SUPERCONDUCTING MAGNET DESIGN FOR BEPC-II INTERACTION REGION

Z. Yin, H. Qu, D. Wu, Q. Peng, C. Shi, G. Ni
Institute of High Energy Physics, Beijing, China

Abstract

There are two sets of superconducting magnets in the BEPC-II interaction region.. The magnets are inside the BES detector and nearby the interaction point. The magnet preliminary design was finished. The details of the design which include the coil structure, field calculation, stray field shielding, cryostat design, quench protection, magnet support and installation are discussed in this paper.

1 Layout of BEPC-II Superconducting Magnets

According to lattice design of BEPC-II Double Rings, there are two sets of superconducting magnets in the interaction region. Each set of superconducting magnet includes one quadrupole named SCQ, one anti-solenoid named ASOL and one bending magnet named SCB which used for synchrotron radiation. In order to obtain good results for anti the field of BES solenoid, the ASOL is divided in to two parts, ASOL_1 and ASOL_2. The SCB and SCQ are inside the ASOL_1 and ASOL_2, respectively. The magnets are located symmetrically at the two sides of the interaction point. The overall of the superconducting magnets of BEPC-II Double Rings is shown in Figure 1. The given requirement for the magnets was listed in Table 1.

Table 1 Requirement of superconducting magnets of BEPB-II Double Rings

Parameter	ASOL	SCB	SCQ
Distance to IP	0.6 m	0.6	1.15 m
Magnetic length		0.4 m	0.4 m
Integral Field strength	2.6Tm	0.32252	
Main field strength		0.8063T	G=17.6T/m
Steering dipole			Bx=200Gs
Vacuum tube aperture		∅106	∅120
Maximum diameter	∅280 at SCB, ∅450 at SCQ		

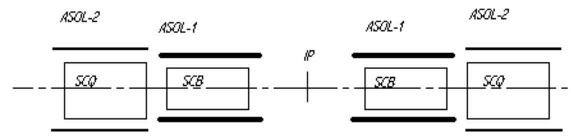


Figure 1 Superconducting Magnets of BEPC-II

2 Coil design

2.1 Basic consideration

The basic considerations in the coil design are as the followings: (1) No iron yoke. The superconducting magnets are located inside the BEPC Spectrometer (BES). There is about 1 T field inside the BES. Any iron yoke around the magnets will be magnetized. Consequently, there are not any iron yoke around the magnets. (2) Separate beam vacuum tube from the magnet to facilitating for installing the beam tube from two side of interaction point. (3) ASOL, SCB and SCQ are installed in same cryostat to easy for supporting and for installing the magnets into BES detector**.** (4)Use the same kind of NbTi supercunducting cable in the all of coil design to simplify superconducting cable selection. The cable is round with diameter ∅1.09 mm.

2.2 Coil Design for SCQ

The SCQ magnet is located inside the ASOL-2. The field gradient in the aperture is 17. 6 T /m and its magnetic length is 0.4 m. The requirement of field quality in the useful field region is B_n/B_2 (at R=43 mm)≤ 1×10^{-4}.

(a) Coil composition of SCQ

The SCQ coils are composed of a quadrupole coil and a vertical steering dipole coil. The quadrupole coil is inner coil. The steering dipole coil is beside the quadrupole coil. Both quadrupole coil and steering dipole coil are a set of cylindrical current shell with the angular wedges. The cross section of SCQ is shown in Figure 2.

(b) Coil structure parameters

The Figure 2 shows the SCQ cylindrical current shells with the angular wedges. This kind of coil structure is simple for the coil winding. If the parameters design is suitable, the field quality in the useful field region will be good enough.

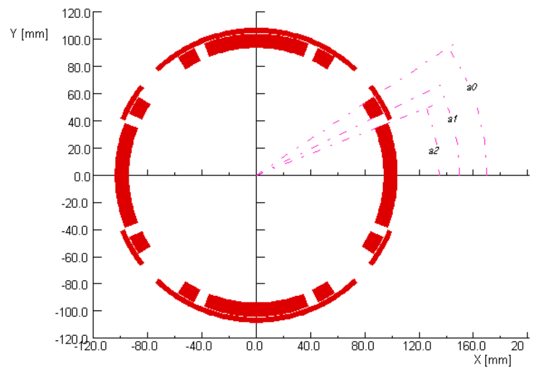


Figure 2 Cross section of SCQ

Assume that the current shell angular is *a0*, the wedge angular are *a1* and *a2* (see fig. 3) and the current shell have the inner radius R_i and the outer radius R_o. The current density is *J*. Then the quadrupole field B_2

$$B_2 = \frac{2\mu_0 J R_{ref}}{\pi}\ln(\frac{R_o}{R_i})[\sin 2a_0 - \sin 2a_1 + \sin 2a_2]$$

