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MAGNETIC FIELD MEASUREMENT SYSTEM FOR THE SUPERKEKB FINAL FOCUS SUPERCONDUCTING MAGNETS

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Abstract

SuperKEKB final beam focusing system consists of different types of superconducting magnets: 8 quadrupole magnets, 4 solenoids and 43 corrector coils. In order to measure the field performances of the magnets and the coils, KEK prepared one set of harmonic coil system during the production stage in a factory, and two sets of harmonic coil systems for the cold tests at 4K for the vertical cryostat test stand in KEK. In this paper, we report these magnetic field measurement systems.

INTRODUCTION

SuperKEKB are now being constructed with a target luminosity of 8×10^{35} which is 40 times higher than KEKB [1]. This luminosity can be achieved by the "Nano-Beam" scheme, in which e- and e+ beams should be squeezed to about 50 nm at the beam interaction point. The final beam focusing system consists of the superconducting quadrupole doublets for each beam [2], and the quadrupole magnets are designed to have error field components less than 1×10^{-4} with respect to the quadrupole field integrally. From the field measurement results of the QC1P and QC1E proto-type magnets, the sextupole field at the level of 1×10^{-3} of the quadrupole field was measured and the reason of the sextupole field was due to the dipole deformation of the four quadrant coils [3]. The beam optics calculation showed that the sextupole field strongly degraded the Touschek beam lifetime, and as the result, the sextupole corrector coils were decided to be installed into the cryostat in the right side. From the above studies, the following field measurement processes are approached: 1) During the production stage in a factory, the integral field quality of the magnet is measured at the room temperature to confirm the sextupole field components less than 1×10^{-3}, 2) As the next step, the magnets are measured at 4K with the vertical cryostat in KEK, and 3) Finally, the magnet-cryostats are measured on the beam lines. In this paper, the magnetic field measurement systems at the factory and with the vertical cryostat in KEK are reported.

QUADRUPOLE MAGNETS

The 8 superconducting quadrupole magnets, which have 4 different cross sections, were designed to be installed into the SuperKEKB interaction region. The parameters of the magnets are listed in Table 1. The QC2LE and QC2RE magnets have the same design of the magnet cross section, but the physical magnet lengths are different. The reference radius is different for each magnet from the requirement of the beam optics.

Table 1: Parameters of the Quadrupole Magnets

Magnet	I.R./O.R., mm	L_{eff}, mm	R_{ref}, mm	G, T/m	I_D, kA
QC1L/RP	25.0/35.5	0.334	10	76.4	1.8
QC1L/RE	33.0/70.0	0.373	15	91.6	2.0
QC2L/RP	53.8/93.0	0.410	30	32.0	1.0
QC2LE	59.3/115.0	0.537	35	36.4	1.25
QC2RE	59.3/115.0	0.410	35	40.9	1.35

In the table, I.R. and O.R.= inner and outer radius of the magnet respectively, L_{eff} = effective magnetic length, R_{ref} = reference radius, G_D= design field gradient, I_D= design current.

FIELD MEASUREMENT SYSTEM

Harmonic Coil System in a Factory

The magnetic field measurements in a factory are performed to measure the sextupole fields of the quadrupole magnets during the collaring process and the mid-plane field angles of the quadrupole magnet and the corrector coils after assembling them together. The 1 m long harmonic coil system was constructed for measuring all magnets and coils. Because of the constraints of their inner bores, the harmonic coil radius of 14.5 mm was designed. The harmonic coil consists of a tangential coil, a dipole coil and a quadrupole coil. The dipole and quadrupole coils are used for an analog bucking process. The harmonic coil parameters, which were calibrated with the normal standard magnets [4], are listed in Table 2.

Table 2: Parameters of the Harmonic Coil in a Factory

	R	ϕ	*P*	*L*	*N*	*B.R.*
T	14.5	23.186	0.0	998	100	–
D	14.59	180	-0.638	1000	10	65
Q	14.59	90	+0.533	1000	10	33

In the table, T, D and Q=tangential, dipole and quadrupole coil, respectively, R=coil radius (mm), ϕ=coil opening angle (degree), P=phase angle (degree), L=coil length (mm), N=turn number of the coil, B.R.=Bucking ratio, rotation speed of the coil=0.2083 Hz.

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The field measurement system consists of the signal integrator (MetroLab PDI 5025), pre-amplifier (Keithley 1801 Nanovolt Preamp), angular encoder, four DVMs, bipolar power supplies and the data acquisition system. Since the field measurements are performed at room temperature, the transported currents are limited to 1A and 0.1A for the quadrupole magnets and correctors, respectively. Because the produced fields by the magnets and coils are weak, the field of geomagnetism strongly influences on the measurement. The magnetic field produced by QC1P with 1 A is 4.2 Gauss at r=10mm in the magnet bore. Therefore, the magnetic field measurements are performed with plus and minus currents. By subtraction of the two signals, the geomagnetism field is excluded.

