ROTATING COIL MAGNETIC MEASUREMENT SYSTEM AND MEASUREMENT RESULTS OF QUADRUPOLE PROTOTYPE FOR BEPCII STORAGE RING

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Abstract

A normal quadrupole prototype magnet with 266-mm long, 105-mm aperture has been designed and fabricated by IHEP. Total of 88 quadrupole magnets are under fabrication. The multipole components, magnetic field gradient and transfer function of the quadrupole magnets were measured in September 2004, using an updated measurement system, which includes a rotating coil measurement system and a Hall Probe measurement system. This paper mainly describes the updated harmonic coil magnetic field measurement system and provides the measurement results for BEPC II quadrupole magnets

INTRODUCTION

The performance of the main quadrupole magnets for Beijing Electron Positron collider (BEPCII) storage ring has to satisfy the field quality specifications. According to the physical parameters and magnetic field specifications of the quadrupole magnet, we designed and fabricated a new set of rotating coil and updated the magnetic field measurement system, detailed magnetic measurement was carried out in the test hall of Building 5 at IHEP. Up to now, over fifty new magnets have been fabricated and their magnetic field measurement has been finished. Main parameters and characteristics of the BEPCII quadrupole magnet are listed in Table 1.

Table 1: Main Design Parameters of Quadrupole

	Value	Unit
Field gradient (2.1Gev)	1260	Gs/cm
Field gradient (2.5Gev)	1450	Gs/cm
Magnetic Length	300	mm
Reference Radius	52.5	mm
Allowed Multipole B_n/B_2 @52.5mm	$\leq 5\times10^{-4}$	
Magnet Weight	1.1	T

MEASUREMENT SYSTEM AND MEASUREMENT METHOD

The field harmonics measurement system is shown in Figure 1. The Magnetic field harmonics measurement system consists of a rotating coil assembly, which includes a main and a bucking coil. Usually a compensation mode can suppress the dipole (n=1) field component and the main (n=2) field component to get higher order multipole harmonics with high precision using large gain value (G>=100) of Digital Integrator (PDI5025). The uncompensated mode, which is also called absolute measurement mode, is used to get main field amplitude, phase and magnetic centre offsets with gain G=1. The measurement coil assembly was inserted into the magnet aperture and positioned on the magnet poles, the shaft of measurement coil is connected to a step motor by a flexible coupling. The step motor and the angular encoder are rigidly coupled by a universal joint. The rotating coil rotates in the magnetic field at a constant angular velocity $\omega=2\pi/2$ rad/s. The angular encoder produces the index signal and a series of 256*64 pluses with uniform intervals per revolution. The induced voltage in the coil is digitized by a voltage–to-frequency converter and an up-down counter, and then by accurate Fast Fourier transformation (FFT), we can get harmonic components of various orders which were evaluated at a reference radius of 52.5mm.

Figure 1: Field harmonics measurement system of BEPCII quadrupole magnets.

ROTATING COIL DESIGN

The rotating coil assembly was designed and built at IHEP in Beijing. In order to obtain a high sensitivity for high order harmonics, we adopted radial coil with bucking structure in design of the rotating coil for quadrupole magnets. The number of turns of Main coil and Bucking coil are 240 and 480, respectively. The bucking ratio is about 90. We used a color-coded multifilar wire for the coil winding, it consists of 20

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strands, each strand is 0.07mm thick and 50μm in diameter. The material of the measurement coil framework is fibreglass reinforced epoxy (G10). Figure 2 shows the pick-up coil cross section.

The Rotating Coil Geometry

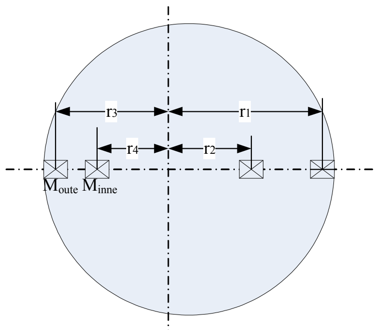

Figure 2: The pick-up coil cross section.

M_{inner} : Number of turns in Bucking coil.
M_{outer} : Number of turns in Main coil.
Length of coil frame: 820mm.

Coil Sensitivity

The coil sensitivity coefficients can be obtained by expression:

$$s_n = 1-(-\beta_1)^n - \mu\rho^n\left[1-(-\beta_2)^n\right] \quad (1)$$

Where $\beta_1 = \left|\frac{r_3}{r_1}\right|, \beta_2 = \left|\frac{r_4}{r_2}\right|$

$$\rho = \frac{r_2}{r_1}, \quad \mu = \frac{M_{inner}}{M_{outer}}$$

The signals of the dipole and quadrupole were compensated in the bucking configuration, the sensitivities with different filed indices are listed in Table 2.

Table 2: Main Design Parameters of Quadrupole

n	S_n	n	S_n
1	-0.00005	10	0.937362
2	0.000031	11	1.038662
3	1.004868	12	0.966319
4	0.502448	13	1.022628
5	1.118715	14	0.981547
6	0.760532	15	1.013006
7	1.097266	16	0.989777
8	0.880024	17	1.007404
9	1.063752	18	0.994299

Theoretical and Actual Parameters of Rotating Coil

As The manufacture, fabrication and alignment process will inevitably produce errors in dimensions of rotating coil, we should know the actual values of r_1, r_2, r_3 and r_4, to improve measurement precision of multipole field components. The theoretical and actual parameters of rotating coil are shown in Table 3.

