SOLENOID FIELD CALCULATION OF THE SUPERKEKB INTERACTION REGION *

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Abstract

The construction of SuperKEKB started from 2011. The design of the superconducting magnets in the interaction region is going with optimization of beam optics. The 3D model for calculating the solenoid field profile along each beam line has been developed. The calculated field profiles have already been involved in the calculations of the beam optics and the beam background noise.

INTRODUCTION

SuperKEKB is the upgrade accelerator of the KEKB B-Factory [1]. The target of SuperKEKB is 40 times higher luminosity of 8×10^{35} $cm^{-2}s^{-1}$ than that of KEKB. The 7 GeV electron beam in the high-energy ring (HER) and the 4 GeV positron beam in the low-energy ring (LER) collide at one interaction point, IP, with a finite crossing angle of 83 mrad. The final focusing system consists of the incoming and outgoing superconducting quadrupole doublets for each beam, 4 compensation solenoids and 40 correctors. The designs of quadrupole magnets are almost completed [2], and the superconducting correctors are now being designed by BNL under the international research collaboration [3]. The compensation solenoids are still being designed with the 2D and 3D calculations. In this paper, we report mainly the magnetic field calculations of the compensation solenoids.

IR SUPERCONDUCTING MAGNET SYSTEM

The interaction region, IR, of SuperKEKB is shown by Figure 1. The superconducting magnets are assembled into the two cryostats, QCS-L and QCS-R, and the assembled cryostats are installed inside of the Belle detector [4]. The superconducting magnet system consists of 8 main quadrupoles, 4 compensation solenoids and 40 correctors. The magnet parameters of the quadrupoles are shown in Table 1. In the table, the field gradients and the magnetic lengths are listed, and the locations of the quadrupole magnetic centers from the interaction point, IP, are shown. QC1LP and QC1RP have not iron yoke while the other quadrupoles have the iron yokes. The quadrupoles have four types of superconducting correctors of a_1, b_1, a_2 and b_4. The magnets and coils are designed to be operated under the magnetic field at 1.5 T by the superconducting solenoid of the Belle detector. This solenoid field produces the large X-Y coupling and the beam kicks by the fringe field because of the large beam crossing angle of 83 mrad. In order to cancel the integral solenoid field, one and three compensation solenoids in the left and the right side, respectively, are designed to be installed in the IR.

