STRETCHED WIRE FLIP COIL SYSTEM FOR MAGNETIC MEASUREMENTS

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Abstract

A flip-coil system using a stretched wire measuring the magnetic field properties is described. This system is similar to the conventional rotating coil system except that the stretched wires are used to measure the magnetic field properties. This system has advantage of simple fabrication and flexible operation so that different length and different bore magnets can be easily measured using the same system. The system also has two loop coils to buck the dominant fundamental field so as to increase the measurement accuracy. The stretched wire loop coil system is evaluated to verify its performances and its results were discussed. The analyzing methods and various efforts for keeping the system in high accuracy are presented. Measurement results with this loop coil system were compared with that of the other system

INTRODUCTION

Usually the magnetic field distribution in accelerator magnets are two dimensional meaning that the length of the magnet is longer compared to the magnetic gap or bore radius of the magnet. Also the effects of the magnetic fields on the charged particles are determined by the integrated effects of the magnets. Taking into account the general characteristics of accelerator magnets, the magnetic measurements of the accelerator magnets are usually carried out using rotating coils that uses the Faraday induction law[1]. The rotating coil system has advantages in the fast measurement speed, and built in characteristics of higher order multipole decomposition. Also it can be easily extended to measure the difference of a magnet from a reference one using a null measurement. But the rotating coil system is difficult to fabricate precisely. And machining non-conducting (ceramic or fiber-glass) raw material is non trivial. Also the rotating coil measurement is limited to the specific target magnet and one need new rotating coils even for slightly difference magnets. In this paper, a flipping coil system that was used to measure residual field integrals[2][3] are extended by adding angular resolution and bucking mechanism for higher sensitivity for the higher harmonic fields. The efforts for the angularly resolved flipping coil system is described.

FLIPPING COILS

For two dimension magnetic field configuration, it is well known that the complex potential given by

$$F(z) = A(x,y) + iV(x,y) = \sum_{n=1}^{\infty} C_n \, (r/r_o)^n \, e^{in\vartheta}$$

is analytic, where $\vec{B}(x,y) = \nabla \times (A(x,y)\vec{z})$, and $\vec{B}(x,y) = -\nabla V(x,y)$ [4]. It can be easily shown that these $A(x,y)$ and $V(x,y)$ satisfies the Cauchy-Riemann conditions. The magnetic flux linking the coil loop can be easily calculated as

$$\Phi(\theta) = \int \vec{B} \bullet d\vec{a} = L_{eff} \; A(\vartheta) \cdot$$

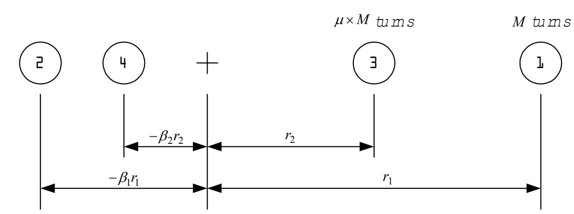

Figure 1: Block Coil geometry of the flip-coil for multipole field measurement.

Therefore, measuring magnetic flux linking the loop coil, one can easily calculate the multipole contents of the magnets using above two equations.

The coil geometries were shown in Figure 1. In Fig 1, outer coil has M turns that enter the plane of the paper at $x = r_1$ and exit at $x = -\beta r_1$, and its center is located at $(1+\beta r_1)/2$ away from the rotation center. Also the inner coil have reversed directionanlity to the outer coil and has $\mu \times M$ turns. While flip-coils intercept the flux Φ of a magnet, opposite sign voltages are induced in two flip-coils. Where r_1 = 24mm, r_2 = 12mm, β_1 = 0.5, β_2 = 0.5, M = 10, and μ =2. With these parameters, when inner and outer coils are connected in series, the fundamental component has zero sensitivity and only higher order multipole components are visible. For fundamental measurement, only outer coils are used for better signal to noise ratio.

The block diagram of the flip coil system is shown in Figure.2. This system consists of flip coils, two xyz stages, driving motors, analogue integrator, a DVM, PC and so on. Two 20-bundle multifilament wires from the MWS Wire Industries were mounted on fixtures of two XYZ stages. Two flipping motors were rotated by the common pulse source which come from the OEM010 indexer from PAKER Co. In this way, the two motors can rotate synchronously. The induced voltages at the coil is integrated by the analogue integrator after selecting the bucked or unbuckled mode. For bucked mode, the two coils connected in series to cancel out the fundamental component so as to increase the sensitivity of the higher multipoles. The self-resistance of the outer coil is 308 Ω resistance in 10 turns and inner coil has 608 Ω resistance in 20 turns. These resistance values are taken into account to calculate the integrator gain.

