A NEW HARMONIC COIL BENCH AT SINAP FOR THE ALS COMBINED FUNCTION SEXTUPOLE MAGNETS

Jidong Zhang, Du Hanwen, Qiaogen Zhou, Lixin Yin, SINAP, Shanghai, China
Arnaud Madur, Nanyang Li, LBNL, Berkeley, USA

Abstract

A new harmonic coil bench has been developed at Shanghai Institute of Applied Physics (SINAP) to measure the ALS combined function sextupole magnets. The measurement system has been designed with the aim to perform precise, fast and reliable measurements of series of magnets. It determines the strength, and the multipole content of the field as well as the magnetic axis for precise positioning of alignment targets on top of the multipoles. The multipole, while supported on a marble platform, can be moved with regard to the rotating coil using multi-dimensional adjustment plate. The resolution of the movement is read out by micrometer with a few μm resolutions. This article introduces the measurement system constitutes.

INTRODUCTION

A total of forty eight combined function magnets are required to upgrade the Advanced Light Source Storage Ring at LBNL. These magnets will provide 4 types of magnetic fields: sextupole, horizontal and vertical dipoles, and skew quadrupole [1]. The field quality specifications of the ALS combined function magnets call for the integrated multipole errors of the order of a few parts in 10^{-4}. Since the electrical sensitivity required to measure these small errors is at the limit of what can be achieved with uncompensated rotating coils, the multipole measurements need to use compensated coils and a data acquisition system which includes a digital integrator. The compensated coils are designed and fabricated with nearly zero sensitivity to the fundamental so that the error multipole amplitudes can be more easily measured with the fundamental signal rejected [2].

THE DESIGN AND FABRICATION OF THE MEASUREMENT COILS

The measurement system is based on the “harmonic coil method” in which a mechanically stable cylinder holding the main measuring coil is rotated inside the bore of the magnet. The induced voltage is a function of rotational angle; its Fourier components give the multipole content of the field. The Fourier analyses are carried out in polar coordinates.

$$B(r,\theta) = (B_\theta+iB_r) \times e^{-i\theta} = \sum_n (Bn+iAn) \times r \times e^{i\theta}$$

Here is An the skew and Bn the normal field component. The multipole order of the field component is given by the index n; n = 1 for the dipole, n = 2 for the quadrupole, n = 3 for the sextupole, and so forth. A multipole of order “n” has several allowed harmonics of the order N = n× (2k+1), here is k = 1,2, and so on. Therefore a quadrupole (n = 2) has 12 and 20 pole, and a sextupole (n = 3) has 18 and 30 pole harmonic contents [3].

As rotating coils two types of windings are used: the radial-coil and the tangential-coil. The bucking-coil is an additional set of windings mounted on the same frame as the main coil. The radial-coil is wound such that in one arm of the winding coincide with the rotational axis, and the other arm is on the surface of the winding frame as near as possible to the pole-tip of the multipole. The bucking-coils is wound in the same plane as the main coil, but with different outer and inner radius. Its signal can be added or subtracted from the signal of the main radial- or tangential-coil to eliminate a harmonic component of the field. For the tangential-coil the windings are located at a common radius on the surface of the winding frame, but with an angular separation ϕ. Several different tangential-coils, all are wound on the same frame, e.g. the dipole-, the quadrupole-coil, and any higher order coil can be connected such, that the corresponding multipole terms are bucked out. The new harmonic coil was designed at SINAP to measure the relative amplitudes of harmonic components in dipole, quadrupole and sextupole with an accuracy of 0.01 %. Our measuring coil assembly contains 2 separate coils, this use a different design to get more sensitivity for the dipole，quadrupole and higher order harmonics. Figure 1 shows the measurement coil schematic diagram. Table 1 lists parameters of the rotating coil.

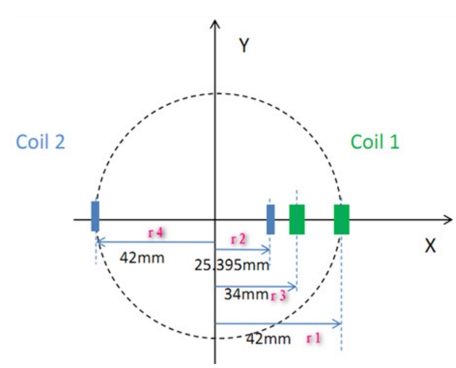

Figure 1: Measurement coil schematic diagram.

