FIELD QUALITY OF THE FINAL-FOCUS SUPERCONDUCTING MAGNETS FOR KEKB INTERACTION REGION

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Abstract

The final field measurements at the interaction region of the KEKB accelerator were carried out to measure the field profile, which was generated by compensation solenoids, final focus quadrupoles and trim coils. At the operation current, the solenoids generated the fields of 4.68 T for the left side and 5.85 T for the right side of the interaction point. The field gradient of the quadrupoles was 22.1 T/m at 3 kA. The multipole coefficients were less than 1×10^{-4} at the radius of 40 mm.

1 INTRODUCTION

In the interaction region of KEKB accelerator, the superconducting magnet system consists of compensation solenoids (S-R, S-L), final focus quadrupoles (QCS-R, QCS-L), and six trim coils; vertical steerings (SD-R, SD-L), horizontal steerings (ND-R, ND-L), and skew quadrupoles (SQ-R, SQ-L) [1,2]. First, the magnets were tested as an acceptance test in the vertical cryostat [3]. After the installation of the superconducting magnet system into the interaction region, the magnetic field measurements were performed in order to get information of the field profile along the beam line, the magnet alignment and the field quality of the magnets. The magnets were placed inside the Belle detector, and the measured results contain the effect of the detector on the magnetic field. The paper summarizes the results of these measurements.

2 FIELD MEASUREMENT SYSTEM

For the measurements, two harmonic coils and a Hall probe were used. Two harmonic coils were 50 mm long and 800 mm long for the field mapping along the magnet axis and for the measurement of the integral field, respectively. The radii of the harmonic coils are 40 mm. The cross sections of the coils are the same and the coils consist of 7 windings [3]. The dimensions of the harmonic coils were calibrated by a normal dipole and quadrupole magnets. The azimuthal positions of the coils to the quadrupole field were calibrated by the normal quadrupole magnet. The Hall probe, which was calibrated by the NMR, was used to measure the solenoid field which was generated by the S-R, S-L and Belle detector solenoid [4].

Fig. 1 shows the 50 mm long harmonic coil which is set in the cryostat at the interaction region. The harmonic coils were inserted into a brass pipe which was aligned to the beam line. The 50 mm long harmonic coil was moved along the pipe to measure the field profile along the beam line. The measurement system contained an angular encoder, a tilt sensor, a position sensor, a moving mechanism and a computer for data acquisition. The angular encoder and the tilt sensor defined the azimuthal position of the mid-plane of the QCSs along the beam line. The revolution speed of the coils was 1 Hz. For the magnet in the right side, the harmonic coil center was aligned to the magnet axis. For the left side, the QCS-L axis was horizontally shifted 35.1 mm from the S-L axis. The harmonic coil was aligned to the S-L axis, therefore the harmonic coil center was horizontally shifted 35.1 mm from the QCS-L axis.

The Hall probe was inserted into the brass pipe and aligned to the pipe center to measure the solenoid field distribution along the beam line.

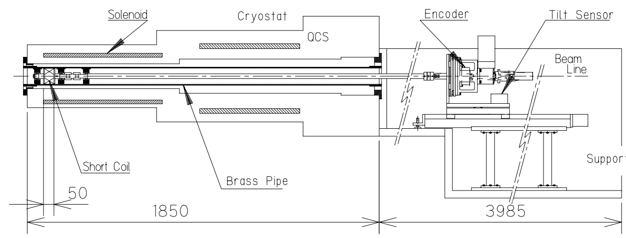

Figure 1: Magnetic field measurement system.

3 FIELD MEASUREMENTS

3.1 Multipole Expansion

The two-dimensional magnetic field can be represented by a multipole expansion as follows,

$$B_y + i\,B_x = \sum_{n=1}^{\infty}\left(B_n + i\,A_n\right)\left(\left(x+iy\right)/R\right)^{n-1} \quad , \quad (1)$$

where the origin of the x-y coordinate system is at the magnet axis. B_x and B_y are the x and y components of the field, and B_n and A_n are normal and skew components. R is the reference radius, and we chose the dimension of 40 mm as the harmonic coil radius. The radius corresponds to 30.8 % of the QCS coil inner radius.

3.2 Integral Field Quality

The integral fields of the QCSs and trim coils were measured by the 800 mm long harmonic coil. The results are summarized in Table 1 including the azimuthal positions of the mid-planes of the coils. The coil currents were 3 kA and 50 A for the QCSs and the trim coils, respectively. The GLs of the QCSs were 8.55 T/m•m and 10.72 T/m•m. The measured field gradients of the QCS-R and the QCS-L were 22.06 T/m and 22.05 T/m, and then the effective lengths are 0.388 m and 0.486 m. The integral fields of the SQs correspond to the angle change of 12.4 mradian and 9.9 mradian for the QCS-R and the QCS-L, respectively. The fields of the steerings produced the quadrupole center shift of 3.0 mm and 2.4 mm for the QCS-R and the QCS-L, respectively.

