DESIGN OF A PRECISE UNIT FOR THE ROTATING COIL MEASUREMENT SYSTEM*

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Abstract

A precise rotating coil measurement system (RCS) is developed to characterize the magnetic field quality of the quadrupole (QM) and sextupole (SM) magnets in the Taiwan Photon Source (TPS). A measurement bench is designed to install the magnets easily and mount the rotating coil unit with high reproducibility. The Fiberglass Reinforced Epoxy (FRP) measurement unit (F-unit) exhibits a large sag and mechanical error while it is 880mm long. Therefore, a new graphite measurement unit (G-unit) with a printed circuit coil is adopted to reduce these errors. The rotating coil design and testing using a QM are also described.

Introduction

A novel synchrotron radiation facility, TPS was planned and designed at National Synchrotron Radiation Center (NSRRC). A high-quality magnet was using in a high-quality light source with high flux and the narrow beam. The RCS is an accurate method of measurement that is used to improve the quality of QM and SM in the TPS. The quality of QM and SM are analyzed by the Fast Fourier Transform (FFT) method. This method was employed to analyze the multipoles of the magnet. Good reproducibility of the position is required when the measurement unit and magnet are reinstalled to channel the multipoles of the magnet. Three types of QM are 215, 285 and 565mm long. These magnets have a bore radius of 37mm. The SM is 225mm long with a 39mm bore radius. The good field region of QM and SM extends to ±30mm. The TPS has 240 QM and 168 SM are required. A realizable bench was designed to be easily setup with high reproducibility when the magnet and measurement unit are reinstalled. In this work, F- and G-units were fabricated and tested. The strength and hardness of graphite reduces the sag and increases the accuracy of machining [1]. Additional, the printed circuit coil was designed to maintain its position precisely [2].

Rotating Coil Bench

The bench of RCS was assembled on a granite bench, a granite V-support, an iron base, a stainless steel (SS) movable V-gland, a measurement coil unit, a coupling, a drive motor, an adjustable adapter of QM, a rotary encoder and a slip ring, as presented in Fig. 1. The granite bench (OPUS, OP-23, DIN-0) is a strong and flat base for the measurement system. The measurement unit was fixed using a granite V-support and an SS movable V-gland in a highly precise position. A QM of the TLS (Taiwan Light Source, 1.5 GeV ring) was adopted to test the reproducibility of the measurement unit when the magnet was reinstalled. An iron base was used in the simulation of the girder of the TPS to determine how to mount the magnet. The adjustable adapter allows the position of the magnet to be fine-tuned. The measurement unit and the drive motor (Parker TS42B-SKS10, ZETA-6108, 50000 points per turn) were connected using a coupling. The other end of the measurements unit has a rotary encoder (Heidenhain ERN120, incremental type, 2048 pulses per turn) and a slip ring (Asiantool, A2S, 2-channels) to recode the angle of rotation and the output voltage of the measurement coil, respectively.

The specifications of the measurement bench are described below. The bottom-left of Fig. 1 displays the corrdinates. (i) The position offset between the center of rotation of the measurement unit and the center of the magnet base is less than 9μm along the x-axis. (ii) The difference between the heights of both ends of the measurement unit on the V-support is 11μm along the y-axis. (iii) The reproducibility of the reinstallation of the measurement unit is within 6μm and 8μm along the x-axis and y-axis, respectively. (iv) The both ends of the measurement unit swing are less than 5μm. These results demonstrate the high mechanical precision of the measurement bench. The measurement unit was driven by a stepping motor that was controlled by a computer via a RS-232 connection. The rotary encoder has a TTL signal with a 5V output, which is counted and divided by a counter/divider unit. These counters were integrated by the integrator and transferred to the computer by a GPIB. An advantage of the integrator is that the signal amplitude of the measurement coil was independent of the angular speed.