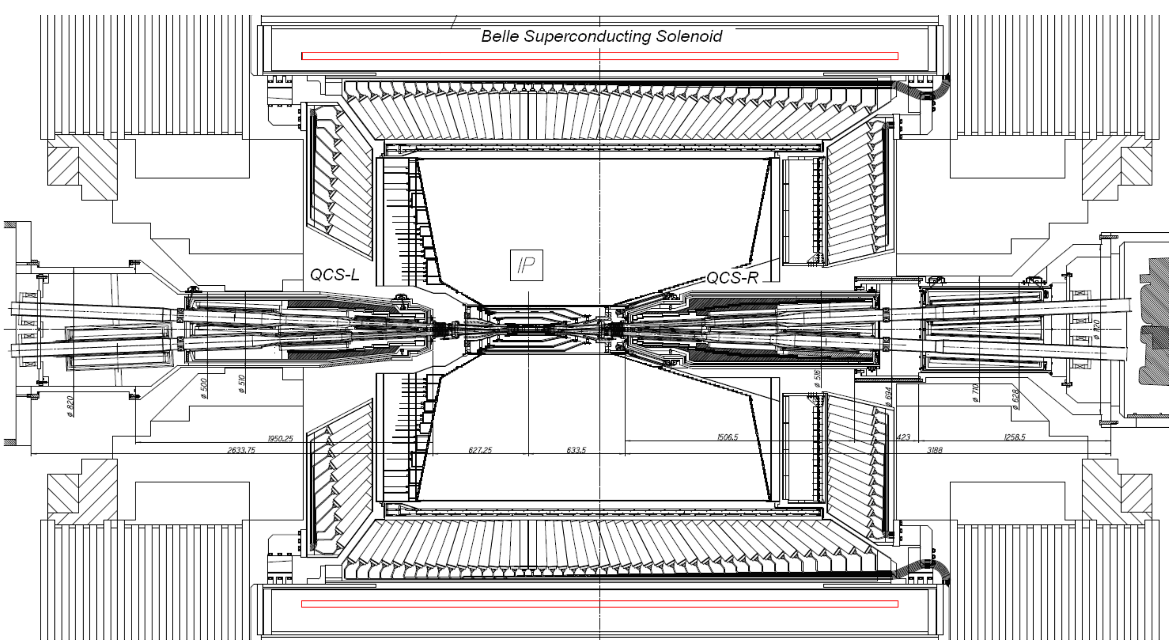

Figure 1: Interaction region of the SuperKEKB. The two cryostats, QCS-L and QCS-R, are assembled inside of the Belle detector. The superconducting solenoid of the Belle detector is shown by the red rectangles.

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Table 1: Magnet Parameters of Main Quadrupoles

Magnets	*G*, T/m	*L*, m	Location, m
QC1LP / RP	67.94 / 66.52	0.337	-0.932/+0.932
QC2LP / RP	27.15 / 27.17	0.414	-1.930/+1.956
QC1LE / RE	70.68 / 66.22	0.377	-1.410/+1.410
QC2LE / RE	24.24 / 34.90	0.60 / 0.37	-2.700/+2.925

Figures 2 and 3 show the cross sections of the cryostats in the felt and right side with respect to IP, respectively. In the left cryostat, QCS-L, the helium vessel is divided into two containers. The compensation solenoid is assembled in the helium vessel close to IP, as shown with the blue boxes. The solenoid has QC1LP and QC1LE with iron yoke within the magnet bore. At the longitudinal position of QC2LP, the both beam lines are covered with the iron block. In Figure 2, material of the red components corresponds to iron. Along the beam lines at QC1LE, the compensation solenoid cancels out the solenoid field profile by Belle, and the remaining field is shielded by the iron components. In the iron components, the magnetic fluxes are designed to be less than 0.5 T. QC2LP is shielded only with the iron block because the extension of the compensation solenoid onto QC2LP leads to extreme increase of electro-magnetic force, EMF, over 1×10^5 N in the axial direction.

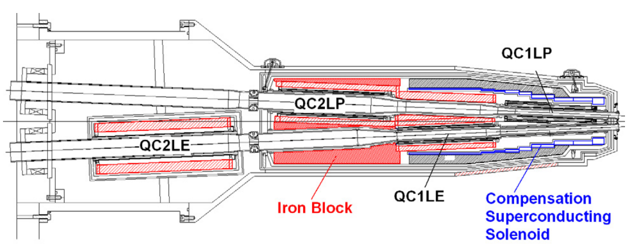

Figure 2: QCS-L cryostat cross section. The blue components are the compensation solenoid, and the red components are iron yokes and blocks.

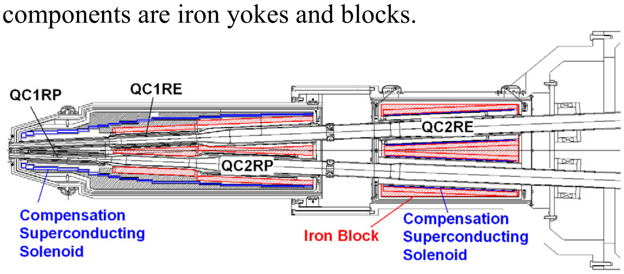

Figure 3: QCS-R cryostat cross section. The compensation solenoids are separated into three parts: the one covers QC1RP, QC1RE and QC2RP, the others are installed on HER/LER beam lines for QC2RE.

