, respectively. The angles between the two apertue centerlines are both 33 mrad. Though the distance between the two aperture centerlines of QD0 is very limited, the field crosstalk between the two apertures is successfully solved by using cos2θ quadrupole coil with iron core. In addition, strong superconducting anti-solenoid is needed to cancel the Detector solenoid field. In this paper, the layout and magnetic design of CEPC final focus superconducting magnets are described, and the detailed design of the QD0 short model magnet is presented.

I. Introduction

Compact high gradient final focus quadrupole magnets are required on both sides of the collision points in interaction region of a Circular Electron Positron Collider (CEPC) collider ring with a circumference about 100 km. The conceptual design of CEPC final focus superconducting magnets was finished in September 2018. Then the development of prototype superconducting magnets started.

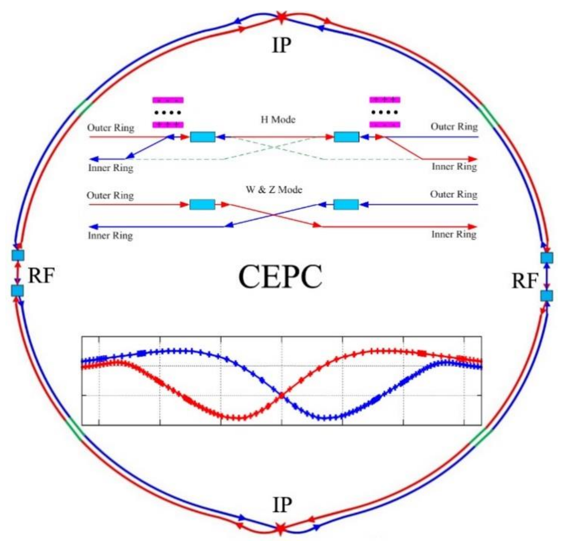

Fig. 1. Sketch of CEPC Collider ring

II. Layout of final focus magnets

The QD0 and QF1 magnets are designed to be superconducting double aperture quadrupole magnets. The crossing angle between the two aperture centerlines is 33 mrad, and the distance from QD0 to the interaction point is only 2.2 m.

TABLE I
DESIGN REQUIREMENTS OF CEPC FINAL FOCUS QUADRUPOLE MAGNETS

Item	Unit	QD0	QF1
Field gradient	T/m	136	110
Magnetic length	m	2.0	1.48
Radius of good field region	mm	9.8	13.5
Minimum distance between two aperture beam lines	mm	72.6	146.2
Multipole field content	1×10^{-4}	≤5	≤5

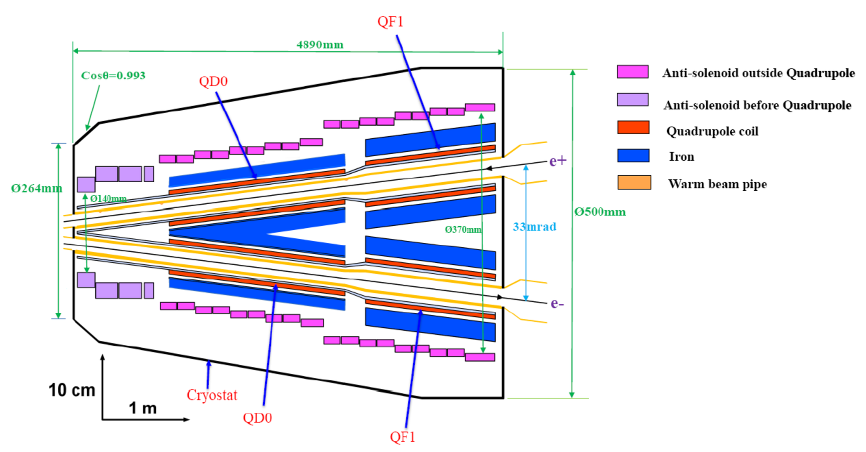

Fig. 2. Layout of the CEPC final focus superconducting magnets

III. Magnet design

Near the middle of the two apertures, the available space in the radial direction in QD0 single aperture is only 16.3 mm. Therefore cos2θ quadrupole coil using NbTi Rutherford cable is selected for QD0 since this type coil has high magnetic efficiency and high cooling capacity. Iron yoke made of low carbon steel is added outside the collar.