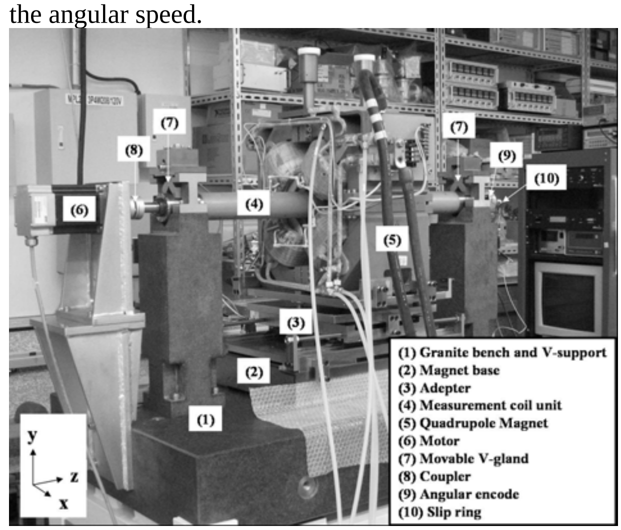

Figure 1: The photo diagram of the RCS and the magnet.

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FRP and Graphite Measurement Unit

The first version of the measurement unit was fabricated from FRP material. The F-unit including the measurement coil, the coil winding plank and the plank holder (which is connected to a ball-bearing). The measurement coil was ten winding of enamel-insulated wires with a diameter of 0.25mm on the coil winding plank. The active area of the measurement coil was 29.5mm*883mm. The coil winding plank was inserted into the coil holder to maintain the rotation center of coil. Figure 2 displays the deformation of the F- and G-unit. The deformation distribution of the F-unit was measured at various points (marked 1 to 10 same as in Fig. 2 inset). Four solid-symbol lines represent the deformation along the sides of the cross-section (A, B, C and D same as in Fig. 2 inset). The maximum deformation of the outer surface of the F-unit is 0.17mm on the D-side.

Graphite was used because it is harder and stronger than FRP material and so improves the precision of a measurement coil. Figure 2 inset displays the graphite measurement unit, which has two pieces of printed circuit board coil (PCB-coil, 1mm thick), a graphite support (G-support) and an SS rotary shaft (connected to a ball-bearing). The density, hardness, Young's modulus and resistively of graphite (SGL, R8510) are 1.83g/cm^3, HRB95, 11.5kN/mm^2 and 13μΩm respectively. The ideal design of the two-piece PCB-coils has a normal PCB-coil and a bucking PCB-coil for measuring the main and higher multipoles, respectively. In this work, the measurement coil is assembled from two normal coils to test the reproducibility of RCS. The deformation distribution of the G-unit was measured and is shown in Fig. 2. Four lines through the hollow-symbols represent the deformation on the various sides of the cross-section (A, B, C and D in Fig. 2 inset). The deformation of G-unit is 60% less than that of the F-unit.

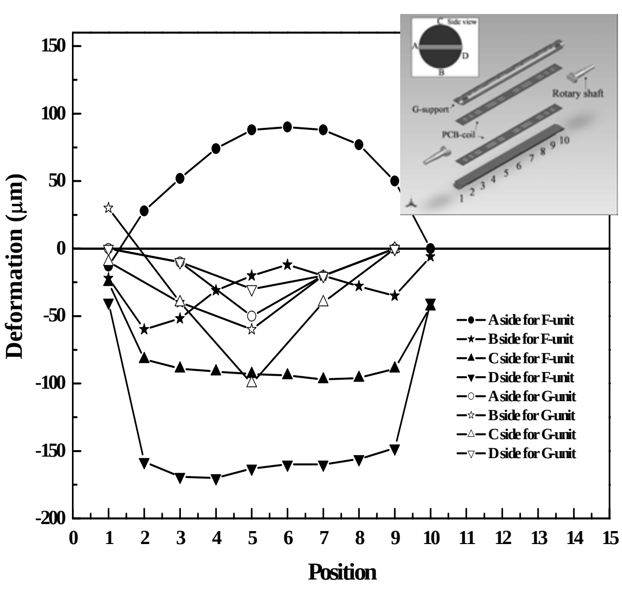

Figure 2: The deformation distribution of the F- and the G-unit.