The QCSs were installed in the cryostats so that the mid-planes of the QCSs had a tilt to the horizontal plane. The design was -33.16 mradian for the QCS-R and 10.47 mradian for the QCS-L. As shown in Table 1, the alignment errors of the QCSs were less than 2.5 mradian, and the errors will be corrected by the SQs. The positions of trim coils are represented as the angles from the mid-planes of the QCSs. The mid-planes of the trim coils were designed to be aligned to those of the QCSs.

The higher multipole coefficients of QCSs are summarized in Table 2. In Table 2, skew and normal coefficients are defined by Eqs. 2 and 3,

$$b_n = B_n / B_2 \quad , \qquad (2)$$
$$a_n = A_n / B_2 \quad . \qquad (3)$$

The measurement were performed under the condition that the S-R, S-L and Belle solenoid were energized to the specific current. The centering correction of the harmonic coil to the quadrupole center are not processed on the results. The octupole coefficient of QCS-L , b_4 , was 1.02 $\times10^{-4}$ and the other multipole coefficients were less than 1.0×10^{-4}.

Table 1: GL, BL and mid-plane position

	GL or BL (T/m•m or Tm)		Mid-plane Position (mradian)	
	R-side	L-side	R-side	L-side
QCS	8.550	10.72	-35.6	10.8
SQ	0.212	0.212	-27.4	0.22
ND	0.025	0.026	3.85	4.59
SD	0.025	0.025	-13.0	1.57

Table 2: Multipole coefficients of QCSs

	QCS-R		QCS-L	
n	a_n	b_n	a_n	b_n
3	-0.46	0.87	-0.36	-0.18
4	0.31	0.46	-0.43	-1.02
5	-0.08	-0.04	0.07	-0.93
6	-0.05	-0.04	0.06	-0.57
7	0.01	-0.01	0.03	-0.42
8	-0.01	0.01	0.01	-0.31
9	0.01	0.00	0.02	-0.22
10	-0.01	-0.01	0.01	-0.15

3.2 Multipole Field Profiles along the Beam Line

The multipole profiles along the accelerator beam line were measured by the 50 mm long harmonic coil. The measurements were taken every 1 cm. Figs. 2 - 6 show the typical field profiles of the results. The measurement and calculation are represented by the circle symbol and the solid line, respectively. The position of x=0 corresponds to the interaction point. The QCS-R and the QCS-L exist 1672 mm<x<2198 mm and -1912 mm<x<-1288 mm. The multipole coefficients are shown as the ratio to the quarupole components at the centers of the QCSs.

Figs. 3 and 4 show the profiles of b_2 along the beam line. The quadrupole components of the QCSs have no flat region because the QCS-R and the QCS-L have the short straight sections of 200 mm and 300 mm compared to the coil inner-radius of 130 mm. Fig. 2 shows the profile of b_1 for the right side. At the end of the S-R, whose location was 851 mm<x<1475 mm, a peak of b_1 was measured. This was due to the off-center of the harmonic coil from the S-R axis. From the peak value, the off-center was estimated to be 1.2 mm in the vertical direction. We evaluated the alignment errors of the magnet-cryostats to the beam line from the dipole profile. The errors will be corrected by the realignment of the magnet-cryostats.

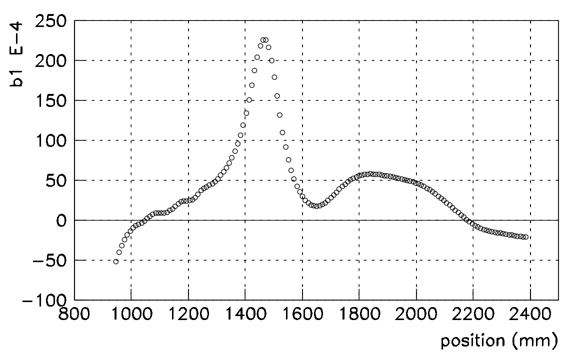

Figure 2: b_1 profile for the right side.

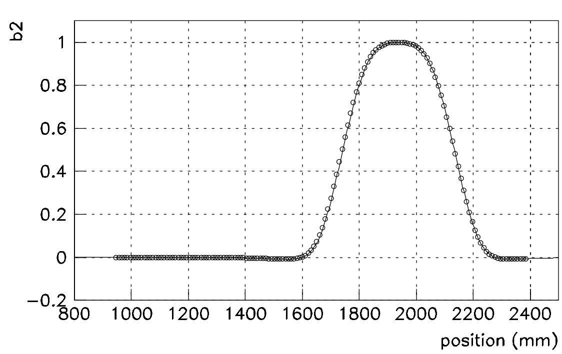

Figure 3: b_2 profile for the right side.