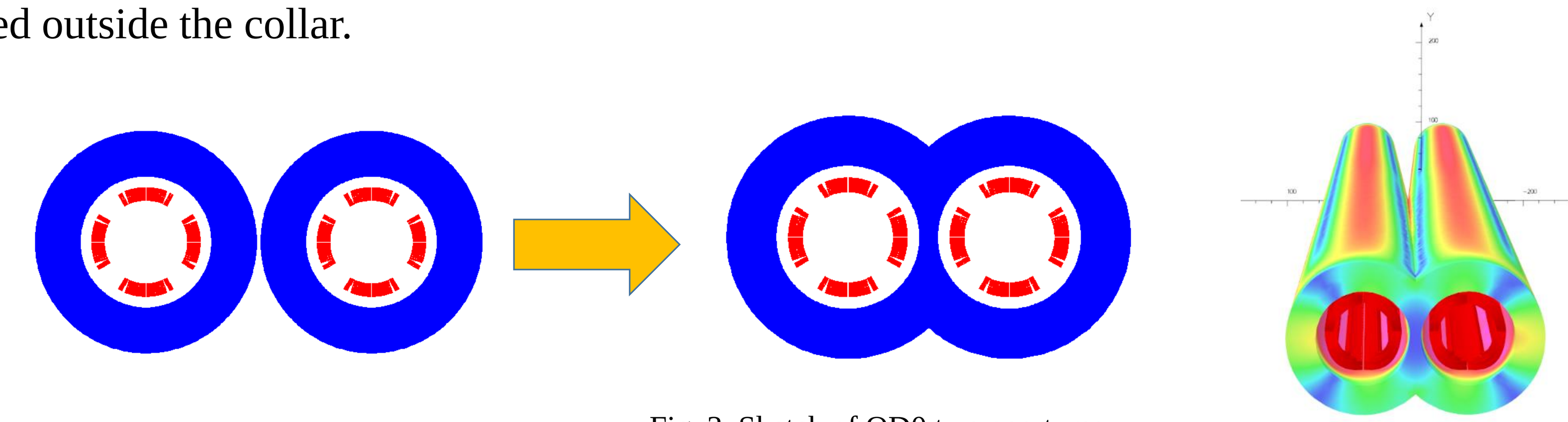
Fig. 3. Sketch of QD0 two apertures

Fig. 4 shows an example of 2D model of the QD0 two apertures, in which case the distance between the two aperture centers is the nearest. The largest multipole field caused by field crosstalk is sextupole field about 0.3 unit. When the distance between the two apertures becomes larger, the field harmonics generated by field crosstalk will be smaller.

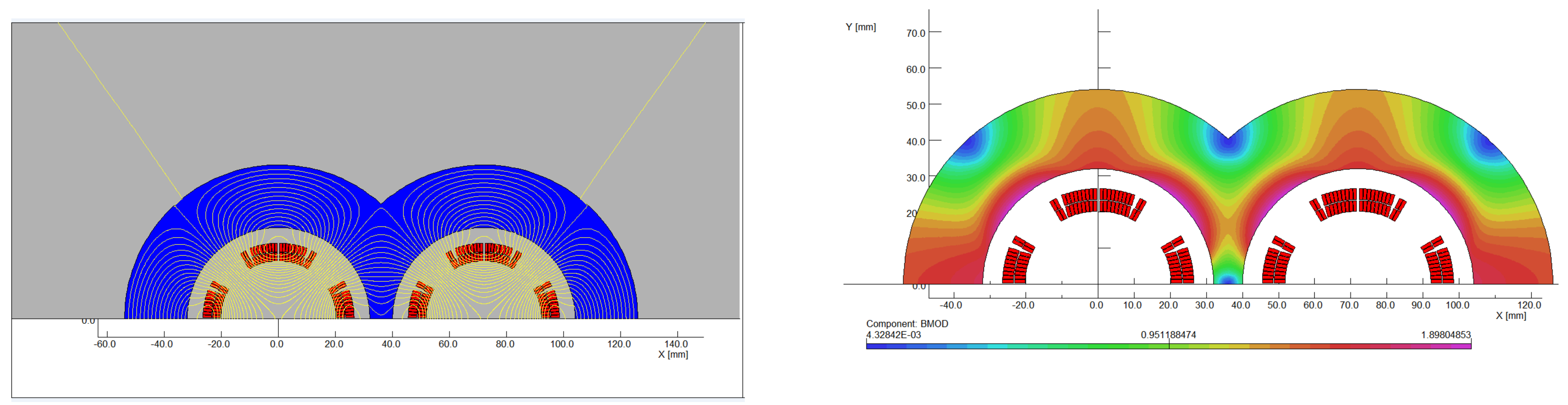
Fig. 4. 2D field simulation of QD0 two apertures