Testing Measurement Unit Using a QM

The F- and G-unit were tested using a QM (TLS, Q54). A reproducibility test, a grounding (GND) test of the G-unit and a revolution test of the G-unit were performed. The location of the test QM in the measurements of F- and G-units was the same. The QM was excited to 180A and monitored using a DCCT. The instability of the power support was less than 10ppm. The data were analyzed by taking the FFT of each spectrum and then averaging all of them. This analysis prevents the spectra from drifting with the revolution. Each component was normalized to 29.5mm (coil width) and 30mm (good field of QM) for the F- and G-units, respectively. The G-support is a conductor, which when rotated in a magnetic field induces an eddy current and causes an offset of the integrator. Therefore, the G-unit must be grounded. Various degrees of grounding of the G-unit are tested and include (i) no GND (>40MΩ), (ii) poor GND (~24Ω), (iii) GND through a ball-bearing (~2Ω) and (iv) direct GND (~0.5Ω). In poor GND, the G-support is grounded via a driver motor only. Bearing GND is grounding though a ball bearing. All measurements were made at 23±0.5^{o}C. Figure 3 (a) presents the reproducibility test of B1 (dipole, %), B2 (quadrupole, %) and B3(sextupole, %) in the F- and G-unit measurements. B1(%) and B2(%) of the G-unit are clearly less than the F-unit, because an eddy current induces on the G-support. Moreover, The eddy current also stranger enhancement the B3(%). Figure 3 (b) displays the normalized multipole analysis of QM, including B1/B2, B3/B2, B4/B2, B5/B2, B6/B2, B10/B2 and B14/B2. The normalized B3/B2 of the G-unit clearly exceeded that of the F-unit, because the measurement of the actual B3 component of the G-unit was erroneous under extra eddy current. Furthermore, B5/B2 and B6/B2 of the G-unit are smaller than those of the F-unit. Table 1 presents the deviations (¶, difference between max. and min. of spectra) for F- and G-units. The calculated multipole errors of QM of TPS are B3/B2, B4/B2, B6/B2, B10/B2 and B14/B2, which equal 1.4E-4, 4E-4, 1.8E-4, 7.02E-4 and 8.98E-5, respectively. In the F-unit, the precision of the higher miltipoles did not suffice to channel the QM, because the deviation of the reproducibility exceeded the calculated multipole errors. In the case of the grounded G-unit, the deviation of the normalized multipoles of reproducibility was less than 1E-4 which suffices to channel the quality of QM. Moreover, good grounding of the G-support improves the reproducibility of the unit. Figures 4 plot the actual percentage of various revolution rate of the G-unit with the bearing grounding. The tested rates of revolution were 4, 6, 8, 10 and 12rpm. B2(%) decreased as the rate of revolution increased, because the eddy current increased with rate of the revolution. B1(%) and B3(%) were independent of the rate of revolution.

