DESIGN AND FABRICATION OF A ROTATING COIL MAGNETIC MEASUREMENT SYSTEM

J.D. Zhang, Z. Cao, F.L. Ren, Q.G. Zhou, L.H. Zhang
Y. Li, H.P. Yan, A.L. Zhang, Y.B. Zhao
Shanghai National Synchrotron Radiation Center,
P.O. Box 800-204, Shanghai 201800, P.R. China

Abstract

A rotating coil magnetic measurement system has been built at SSRC to measure the quadrupole and sextupole magnet prototypes of SSRF. The system consists of several rotating coils designed for different magnets and a control system. The coils are designed to have nearly zero sensitivity to the fundamental signals in bucked configurations. The control system is designed to be versatile, modular, expandable, maintainable, quick and easily reconfigurable in both hardware and software. This system can provide 0.01% precision.

1 INTRODUCTION

The field quality specifications of SSRF magnets call for the integrated multipole errors of the order of a few parts in 10^{-4} [1, 2]. Since the electrical sensitivity required to measure these small errors is at the limit of what can be achieved with uncompensated rotating coils, the quadrupole and sextupole 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. The integrator makes the measurements insensitive to variations in the rotational velocity of the measurement coils.

2 THE DESIGN AND FABRICATION OF THE MEASUREMENT COILS

Table 1 lists the parameters of SSRF mulitpole magnets. The measurement coils of the quadrupoles are configured to measure the multipole components with the dipole and quadrupole signals bucked out and the coils of the sextupoles are with the quadrupole and sextupole signals bucked out. Let r_1 and r_3 be the two radii of the outer coil (the main coil) and the turn number is N_1, r_2 and r_4 be the two radii of the inner coil (the bucked coil) and the turn number is N_2. Define the bucked sensitivity:

$$\sigma_n = \left|1-(-\beta_1)^n\right| - \mu\rho^n \left|1-(-\beta_2)^n\right|,$$

where $\beta_1 = |r_3 / r_1|$, $\beta_2 = |r_4 / r_2|$, $\rho = r_2 / r_1$, $\mu = N_2/N_1$. Then for quadrupoles, $\sigma_1=\sigma_2=0$, for sextuupoles, $\sigma_2=\sigma_3=0$.

Table 2 lists the theoretical and the actual coil parameters of four magnets. Figure 1 shows the measurement coil cross-section of the booster sextupoles. The housing is fabricated from the super-strong aluminium alloy. The coil axis is fabricated from NEMA G10. The bearings are C grade. Figure 2 shows the completed measurement coil.

Table 1: Parameters of the SSRF mulitipole magnets

Magnet	Storage ring Quadrupole	Storage ring Sextupole	Booster Quadrupole	Booster Sextupole
Gradient	dB/dr= 18.5 T/m	d^2B/dr^2= 440 T/m^2	dB/dr= 15.9 T/m	d^2B/dr^2= 132 T/m^2
Inscribed radius	36 mm	44 mm	30 mm	30 mm
Core length	0.6/0.3/0.2 m	0.194 m	0.36/0.26 m	0.1 m
Good field region	R<30mm	R<30mm	R<24mm	R<24mm
Field quality specification	$B_n<3\times10^{-4}$ n>2	$B_6<1\times10^{-3}$ $B_9<2\times10^{-3}$	$\Delta BL/B_2L$ $<1\times10^{-3}$	$\Delta BL/B_3L$ $<5\times10^{-3}$

Table 2: Parameters of the rotating coils
(The values in the bracket are actual)

Magnet	Storage ring Quadrupole	Storage ring Sextupole	Booster Quadrupole	Booster Sextupole
r_1(mm)	28.00 (27.95)	35.00 (34.64)	24.00 (24.13)	24.00 (23.98)
r_3(mm)	-21.00 (-20.997)	-24.50 (-24.59)	-18.00 (-18.14)	-19.06 (-19.00)
r_2(mm)	19.820 (19.96)	25.04 (25.05)	17.00 (17.21)	18.72 (18.58)
r_4(mm)	-12.820 (-12.47)	-19.42 (-19.25)	-11.00 (-11.21)	-15.62 (-15.48)
N_1	400(288)	280(240)	400(320)	300(280)
N_2	600(432)	700(600)	600(480)	600(560)
L_{coil}(mm)	1000	600	780	360

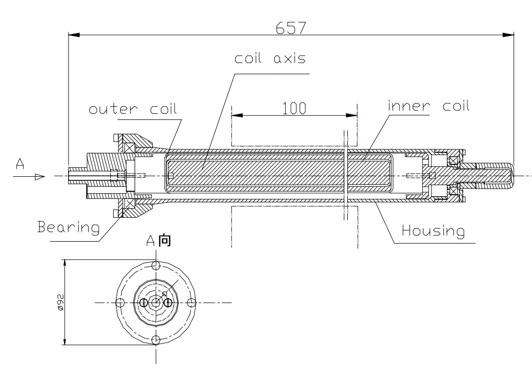

Figure 1: The measurement coil of the booster sextupoles.