If set a_0=33.63765, a_1=26.0763, and a_2=21.58955 for quadrupole coil, the high order field produced by the coils will be $B_6=B_{10}=B_{14}=0$ [1)]. In the SCQ design, we set a_0=33.6°, a_1=26.1° and a_2=21.6°. For the steering dipole coil, In the same way, the quadrupole field B_1

$$B_1 = \frac{2\mu_0 J}{\pi}(R_o - R_i)[\sin a_0 - \sin a_1 + \sin a_2]$$

In order to obtain B3=B5=B7=0, then need to set a_0=67.2753, a_1=52.1526, and a_2=43.1791. In a similar fashion, set a_0=67.1°, a_1=52.2° and a_2=43.2° then rotating a angular of 90° were selected for the vertical correction dipole coil. The quadrupole coils of SCQ have 3 double layers of conductor and its thickness is about 9.9 mm. The inner diameter of the SCQ quadrupole coil is ∅188mm and the outer diameter is ∅207.8mm. The steering dipole coils have one double layer with inner diameter of ∅210 mm and outer diameter of ∅216.6mm.

(c) Field quality of SCQ

The magnetic field distribution in two dimensions was calculated by using program OPERA-2D. When the current density in the coil is 223A/mm^2 (the excitation current is 496 A) the field gradient at the center is 17.6 T/m. The maximum flux density in the coil is 2.26 T. The ratio of the operating current with respect to the

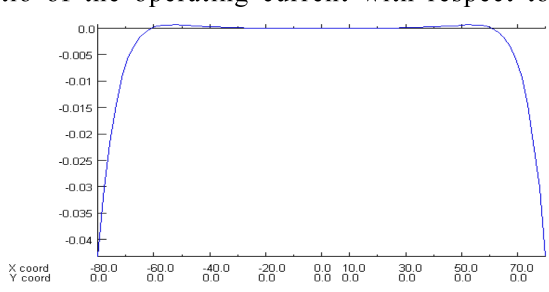


Figure 3 Field gradient error distribution of SCQ

cable critical current (I_{op}/I_c) is 60%. From Figure3, the field quality in the useful field region is good enough. In the useful field region (R≤43 mm), the field gradient error is less than 1×10^{-3}. For SCQ with the simple coil head, the magnetic field distribution in three dimensions was calculated by using a 3D-program. The field distributions along *z*-axis are shown in Figure 4. When the length of the coil straight section is 308.55 mm, the field effective length is 400 mm.

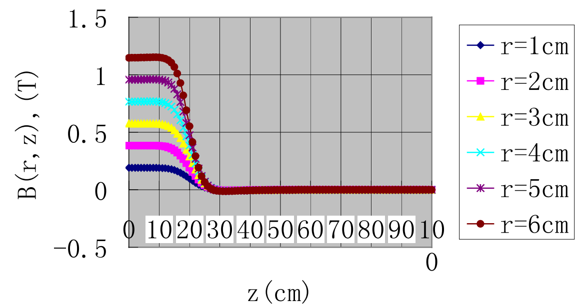


Figure 4 The SCQ field distributions in three dimensions

For the field produced by steering dipole coil, when the current density is 10A/mm^2 the field *B*x at the center is 200 Gs.

2.3 Coil Design for SCB

The superconducting bending magnet used for synchrotron radiation (SCB) is located inside the ASOL-1. The field strength *By* in the aperture is 0.8063 T and its magnetic length is 0.4 m. The requirements of field quality in the useful field region is $B_n/B_1 \le 1\times10^{-4}$.

(a) Coil structure

In the SCB design, set a_0=67.1°, a_1=52.2° and a_2=43.2°. The SCB coils have 2 double layers of conductor and its thickness is about 6.6 mm. The inner diameter of the SCB coil is ∅188 mm which is as the same as the SCQ. Its outer diameter is ∅201.2 mm.

(b) Field quality

The field distribution produced by SCB coil is shown in Figure 5. When the current density is 180.1A/mm^2 the

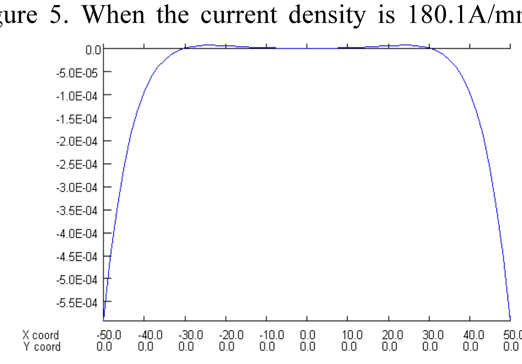


Figure 5 Field distribution of SCB

field *B*x at the center is 8063 Gs. In the useful field region of 76 mm, the field relative error Δ*B*/*B*o are less then 1×10^{-4}. The excitation current is 327.8 A. The maximum flux density in the coil is 1.3T. The I / Ic is 40%.