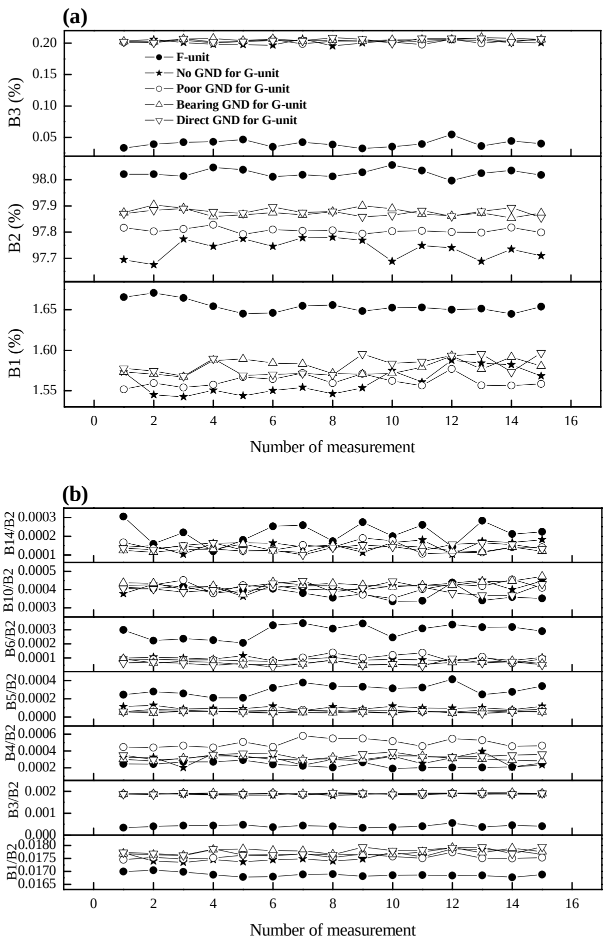

Figure 3: (a) The reproducibility test of B1(%), B2(%) and B3(%) in the F- and G-unit measurements. (b) The normalized multipole analysis of QM.

Table 1. The deviations (/, difference between max. and min. of spectra) for F- and G-units.

Multi poles	**F-unit**	**G-unit**			
		Direct GND	Bearing GND	Poor GND	NO GND
ΔB1(%)	0.026%	0.029%	0.026%	0.025%	0.045%
ΔB2(%)	0.059%	0.041%	0.05%	0.037%	0.11%
ΔB3(%)	0.022%	0.0085%	0.0053%	0.0084%	0.011%
ΔB1/B2	2.7E-4	3.1E-4	1.3E-4	2.9E-4	5.2E-4
ΔB3/B2	2.2E-4	7.9E-5	6.0E-5	7.8E-5	1.0E-4
ΔB4/B2	1.0E-4	9.0E-5	6.0E-5	1.3E-4	1.9E-4
ΔB5/B2	2.0E-4	3.3E-5	2.1E-5	2.8E-5	6.1E-5
ΔB6/B2	1.4E-4	6.0E-5	4.1E-5	7.6E-5	4.0E-5
ΔB10/B2	1.0E-4	8.0E-5	1.0E-4	1.0E-4	8.7E-5
ΔB14/B2	1.8E-4	6.3E-5	4.6E-5	8.1E-5	7.9E-5

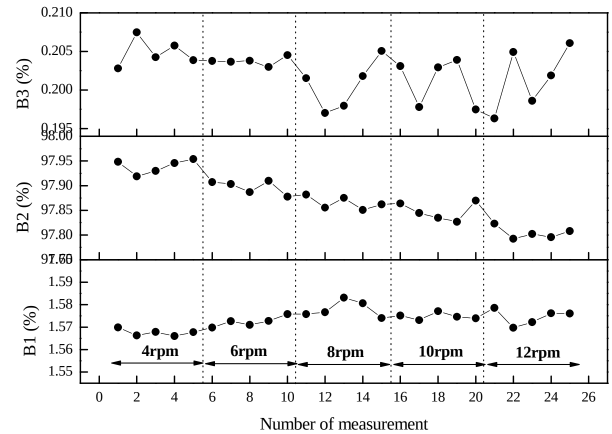

Figure 4: The actual percentage of multipole analysis of various revolution rate of the G-unit

Summary

The granite bench is provides a precise relative position of the measurement unit and the magnet. The reproducibility of the measurement unit on the bench was reasonably good. An integrator was adopted to make the amplitude of the measurement signal independent of the rate of revolution of the coil. The deformation of the G-unit is 60% less than that of the F-unit. The deviation analysis of reproducibility for the grounded G-unit was better than that by the calculated errors. In the QM test, an eddy current was induced on the G-support when the conductor G-unit was rotated in the QM. The extra eddy current was lower than that in the B1 and B2 components. Additional, the actual of B3 component measurement in the G-unit was erroneous because of the eddy current. The eddy current of the G-support was not strongly related to the rate of revolution of the G-unit except B2(%). These tests reveal that the G-unit offers good reproducibility but the actual B3 actual component measurement in the QM test is erroneous

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