In order to measure the multipole field components, the analog dipole and quadrupole bucking processes are applied. The bucking ratios of dipole and quadrupole coils are 64.8 and 33.4, respectively. In order to measure the sextupole field less than 1 $\times 10^{-3}$ with respect to the quadrupole field, the bucked signal is amplified by 200,000 with the pre-amplifier and the amplifier in the integrator. For the QC1P with 1 A, the amplitude of the bucked voltage is 1.3 V and the integrator has the resolution of 1 $\times 10^{-5}$. The sextupole field component is able to be evaluated by this measurement system.

Harmonic Coil System for the ertical Cryostat in KEK

Two units of the harmonic coils were constructed for the field measurements with the vertical cryostat. The QC1 and QC2 magnets are measured with the 12 mm and 20 mm radius harmonic coils, respectively. The harmonic coils are shown in Fig. 1. Each unit consists of the 600 mm long harmonic coil and the 20 mm long harmonic coil, which measure the integral magnetic field of the magnet and the field profile along the magnet length, respectively. Two coils are connected with the plastic coupling. The coils rotate at the speed of 0.2083 Hz.

The measured field profiles along the magnet axis are used in the study of the beam optics. Because the harmonic coil integrates the magnetic field along its length, the coil length need to be optimized to reproduce the real profile from the measurement. Figure 2 shows the B_2 and B_6 field profiles of the QC1P magnet. The solid line corresponds to the calculation by the 3-D magnet model. The symbols are the integrated fields along the length of 20 mm in every 4 mm and 20 mm steps, and the length of 40 mm in every 40 mm step. From the evaluation, the coil length was decided as 20 mm.

The harmonic coils consist of a tangential coil, three dipole bucking coils and three quadrupole bucking coils. The parameters of the four harmonic coils are listed in Tables 3-6. The D_0 and Q_0 coils are used for applying the analog bucking process to the signal of the tangential coil. The D_0 and Q_0 bucking ratios of four coils are listed in Tables 3-6. In the actual measurements, the analog bucking process with the D_0 and Q_0 coils and the digital bucking process with the Q_1 and Q_2 coils are applied [4]. The measurement system with the harmonic coils of R=12 mm and L=20mm has the resolution of 5 $\times 10^{-6}$ for the

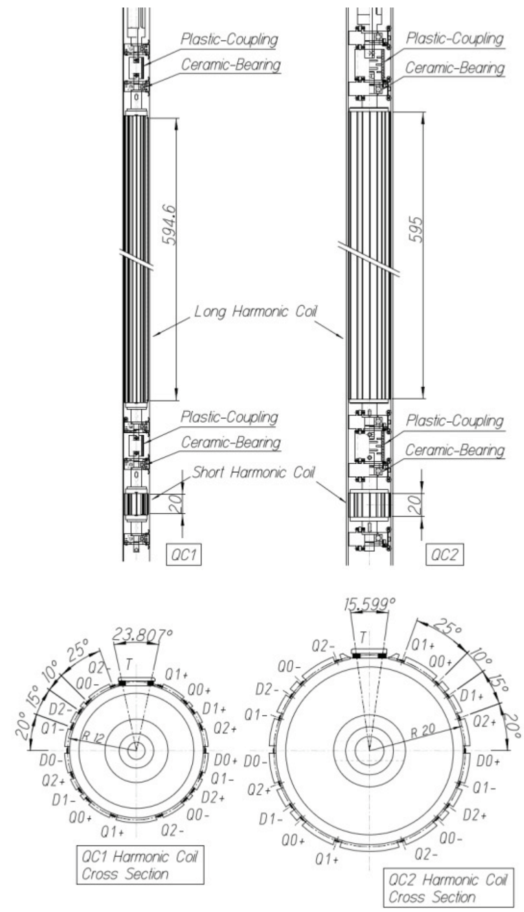

Figure 1: Harmonic coils for the vertical cryostat.

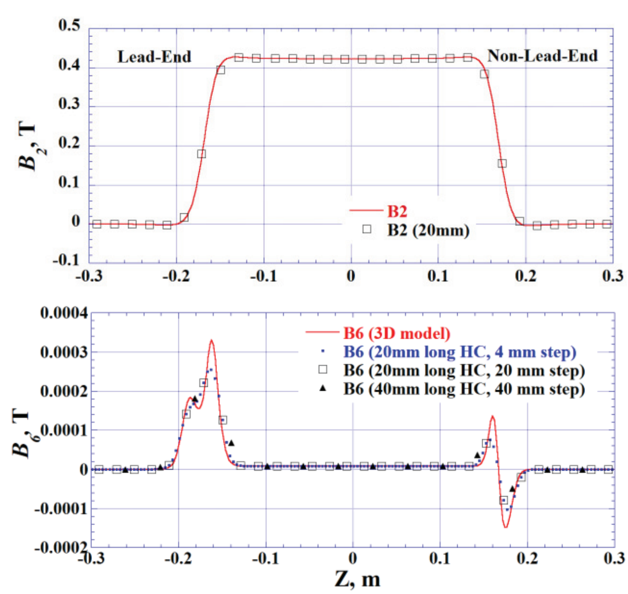

Figure 2: B_2 and B_6 field profiles of QC1P. The position of Z=0 corresponds to the magnet center.