The inter-beam distance for QF1 is much larger and the one in QD0, there is enough space to place two single apertures side by side. The field cross talk between the two apertures of QF1 is not an issue.

The anti-solenoid is divided into a total of 29 sections with different inner coil diameters. The first section of solenoid has the strongest magnetic field, with a peak value of 7.0 T. The net solenoid field in QD0 and QF1 region at each longitudinal position is smaller than 300 Gs.

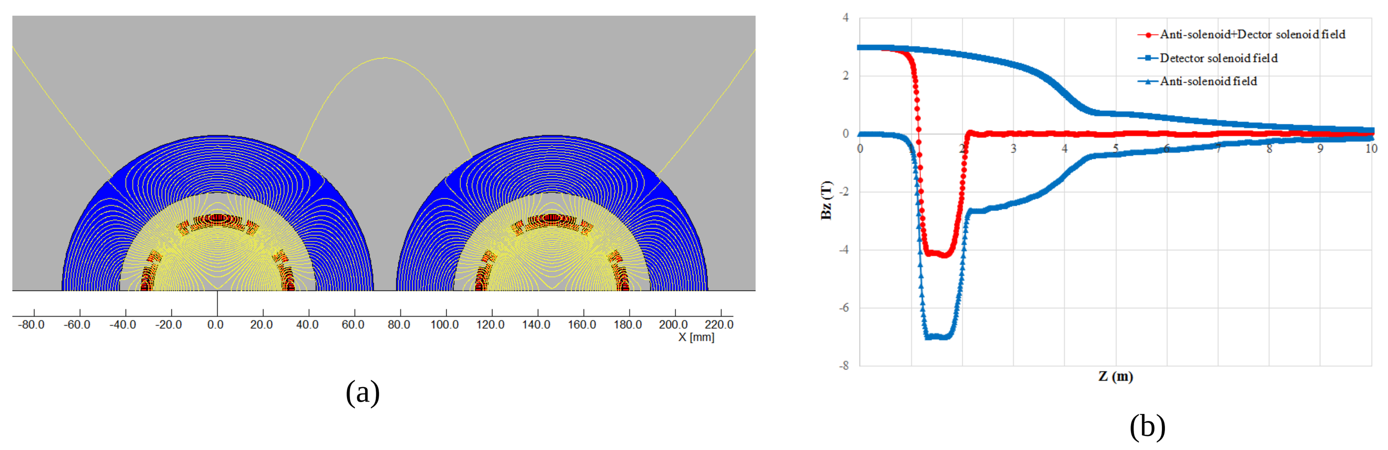

Fig. 5. 2D field simulation (a) QF1 flux lines (b) Combined field of Anti-solenoid and Detector solenoid

IV. Design of QD0 short model magnet

The first step of the R&D of CEPC final focus superconducting magnets is to develop a QD0 short model magnet with a magnetic length of 0.5 m.