Table 3: Theoretical and Actual Parameters of Rotating Coil

	Theoretical Design	Actual
r_1(mm)	43.5	43.51
r_2(mm)	24.468	24.42
r_3(mm)	-32.625	-32.66
r_4(mm)	-13.593	-13.55

MAGNETIC FIELD MEASUREMENT OF BEPCII QUADRUPOLE

Transfer Function and Magnetic Length

The transfer function of the BEPCII quadrupole was measured with Hall Probe after standard magnetization cycles and plotted in Figure 3. The magnetic length of the BEPCII quadrupole prototype is 31.1cm.

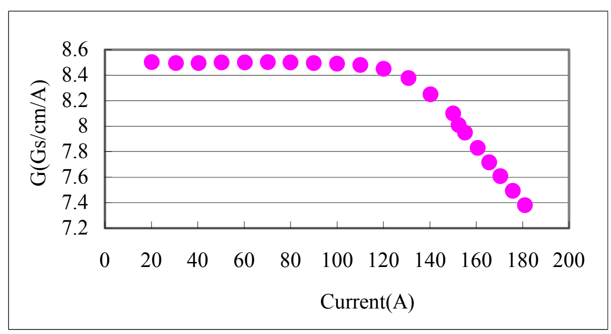

Figure 3: Transfer function of quadrupole magnet prototype.

Harmonic Errors

The relative harmonic errors are ratios of high order harmonic components Bn to the main field B_2 of the quadrupole field at R_{ref}=52.5 mm. Before magnetic field measurement, a magnetic standardization cycle must be carried out, that was the following:

- First, ramp current from minimum current to 200A with a rate of 1.5A/S one time (Pre-cycle).
- Second, ramp current from minimum current to 180A at 1.5A/S three cycles.
- Magnetic field measurement were performed at 8,13,18,27,36,45,54,63,72,81,90,99,108,117,126, 135,144,151 and 162 Amps. The field

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measurements in compensated mode were made at four different current levels: 18,63,108 and 162 Amps, other measurement was made in uncompensated mode.

The results of measurement basically satisfy the requirement for field quality. The B6/B2 harmonic component is 3.68×10^{-4}, it slightly exceeds the requirement value 3.16×10^{-4} at 108 Amps. The magnetic center offset is computed by using the uncompensated configuration: Δ x=0.045mm, Δ y=-0.069mm. The multipole errors including the systematic and non-systematic multipole errors are less than 3.73×10^{-4} of the fundamental field at radius of 52.5mm. Table 4 shows the multipole components of quadrupole prototype at excitation currents 108A and 162 Amps. Figure 4 shows pre-cycle and ramping cycle, Multipole errors spectrum at I=108A and I=162A were shown in Figure 5.

Table 4: Multipole Components Measured of Quadrupole

n	Bn/B2 (I=108A)	Bn/B2 (I=162A)
3	8.321E-05	1.732E-04
4	4.801E-05	5.135E-05
5	2.927E-05	2.696E-05
6	3.684E-04	2.189E-04
7	4.861E-05	4.441E-05
8	7.277E-05	7.391E-05
9	4.087E-05	3.283E-05
10	2.794E-04	3.207E-04
11	2.936E-05	2.425E-05
12	6.074E-05	6.434E-05
13	3.159E-05	2.470E-05
14	7.035E-06	5.271E-06
15	3.320E-05	3.235E-05
16	5.628E-05	4.229E-05
17	4.331E-06	1.256E-05
18	3.259E-04	3.586E-04

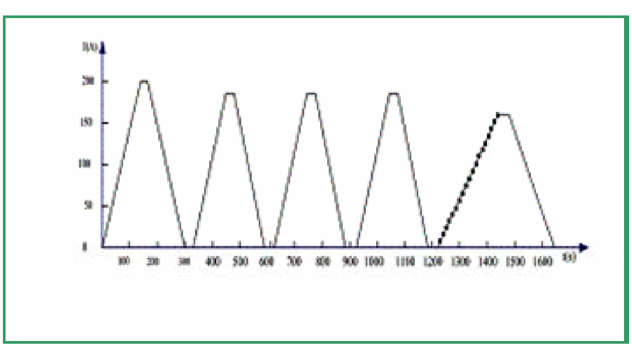

Figure 4: Pre-cycle and ramping cycle for BEPCII quadrupole magnets.

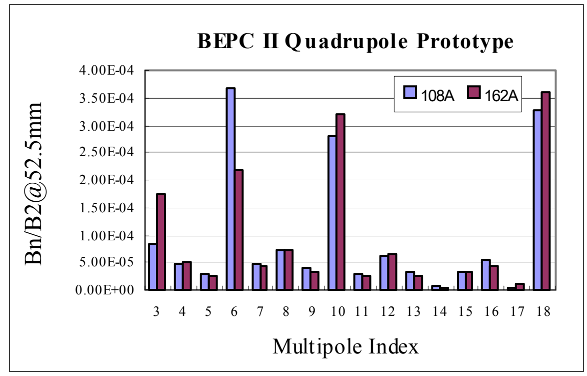

Figure 5: Multipole error spectrum for BEPCII quadrupole prototype.

SUMMARY

The rotating coil magnetic measurement system and the measurement results of quadrupole prototype were detail. The field quality satisfy physical requirement, the magnetic measurement of the series production for BEPCII is measuring until Summer 2005. Up to now we have finished magnetic field measurement of fifty-first quadrupoles, at present magnetic capability of all the magnets basically satisfy the requirement.

ACKNOWLEDGMENTS

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