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quadrupole field of the QC1P magnet at the nominal current.

The vertical cryostat test stand is shown in Fig. 3. The harmonic coil system, which consists of two harmonic coils, the angular encoder, the driving motor and a rotary connector, is supported with the movable stage.

Table 3: Parameters of the R=12 mm Coil (L=600mm)

	R	*ϕ*	*P*	*L*	*N*	*B.R.*
T	12.104	23.52	0.0	594.6	100	–
D_0	12.074	180	-0.69	600	10	204
D_1	12.106	180	35.92	600	10	–
D_2	12.063	180	-35.50	600	10	–
Q_0	12.128	90	-0.40	600	10	52
Q_1	12.157	90	24.45	600	10	–
Q_2	12.161	90	-25.19	600	10	–

Table 4: Parameters of the R=12 mm Coil (L=20mm)

	R	*ϕ*	*P*	*L*	*N*	*B.R.*
T	12.21	21.98	0.0	20.0	120	–
D_0	11.96	180	-0.23	23.1	10	61
D_1	12.08	180	34.79	23.1	10	–
D_2	12.02	180	-35.28	23.1	10	–
Q_0	12.09	90	0.04	23.1	10	35
Q_1	12.10	90	19.80	23.1	10	–
Q_2	12.08	90	-19.82	23.1	10	–

Table 5: Parameters of the R=20 mm Coil (L=600mm)

	R	*ϕ*	*P*	*L*	*N*	*B.R.*
T	20.10	15.29	0.0	594	150	–
D_0	20.02	180	-0.13	599	10	146
D_1	20.02	180	35.10	599	10	–
D_2	20.04	180	-35.27	599	10	–
Q_0	20.02	90	-0.03	599	10	45
Q_1	20.03	90	24.91	599	10	–
Q_2	20.03	90	-24.98	599	10	–

Table 6: Parameters of the R=20 mm Coil (L=20mm)

	R	*ϕ*	*P*	*L*	*N*	*B.R.*
T	20.08	18.98	0.0	20.0	150	–
D_0	20.04	180	-0.02	23.1	10	27.5
D_1	20.02	180	35.45	23.1	10	–
D_2	20.03	180	-34.81	23.1	10	–
Q_0	20.02	90	0.08	23.1	10	27.9
Q_1	20.02	90	25.17	23.1	10	–
Q_2	20.03	90	-24.81	23.1	10	–

The position of the stage is measured with the magnetic position monitor, which has the precision of 10 μm. The relative position between the harmonic coils and the magnet is defined with the monitor system.

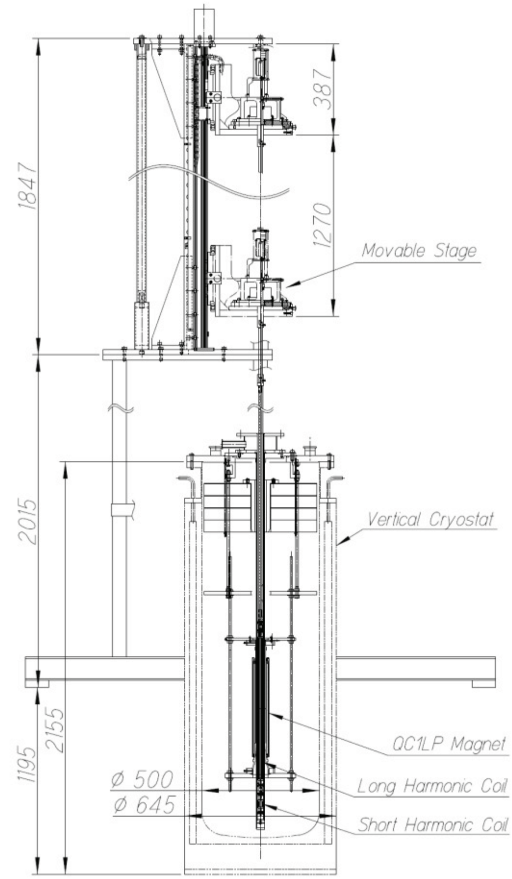

Figure 3: Magnetic field measurement system with the vertical cryostat.

CONCLUSION

KEK constructed the field measurement systems for the superconducting magnets for SuperKEKB IR. Five harmonic coils have been constructed for the construction stage. The systems have sensitivity less than 1×10^{-5} to the main field of the quadrupole magnet.

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REFERENCES

[1] K. Akai et al., WEOCA01, IPAC'14, Dresden, June 2014; http://www.JACoW.org
[2] N. Ohuchi et al, NA-PAC'13, Pasadena, September 2013, WEODA1; http://www.JACoW.org
[3] N. Ohuchi et al, NA-PAC'13, Pasadena, September 2013, THPBA04; http://www.JACoW.org
[4] A. Jain, CERN 98-05, pp.175-217, August 1998.