CEPC COLLIDER AND BOOSTER MAGNETS*

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Abstract

A Circular Electron Positron Collider (CEPC) with a circumference of about 100 km, a beam energy up to 120 GeV is proposed to be constructed in China. Most magnets for CEPC booster and collider ring are conventional magnets. The quantities of the magnets are large, so the cost and power consumption are two of the most important issues for the magnet design and manufacturing. The dual aperture dipole and quadrupole magnet with low current high voltage are used in the collider ring. Whereas in the booster the dipole magnet works at very low field, so a low packing factor dipole magnet or a coil type without iron design will be investigated and chosen. In this paper, the conceptual design of the CEPC main magnets are described in detailed and the R&D plan is presented.

INTRODUCTION

A Circular Electron Positron Collider (CEPC) is proposed to be constructed in China. It is an important part of the world plan for high-energy physics research. The CEPC will operated at different beam energy of Z, W and Higgs factory. The accelerator complex of CEPC consists of a linear accelerator (Linac), a damping ring (DR), the booster, the collider and several transport lines. The booster and the collider ring are in the same tunnel with a circumference of about 100 km [1].

There are about 9370 magnets in the collider ring and nearly 20000 magnets in the booster ring. Most magnets except some magnets in the interaction region operated at a relatively low field are designed as conventional magnets. A significant effort has been made in optimizing of the power consumption, manufacturing and operation cost of the magnets like that in the LEP and FCC-ee [2-3]. The synchrotron radiation damages to the conductor are considered with more space on the coil windings to place the radiation absorber. All the magnets have been designed using OPERA software [4].

COLLIDER MAGNET SYSTEM

The CEPC collider ring is a double ring collider and most of the dipoles and quadrupoles have similar strength and length. To reduce the cost and power consumption, 2384 dipoles and 2392 quadrupoles are designed as dual aperture magnets to provide magnetic field for both beams whose separation is 350 mm.

Besides the dual aperture magnet design, several special technologies are used to reduce the magnet cost, including the core steel dilution for dipoles and aluminium conductors instead of copper. To reduce the magnet power consumption, the low current density and high voltage operation mode are used to cut down power consumption of the magnet power supply and the power cables. The main magnet requirements are listed in Table 1.The gap height of the dipoles is 70 mm and the aperture diameter of quadrupoles and sextupoles is 76 mm and 80 mm, respectively.

Table 1: Main Parameters of CEPC Collider Ring Magnets

Magnet	Field strength	Magnetic length	Width of GFR
Dipole	0.0373 T	28.7 m	13.5 mm
Quadrupole	8.42 T/m	2.1 m	12.2 mm
Sextupole	506.2 T/m^2	1.4 m	13.9 mm

Dual Aperture Dipole Magnet

The dipoles are kept as long as possible to limit the synchrotron radiation losses which have a length of 28.7 m. Its iron is divided into five segments for easily fabrication and transportation. The ‘I’ shape core magnet sharing one coil is chosen to save about 50% power consumption and provide two identical field in the twin apertures. In the first and last segments, the dipole-sextupole combined magnet profile are used to reduce the sextupole strength of the individual sextupoles.

Considering the beam energy saw tooth effect, the trim coils are used for both apertures to adjust the field by the order of ±1.5% independently. 2D field simulation results show that the field quality is sensitive to the position of the aluminium busbars and the trim coil in one aperture has no coupling effect in the other aperture. Figure 1 shows the cross section of the dual aperture dipole magnet with and without the sextupole component.

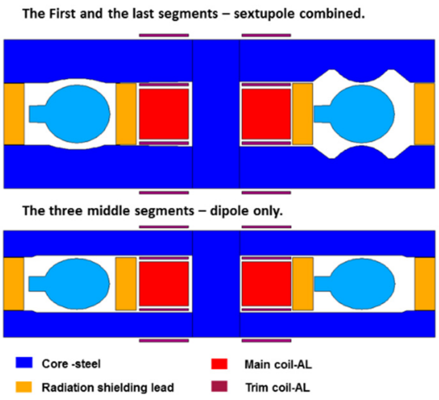

Figure 1: Cross section of the dual aperture dipole.

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Dual Aperture Quadrupole Magnet

The dual aperture quadrupoles have different polarities in the twin apertures. The two apertures sharing two racetrack coils made of hollow aluminium cables, compared to eight coils in two independent single aperture quadruples, can save nearly 50% of power. The dual aperture quadrupole design gives not only mechanical coupling but also magnetic coupling. To reduce the field coupling between the two apertures, a 50 mm gap filled with stainless steel is inserted into the yoke and separates the yoke into two parts. Trim coils in both apertures have ± 1.5% adjustment capability to compensate for the sawtooth effect in beam energy. Figure 2 gives the cross section of the dual aperture quadrupole and Fig. 3 shows the magnetic flux.