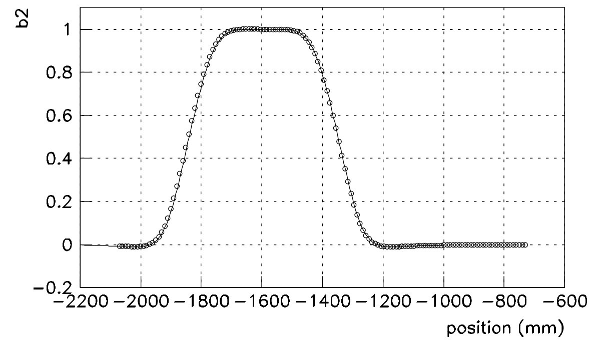

Figure 4: b_2 profile for the left side.

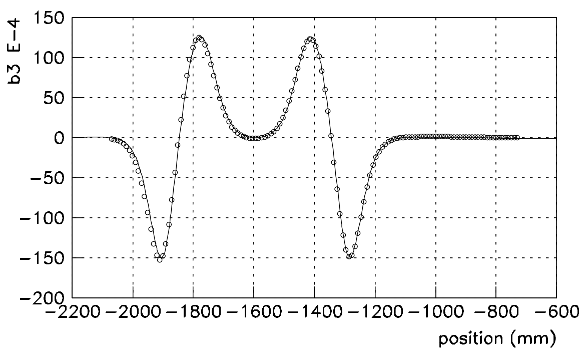

Figure 5: b_3 profile for the left side.

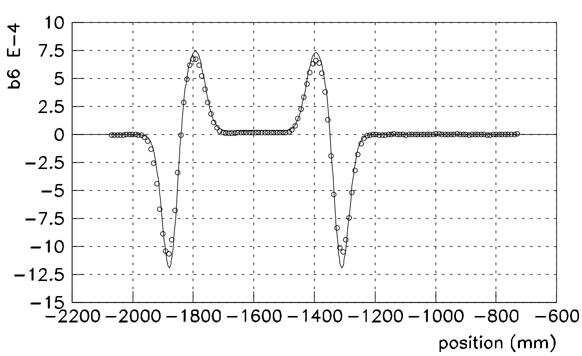

Figure 6: b_6 profile for the left side.

Fig. 5 shows the b_3 profile along the beam line for the left side. The measurements were in good agreement with the calculations. The peaks reached 1.5×10^{-2}, however, the integral b_3 was -0.18×10^{-4} as shown in Table 2. The sextupole component was generated by the end regions of the QCS-L coil because the harmonic coil was shifted 35.1 mm to the QCS-L axis.

Fig. 6 shows the b_6 profile. The b_6 reached 10.5×10^{-4} for the QCS-L, and the b_6 for the QCS-R was 5.3×10^{-4}. The measured profile was in good agreement with the calculations.

3.2 B_z Distribution along the Beam Line

Fig. 7 shows the B_z distribution along the beam line with and without the operation of the Belle solenoid. In the figure, the calculation results are shown, too. Without the Belle solenoid, the S-R produced the B_z component of 5.85 T at 608 A and the S-L produced 4.68 T at 503A. When the Belle solenoid was energized to the specific current, the measured B_z component were 4.35 T and 3.27 T for the S-R and the S-L, respectively. The Belle solenoid produced the central field of 1.50 T, whose direction was opposite.

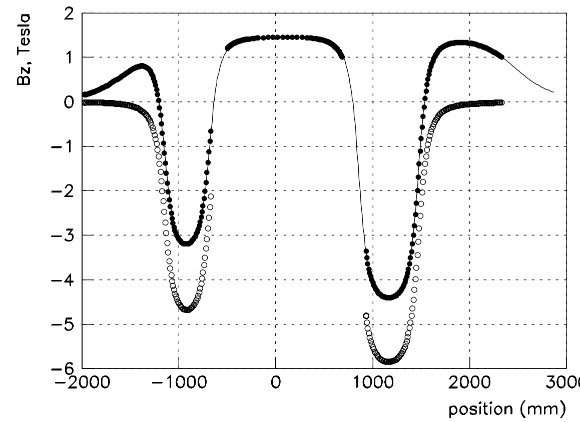

Figure 7: B_z distribution along the beam line. The open circle and the closed circle symbols correspond to the operations without and with the Belle solenoid, respectively. The solid line is the calculation.

4 CONCLUSION

1) The QCS-R and the QCS-L generated the GLs of 8.55 T/m•m and 10.72 T/m•m at the specific current, respectively. The multipole coefficients were less than 1×10^{-4} at the radius of 40 mm. The QCSs had alignment errors, and the errors can be corrected by the trim coils.

2) The multipole field profiles along the beam line were measured by the 50 mm long harmonic coil. The results were well agreed with the calculations.

3) The B_z profile along the beam line was measured by the Hall probe and compared with the calculation result.

5 ACKNOWLEDGMENT

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