2.4 Coil Design for Anti-Solenoid

The requirements of the Anti-Solenoid (ASOL) are as the followings: (1) Its integral field will be anti the integral field of BES solenoid. (2) Shielding the detector field in the SCQ region. The field distribution of the BES solenoid is uniform in the center region, but it drops down intensively in the SCQ region. So we need to use a special shape of anti solenoid coil to achieve above two requirements. Figure 6 shows the coil structure of ASOL inside BES detector and is field flux map. The ASOL coil consist of two solenoid parts. One part is main solenoid named ASOL-1 located outside the SCB. Its thickness is 9.9 mm (3 double layers of conductor). Considering the space of the SCB, the inner diameter of the ASOL-1 coil is ∅204 mm and its outer diameter is ∅223.8mm. Another part of the ASOL is a shield solenoid named ASOL-2. It locates outside the SCQ. Also, considering the SCQ space, the inner diameter of the ASOL-2 coil is ∅220 mm and its outer diameter is ∅226.6mm. The ASOL-2 coil have 1 double layers of conductor and its thickness is about 3.3 mm. In order to shield the BES field in SCQ region well, the ASOL-2 coil is divided to two parts. One part nearby ASOL-1 is longer than another part.

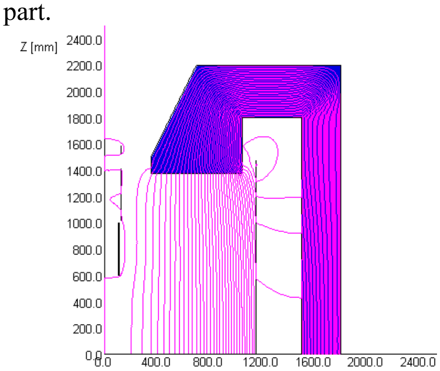


Figure 6 The ASOL coil structure and field distribution

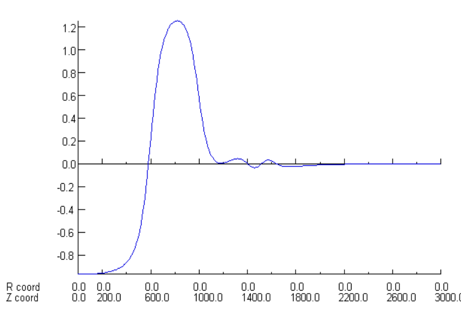


Figure 7 ASOL field distribution along z-axis

The field produced by both ASOL coils and BES detector solenoid are shown in Figure 6. Figure 7 shows the field distribution along the z-axis. When the current density in ASOL coils is 200.6 A/mm^2, the integral field of ASOL is just anti the BES integral field. Within the SCQ region, the field become to very low, less than ±300 Gs.

3 Magnet Structure

The whole structure of the superconducting magnet is shown in Figure 8. The SCQ, SRB and ASOL coils are installed in one cryostat. The structure keep the magnet separated from beam vacuum tube to facilitating for installing the beam tube from two side of interaction point. The SCQ and SRB are winding on the same diameter size of supporting tube.

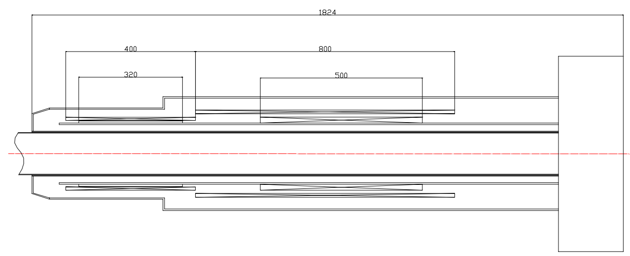
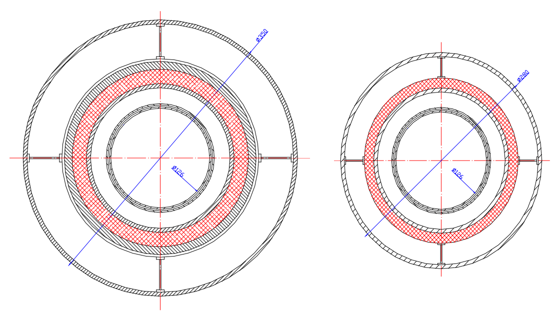


Figure 8 Whole structure of the superconducting magnet

The Cross section of the magnet at SCQ1 and SSOL is shown in Figure 13. The beam tube shape in the magnet is round with inner diameter of ∅126 mm and outer diameter of ∅130 mm. The coil support tube is round with outer radius of ∅188 mm and with thickness of 6 mm. The SCQ1 quadrupole coil and steering dipole coil are winded round the support tube. The shield solenoid coil (SSOL) is winded round another support tube with diameter of ∅244 mm. The maximum diameter of SCQ1 magnet is ∅350 mm.



(a) Cross section at SCQ1. (b) Cross section at SCB

Figure 9 Cross section of the SC magnet

The Cross section of the magnet at SCB and SCQ is shown in Figure 9. The maximum diameter of the magnet here is ∅280 mm.

REFERENCES

[1] Mini-workshop, lecture by Dr. Brett Parker, BNL, IHEP, Beijing, Oct. 2000

[2] Arnaud Devred, 1999 Review of superconducting dipole and quadrupole magnets for Particle Accelerators.