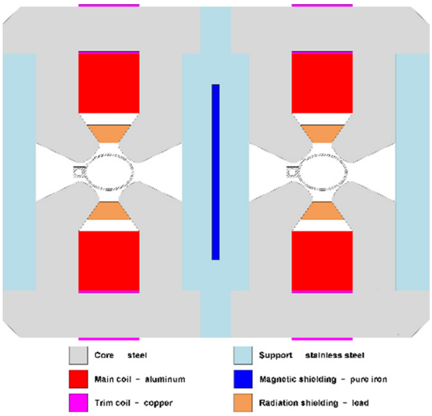

Figure 2: Cross section of the dual aperture quadrupole.

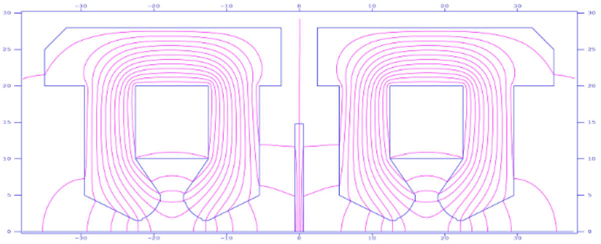

Figure 3: Magnetic flux in the dual aperture quadrupole.

By optimizing the profile of the pole, the systematic harmonics are suppressed to be less than 3×10^{-4}. However, field coupling introduces non-systematic harmonics even if there is a 50 mm gap between the two yokes. To compensate these non-systematic harmonics, a pure iron shielding plate is inserted between the two apertures. Simulation shows that the non-systematic harmonics in both apertures are sensitive to the thickness of the shielding plate. An optimal shielding thickness of 11.52 mm will compensate the non-systematic harmonics and reduce them to close to zero, which does not affect the systematic harmonics in both apertures.

Sextupole SD/SF Magnet

The sextupoles are two individual parallel magnets instead of a dual aperture one. The distance between the e+ and e- beam is quite close; therefore the sextupole size is limited and the space between two neighbouring sextupoles is restricted. Figure 4 shows the cross sections and positions of the sextupoles in the two rings.

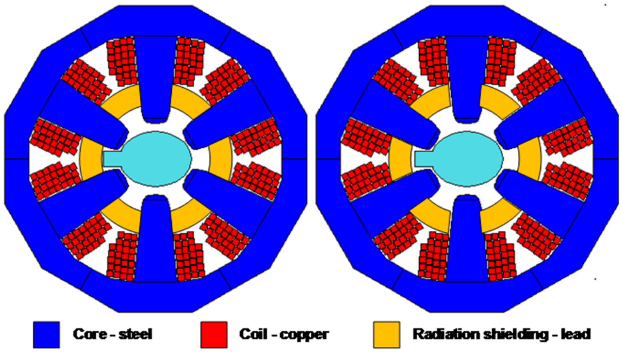

Figure 4: Cross section of two neighbouring sextupoles in the two rings.

Although the two sextupoles are close to each other, the field interference between them is negligible. The pole surface profile is optimized to compensate the harmonics.

BOOSTER MAGNET SYSTEM

The booster has 16320 dipoles, 2036 quadrupoles and 448 sextupoles. The field of the dipole, quadrupole and sextupole magnets will change with the beam energy ranging from 10 GeV to 120 GeV and the field ramping profiled in shown in Fig. 5. The ratio of the maximum field to minimum field of the magnets is 12. The main parameters of the booster ring is represented in Table 2. The dipole magnets have a gap of 63 mm and the aperture diameter of the quadrupoles and sextupoles is 64 mm.

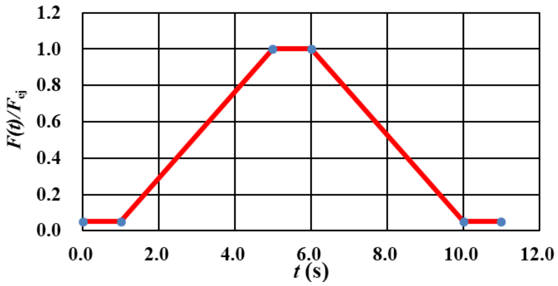

Figure 5: The magnetic field cycle of the booster.

Table 2: Main Parameters of CEPC Booster Magnets

Magnet	**Field strength**	**Magnetic length**	**Width of GFR**
Dipole	0.0338 T	4.7 m	55 mm
Quadrupole	11.07 T/m	1.0 m	28 mm
Sextupole	216 T/m^2	0.4 m	28 mm

Low Field Dipole Magnet

Most dipole magnets are 4.7 m long, the others are 2.4 m and 1.7 m long. The field will change from 29 Gauss to

392 Gauss during acceleration. Due to this very low injection field level, the cores are an H-type structure and composed of a stack of 1 mm thick low carbon steel laminations spaced by 1 mm thick aluminium laminations. Because the magnetic force on the poles is very small, the return yoke of the core can be made as thin as possible. In the pole areas of the laminations, some holes will be stamped to further reduce the weight of the cores as well as to increase the field strength in the stack. The considerations of steel-aluminium core, the thin return yoke and the holes in pole areas can improve the performance of the iron core and considerably reduces the weight and capital cost. Also for economic reasons, the excitation bars are made from 99.5% pure aluminium with a cross section of 30×40 mm^2. Thanks to low Joule loss in the bars, the magnets are cooled by air instead of water.