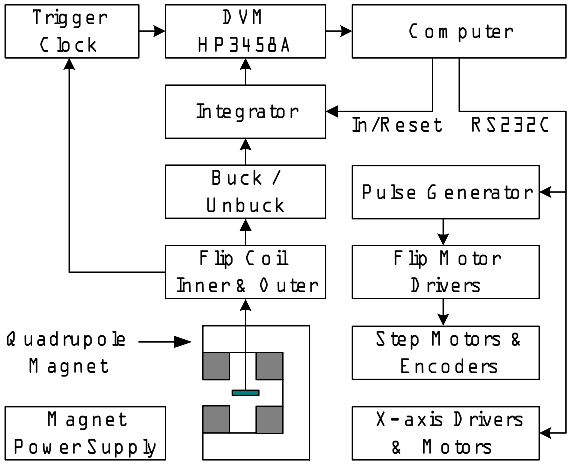

Figure 2: Block diagram of the flip coil system

The integrated voltage was digitized by a DVM HP3458A while flip-coil was revolved with constant velocity. The DVM was triggered by the clocks of the incremental encoder for sampling the data. The encoder value is directly proportional to the angular positions of the flip coil. The sampling rate is 2000 samples/revolution with 4-byte integer per sample, and the sampled data were transferred to the PC in burst mode by the GPIB. A typical sampled voltage waveform was shown in Figure.3.

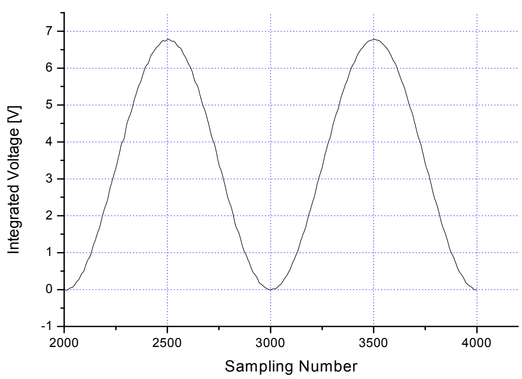

Figure 3: Integrated voltage waveform of the quadrupole magnet.

Two different AC voltages for 120V and 220V are applied to the system to increase signal to noise ratio in this system. One 120V is for signal processing part, and the other 220V for stepping motor drives which are the major noise sources because it is switching about140V DC to make a stepping pulses. The ground of the integrator, encoder clock counter and stepping pulse generator were isolated each other by using the photo-coupler and transformer. The reproducibility of this system was better than 1.414×10^{-5} Tm in RMS by measuring the variations of ten successive measurement results as shown in Figure 4, which was reasonable values to accept.

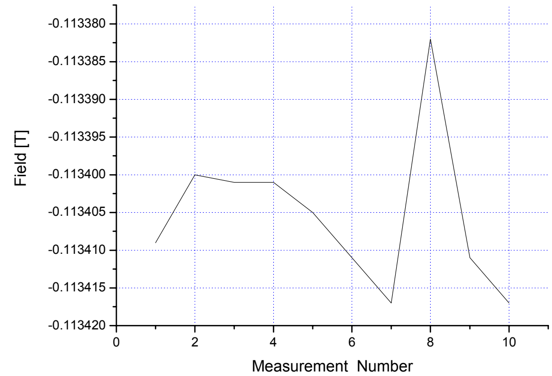

Figure 4 : The results of the reproducibility measurement of the system.

The sampled data were processed to evaluate the multipole components by Fourier expansion. The sensitivities of the coil and pre-scaling factors such as integrator gain, coil turns, multiple number and so on are calculated. The measured data are normalized to the "good field" radius of 30mm. The program was written in "C" in MS windows operating system.

MEASUREMENTS AND ANALYSIS

The measured multipole coefficients by this system are compared with those results of the previous rotating coil system. We found out the differences of two results was less 1.7% which might be came from mechanical tolerance of coil fixtures. The analyzed multipole components, which were normalized by the fundamental components of B_2 , were shown in Fig.5. With more careful aligning and calibration, we believe the accuracy can be improved to better than 0.1%.

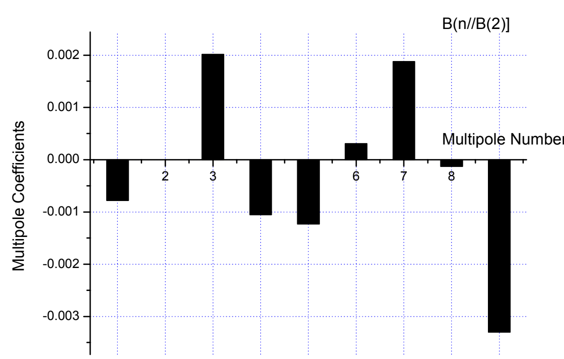

Figure 5: Multipole components normalized by the fundamental

SUMMARY AND DISCUSSION

In this paper, development of angularly resolved flipping coil system is described. This system has advantage in the flexibility that can measure wide variety of core radius and length of the magnets. The measurement results are compared with the old results from the conventional rotating coil system. The difference was less than 1.7% which may be attributed to the geometrical inaccuracies of the flipping coil system. More exact calibration procedures are needed with methods than can align the coil with respect to the magnet efficiently and accurately. More detailed studies will be carried out in the future to make it a useful tool for versatile magnetic measurement system.

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