Figure 2: Completed measurement coil

3 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 3 show the hardware architecture of the control and data acquisition system.

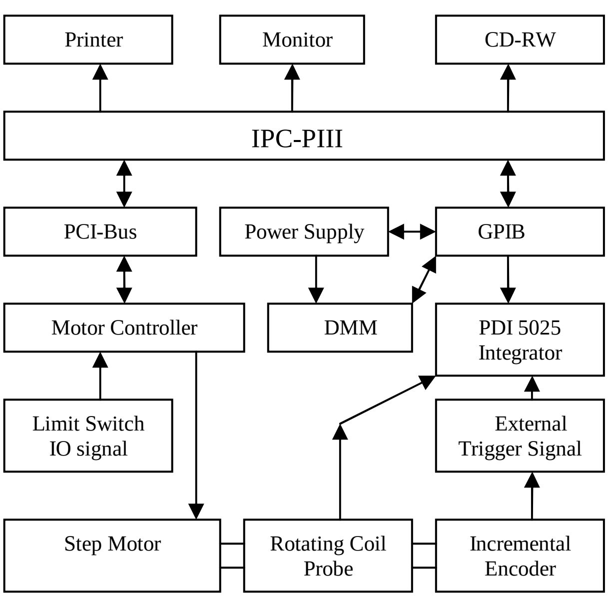

Figure 3: Rotating coil magnetic field measurement system schematic

3.1 PDI-5025 Precision Digital Integrator

Metrolab PDI-5025 is used to integrate the flux linkage. It has a maximum resolution of 10^{-8} Vs and 50ppm 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.

3.2 Motor Controller

The motor control is NI-valuemotion step motor control. 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 (PD-2D44M) for rotating the magnet measurement coil. 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 $\pm 10\,\mu$m. This correction can take place at any calculated position for the entire distance at any time. A motor holder (Figure 4.) not only applies to fix the motor and rotary encoder, but also provides the movement for multi-direction.

Figure 4: Motor holder of the rotating coil magnetic measurement system

3.3 Power Supply

Power is supplied to the magnet from Danfysik Corporation System 8000 power supply. The unit supplies current via press the "FINE" button and turn the current setting knob clock-wise, the current setting will be altered by 10ppm for each turn and is stable to 1 part in 10^6 over a period of 1 hour. An IEEE-488 interface is provided for computer control of the current supply.

3.4 IPC

An industrial process control computer is used for instrumentation control, data acquisition and analysis. It includes the GPIB card, the PCI step motor control card and the RS232 interface. A CD-R driver is used for storage.

3.5 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 5 show the main software interface of the control and data acquisition system.

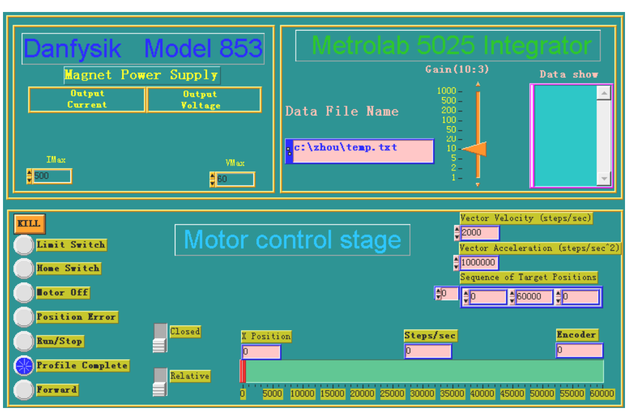

Figure 5: The main software interface of the control and data acquisition system

4 MAGNETIC MEASUREMENTS

First, 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 of its features are as the follows: (1) Measurement coil assembly is made with high bucking ratio (∽100) in order to get a high sensitivity for higher harmonics. It is wound with adequate number of turns such that the voltage signals anticipated in both configurations, unbucked and bucked, are large compared to the ambient electrical noise. (2) The barrel construction for the measurement coil assembly is chosen for positioning it in aperture of magnet easily and rapidly. (3) A cycle of the measurement including data acquisition and processing can be finished automatically in less than one minute. All coil signals are corrected assuming linear drift of the integrator [3].

Some results of these measurements are reported at this conference [4].

5 ACKNOWLEDGEMENTS

We would like to express many thanks to Prof. R. Hou (IHEP) and Prof. C.G. YAO (NSRL) for giving us a lot of invaluable help.

REFERENCES

[1] SSRF Design Report, March 2001.
[2] Q. Zhou, Z. Cao, Y. Sun, et al., The Magnet Design of the SSRF Storage Ring and Booster, IEEE Trans. On Applied Superconductivity, Vol. 10, No.1, March 2000, p256-259.
[3] R. Hou, F. Ren, Y. Hao, et al., "Field Measurement of PEP-II LER Dipoles and Quadrupoles at IHEP", PAC'97, Vancouver, B.C., Canada, 12–16 May 1997.
[4] Q. G. Zhou, Z. Cao, Y. L. Sun, et al., "Design and Measurement of the SSRF Magnet Prototypes", Proceedings of this Conference.