The integrated field uniformity of the 4.7 m long dipole cores can be optimized within 5×10^{-4} by pole shimming in 2D or end chamfering in 3D. The cross section and magnetic flux of the dipole magnet is shown in Fig. 6.

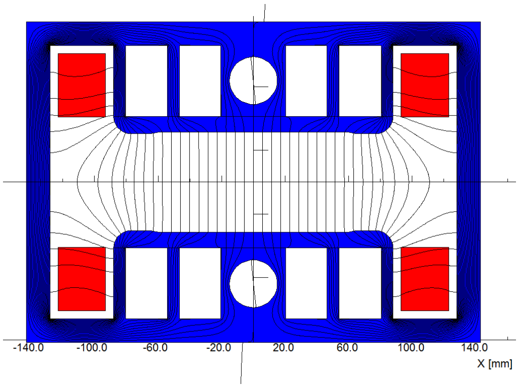

Figure 6: The magnetic flux distribution of the booster dipole magnet.

Quadrupole Magnet

A common design is used for the booster quadrupole magnets. The magnet yoke consists of four pieces (quadrants) made of 0.5 mm thick laminated low carbon silicon steel sheets, which permits installation of the coils between each pole. The assembled magnet can also be split into two halves for vacuum chamber installation. While the hollow aluminium conductor will be chosen for the coil for its lower price and weight. The coil windows leave a certain amount space for radiation shielding blocks.

Due to the length of the magnet is long, 2D magnetic field analysis is sufficient. The pole profiles are designed to introduce positive 12-pole and 20-pole multipole fields to compensate for the end field effects. The cross section and the magnetic flux lines of the quadrupole are shown in Fig. 7.

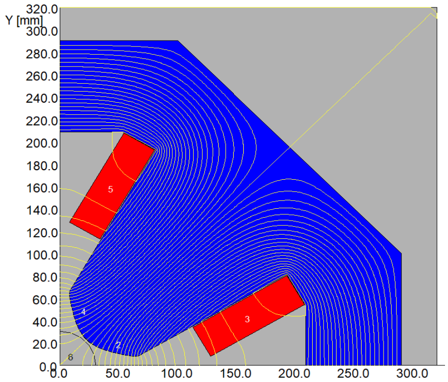

Figure 7: Magnetic flux lines of the booster quadrupole magnet (one quarter).

Sextupole Magnet

The sextupole magnets are divided into two families, focusing or defocusing (horizontal), both of which have the same aperture diameter and magnetic length but have different field strength. The magnetic field will change with the beam energy and the minimum sextupole field strength is 1/12 of the maximum value.

The magnetic core is a two-in-one structure, made of low carbon silicon steel sheets and end plates. By using the end chamfer, the field errors can be reduced to meet the strict field requirements. The coils are wound from solid copper conductors and have a simple racetrack-shaped structure. The cross sections of the sextupole magnets have been designed and optimized using the OPERA-2D and the magnetic flux lines are shown in Fig. 8.

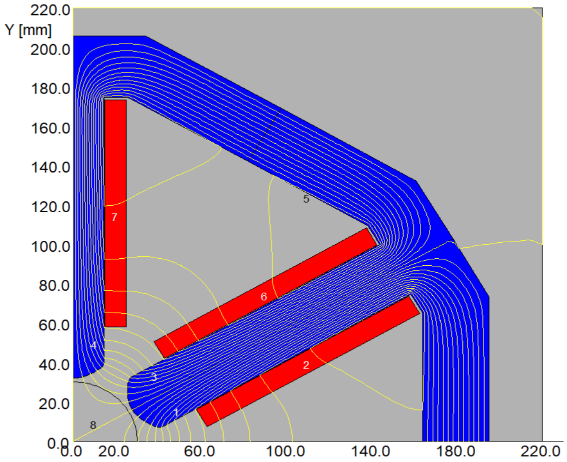

Figure 8: Magnetic flux distribution of the booster sextupole magnet (one quarter).

R&D PLAN

Prior to the construction of CEPC, there will be a five-year R&D period (2018-2022). During this period, prototypes of key technical components will be built.

The field of the dual aperture dipole in the collider is about 140 Gauss at Z mode. The requirements of the field quality is hard to achieve at low field. To study the possible field distortions for Z running, a short prototype of dual aperture dipole will be developed and tested. The dual aperture quadrupole uses the multi-turn coils made of hollow aluminium and a shielding plate to compensate for the non- systematic harmonics. A dual aperture quadrupole prototype will be built to study the crosstalk.

In the booster, one high precision low field dipole prototype will be developed to study the technical issues of design and production. The oriented low carbon silicon steel laminations with lower coercive force will be used to stack the core. Also the design of dipole magnet without core like the superconducting magnets will be considered and prototypes will be tried.

CONCLUSION

Conceptual design of CEPC collider and booster magnets has been finished. The cross section of the main magnets are represented in this paper. Some technical difficulties have been considered and will be further optimized and studied. The prototypes will be built and measured.

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