Table 1: Parameters of the Rotating Coil

	Coil 1 (turns)	Coil 2 (turns)	r1, r2, r3, r4 (mm)
Parameter	520	200	42,25.395,34,42

The two coils are connected in series opposition.

$$\left(\int V dt\right)_{compensated} = L\sum_{n} |C_n|\left[M_{Coil1}\left(r_1^n - r_3^n\right) - M_{Coil2}\left(r_2^n - r_4^n\right)\right]\cos(n\theta + \psi_n)$$

Define the following parameters:

$$\beta_1 = \left|\frac{r_3}{r_1}\right| \quad \beta_2 = \left|\frac{r_4}{r_2}\right| \quad \rho = \frac{r_2}{r_1} \quad \mu = \frac{M_{Coil2}}{M_{Coil1}}$$

Get the bucked sensitivity:

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

Change these parameters; we can get the compensated sensitivities table shown in Table 2, the compensation gain for dipole is 3.24Coil1-Coil2; the compensation gain for quadrupole is -0.708Coil1-Coil2; the compensation gain for sextupole is Coil1-Coil2.

Table 2: The Compensated Sensitivities

	Bucked dipole	Bucked quad.	Bucked sext.
S1	-0.000008	1.062186	-0.426694
S2	0.419981	0.000035	0.588674
S3	0.324546	1.132823	-0.000140

The magnet is also measured with the rotating coil wired in the uncompensated condition to measure the fundamental field integral.

CONTROLS AND DATA ACQUISITION SYSTEM

In recent years advances in the speed, resolution and accuracy of analogue to digital converters have increased dramatically. It was decided that a modern analogue to frequency converter, an integral part of a high accuracy digital integrator, could perform data collection quickly and accurately so that recording of the flux linkage could take place in real time. Thus analogical integrators, which can be inherently unstable and represent the weak link in this type of apparatus are no longer required in the measurement process. This section describes the accuracy digital integrator and other instrumentation associated with the measurement system. Figure 2 shows the hardware architecture of the control and data acquisition system. It consists of the following devices:

Switch Box

Switch box is made in SINAP. It is used to switch the working mode of the measurement coil.

Tilt Sensor

Spectron Sensor SH50055-A-009, range: ±17 mrad (±8 mrad linear), resolution: 1 μrad.

Voltage Integrator

Metrolab PDI-5025 is used to integrate the flux linkage. It has a maximum resolution of 10-8 Vs and 50 ppm gain linearity. In this system the PDI-5025 is connected to one or two sense coils, the host IPC initializes it for a definite series of measurements, then collects the results and performs the required data analysis.

Motor Controller

The motor controler is NI PCI-7352 2-Axis Stepper/Servo Controller. It provides forward and backward direction, speed, IO, distance, step size, acceleration, and deceleration functions. The card was installed in the PCI slot and connected with the motor driver (RM59B2D) for rotating the magnet measurement coil.

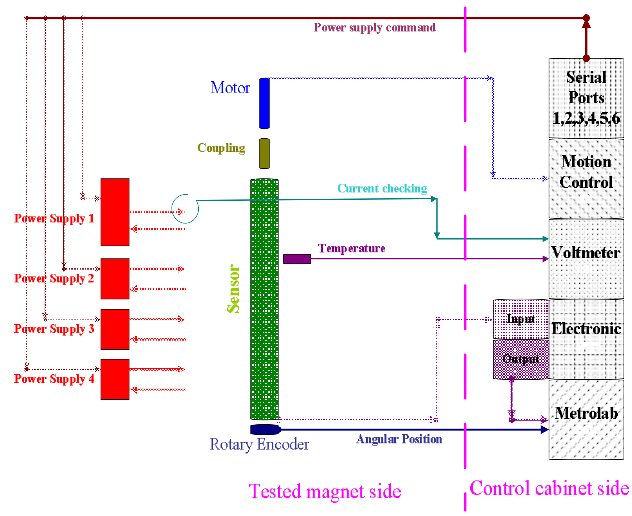

Figure 2: Measurement coil schematic diagram.

Rotary Encoder

The position of coil can be read from the optical rotary encoder. The signals coming from the optical rotary encoder can be decoded simultaneously to correct the position error to less than 0.0002°. We choose HEIDENHAIN ERN 180 rotary encoder and IBV660B divider， max resolution is 2000000 plus/ revolution.

Magnet Power Supply

Sextupole and quadrupole use DANFYSIK power, Stability better than 10ppm. Vertical dipole and horizontal dipole use 100A/20V power, Stability better than 100 ppm. Current measurement use DANFYSIK ULTRASTAB 864 current transducer and HP34401 digital voltmeter.

Bench Support

Granite precision table is stable structure for the bench support. The multipole, while supported on a marble platform, can be moved with regard to the rotating coil using multi-dimensional adjustment plate. The resolution of the movement is read out by micrometer with a few μm resolutions.