In the right side, the cryostat, QCS-R, is installed closer to the Belle center than the QCS-L cryostat. The compensation solenoid covers QC1RP, QC1RE and QC2RP. The remaining field for QC1RE and QC2RP is shielded with the iron components as same as the QCS-L. From the request of beam operation, beam monitors will be installed between QC2RP and QC2RE, and therefore QC2RE is assembled in the separate helium vessel. Since the area between QC2RP and QC2RE is not shielded with magnetic material, the solenoid field by the Belle detector penetrates in this area. For cancelling this solenoid field, the weak compensation solenoid for each beam is designed within the bore of the iron components for QC2RE.

MAGNETIC FIELD CALCULATION IN 2D

The calculation model in 2D was constructed with ANSYS [5]. The model has a cylindrical symmetry. As the result, the model was assumed to have one beam line on the Belle axis. The calculated field profile along the Belle axis is shown in Fig. 4. The Belle solenoid generates the magnetic field at 1.5 T. In calculation, the integral solenoid fields of $-1.2<z<0$ and $0<z<1.2$ are forced to be zero, respectively, by the compensation solenoids. Between QC2RP and QC2RE, there exists a solenoid field bump, where the peak is 0.56 T. This solenoid field is integrally cancelled with the opposite field at 0.3 T by the compensation solenoid in QC2RE.

The parameters of the compensation solenoid are listed in Table 2. The operating currents, I_{op}, to the critical current, I_c, at 4.7 K are less than 72 %, and these solenoids have sufficient margin for operation.

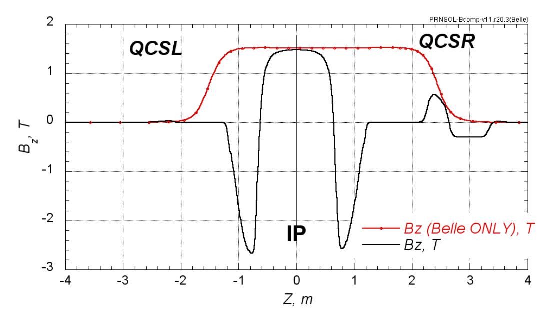

Figure 4: B_z profile along the Belle axis in the interaction region by 2D calculation. The black line is the B_z profile with all components in the IR. The red line corresponds to the B_z profile only by the Belle solenoid without the accelerator components.

Table 2: Magnet Parameters of Compensation Solenoids

Solenoid	Max. field, T	I_{op}, A	I_{op} to I_c, %
QCS-L	3.6	348	68
QCS-RF	3.3	462	72
QCS-RR	0.3	210	<20

QCS-RF: compensation solenoid for QC1RP, QC1LP, QC2RP, and QCS-RR: compensation solenoid for QC2RE. I_{op} is the operation current, and I_c is the critical current of the superconductor.

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Table 3: Electro-Magnetic Forces on Solenoids and Irons

	Excitation	EMF on Sol., N	EMF on Iron, N	Total, N
QCS-R	ON	3.58×10^4	-0.60×10^4	2.98×10^4
	OFF	0	-2.37×10^4	-2.37×10^4
QCS-L	ON	-4.69×10^4	0.42×10^4	-4.27×10^4
	OFF	0	8.04×10^4	8.04×10^4

The electro-magnetic forces on the solenoids and iron components were calculated, and the results are shown in Table 3. For QCS-R, the EMF on the excited solenoid coil was calculated to be 3.58×10^4 N and this EMF pushes the solenoid out from the IP. When the solenoid is not excited, the EMF acts on the iron components and pulls them into the IP. In case of the solenoid quench, the EMF on the cryostat changes very quickly from 2.98×10^4 N to -2.37×10^4 N. For QCS-L, the EMF change at quench is more severe and it swings from -4.27×10^4 N to 8.04×10^4 N.