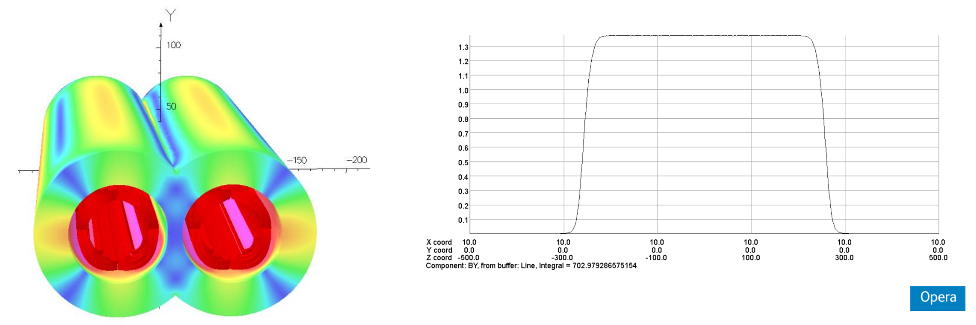
Fig. 6. 3D field simulation of QD0 short model magnet

The distribution of multipole field contents caused by the field crosstalk are shown in Fig. 7. The integrated non-systematic multipole field is very small, and the largest one is the integrated sextupole field with a magnitude of 0.17 unit.

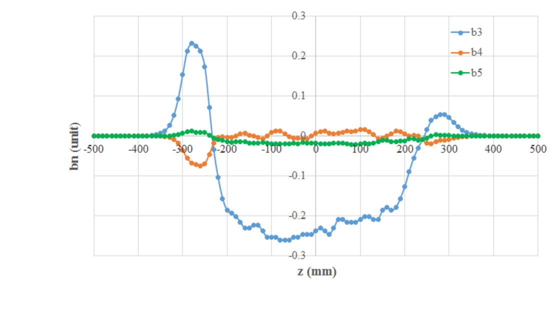
Fig. 7. Longitudinal distribution of field harmonics caused by field crosstalk.

TABLE II
DESIGN PARAMETERS OF QD0 SHORT MODEL MAGNET

Item	Unit	Value
Field gradient	T/m	136
Magnetic length	m	0.5
Coil turns per pole		21
Nominal excitation current	A	2080
Coil layers		2
Stored energy	kJ	5.0
Inductance	H	0.0023
Peak field in coil	T	3.4
Load line ratio		73%
Coil inner diameter	mm	40
Coil outer diameter	mm	53
Yoke inner diameter	mm	64
Yoke outer diameter (single aperture)	mm	108
X direction Lorentz force/octant	kN	24.3
Y direction Lorentz force/octant	kN	-23.5

Coil fabrication accuracy, magnet assembly accuracy, non-magnetic characteristics of the collar need to be guaranteed. The target azimuthal pre-stress at the coil pole is 70 MPa at ambient temperature.

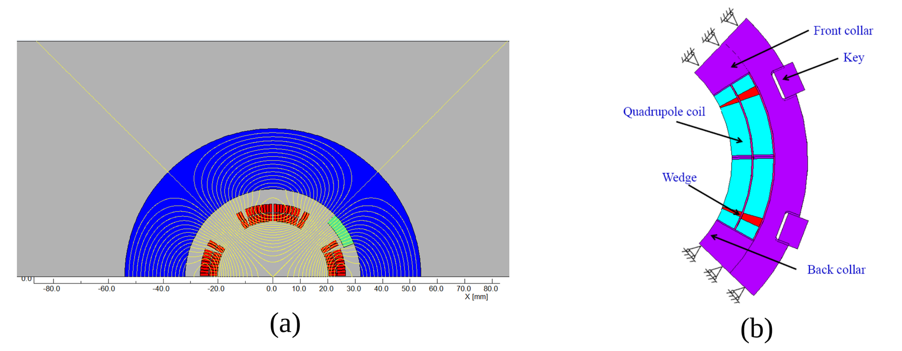

Fig. 8. (a) 2D field error analysis (b) 2D stress analysis model

V. Conclusion

Compact design of final focus superconducting magnets for CEPC are obtained. The QD0 is designed as a collared cos2θ quadrupole magnet using Rutherford cable with iron yoke, and the crossing angle between two aperture centerlines is 33 mrad. The problem of field harmonics as a result of field crosstalk between QD0 two apertures is successfully solved. Compared with the iron-free design, the excitation current can be substantially reduced. The magnetic design, quench simulation, stress analysis of QD0 short model magnet has been finished.

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