ISBN 978-3-95450-122-9

Measurement Software

The data acquisition and instrument command functions are controlled by software based on a graphic software package LabVIEW. It is a powerful and flexible instrumentation and analysis software development application created by the folks at National Instruments. The main advantages of the software are (1) It contains a set of interface control functions which can be easily called to control the interface cards mounted in the computer. (2) It has built in analysis functions which can perform, for example, Fourier transforms on the acquired data. (3) It has a set of graphics routines which can be used to quickly display the results of operations on acquired data. Figure 3 shows the main measurement menu interface of the control and data acquisition software.

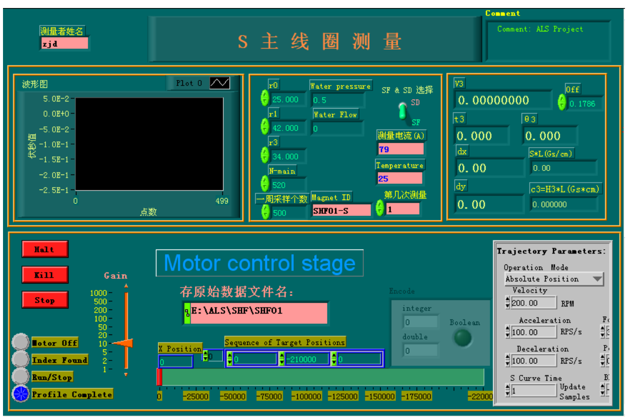

Figure 3: The main measurement menu interface of the control and data acquisition software.

MAGNETIC MEASUREMENTS

Figure 4 shows the photo of new harmonic coil bench during the measurement.

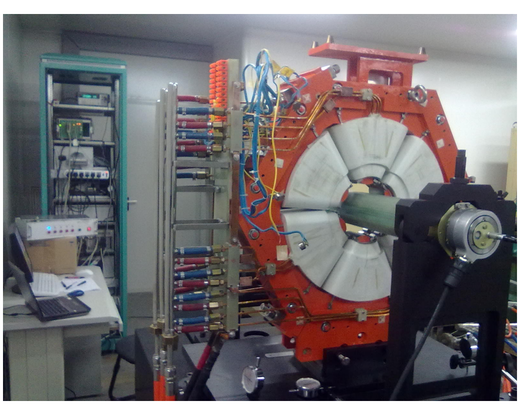

Figure 3: The photo of new harmonic coil bench.

First, establish a coordinate system of the magnet that is being measured. Determine the magnetic center of the magnet, which will be interpreted by the coordinates of tooling ball on four top posts of the magnet. Refer to its selected features to adjust angles of pitching, swing and rotating of the magnet. Refer to its magnetic measurement data to align the rotating angle and positions of X and Y of the magnet magnetic center until the mechanical center of the magnet coincides with magnetic center less than 0.005mm and xz plane of the magnet as parallel to 0 plane of the magnetic field of the magnet as possible.

The coils are connected to digital integrators. Then the motor is rotated to find the reference signal (i.e., the original position) which is created from the encoder reference pulse (one pulse per cycle). This reference pulse is received by the 5025 integrator. When this integrator receives the reference pulse, it is resettled. Simultaneously, integrator's status will be changed to the status of the encoder trigger's source mode. Flux leakage value, having cumulated from the start of the measurement, is stored in the output buffer of the integrator at any measurement interval. The data in the buffer are in ASCII format and are then transferred to the PC via the GPIB interface to save in hard disk memory. In the end, the computer controls the measurement procedure and performs the FFT analysis. Some results of these measurements are reported at this conference [1].

CONCLUSION

Having experienced tests under real magnetic field measurement environment, this set of rotating long coil measurement system can work with high stability, precision and efficiency, it has friend and easy-to-use interface with high level automation and less Man-Machine interactions. In a word, it has excellent performance and is competent for the magnetic field measurement work quite well.

ACKNOWLEDGMENT

First of all, I would like to thank Mr. Arnaud Madur for her guidance and valuable suggestions on my work. I am also very grateful to all the people that involved in magnetic field measurement for ALS magnets for their support and kind help.

REFERENCES

[1] Nanyang Li et al., "A Summaty of the Quality of the ALS Combined Function Sextupole Magnets," (THPME046, IPAC 2013, these proceedings).

[2] J.D. Zhang et al., "Design and Fabrication of a Rotating Coil Magnetic Measurement System," APAC'01, Beijing, September 2001, THP029, p. 595 (2001).

[3] Jack Tanabe, Magnetic Measurements Lecture, IMMW13, Stanford, California, May 2003, WE08, (2003).