MAGNETIC FIELD CALCULATION IN 3D

The 3D model for calculating the magnetic field profile along two beam lines has been constructed with ANSYS, as shown in Fig. 5. The calculations were done by the half model because the IR system has symmetry with respect to the horizontal plane. The IR model consists of 25 million elements, and it took 30 hours to calculate one problem with the 8-CPU computer.

The calculated field profiles along the HER and LER beams are shown in Figs. 6 and 7, respectively. The B_z components for HER and LER have the almost same profile along the beam line while the B_r components have the opposite sign. Because the beam lines locate on the horizontal plane, the B_θ components are zero.

By comparison between the 2D and 3D calculations, the negative peaks of the solenoid field profile in the right and the left sides of the IP by the 2D model are -2.57 T and -2.67 T, respectively, and by the 3D calculation, they are -2.44 T and -2.41 T. The solenoid bump field between QC2RP and QC2RE shows the peak of 0.56 T and 0.71 T by 2D and 3D models, respectively.

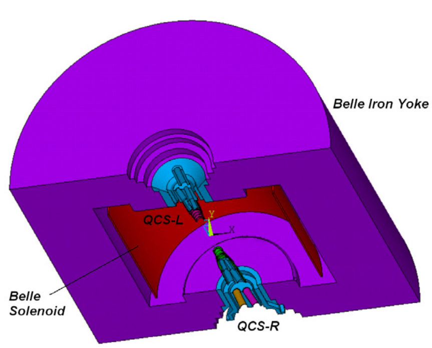

Figure 5: 3D model of the solenoids and iron components in the IR by ANSYS.

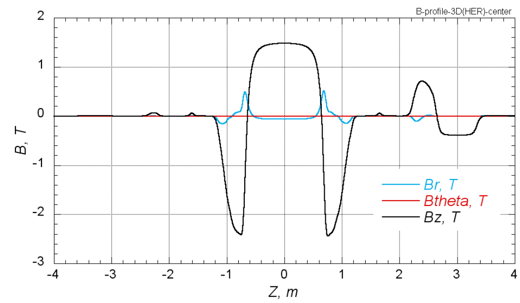

Figure 6: Magnetic field profile along the HER beam line.

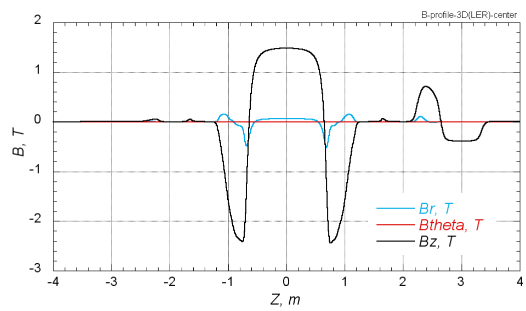

Figure 7: Magnetic field profile along the LER beam line.

The 3D magnetic field profile in the IR has been calculated by ANSYS, and we are constructing the 3D model by OPERA [6]. We will compare the calculations between these models by ANSYS and OPERA.

CONCLUSION

The solenoid field profile in the SuperKEKB interaction region has been computed by the 2D and 3D models. These calculation data are already set in the calculations of the beam optics and the beam background noise to Belle.

ACKNOWLEDGMENT

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REFERENCES

[1] M. E. Biagini., "Overview of B Factories," this conference, WEYA03; http://www.JACoW.org
[2] M. Tawada et al., "Design Study of Final Focusing Superconducting Magnets for the SuperKEKB," IPAC'11, San Sebastian, September 2011, WEPO027, p. 2457 (2011); http://www.JACoW.org
[3] B. Parker et al., "Direct Wind Superconducting Corrector Magnets for The SuperKEKB IR," this conference, WEEPPB013; http://www.JACoW.org
[4] Z. Dolezal and S. Uno, "Belle II Technical Design Report," KEK Report 2010-1, July (2010).
[5] ANSYS is trademark by CYBERNET. Inc.
[6] OPERA is trademark by Cobham plc.