A LONG LOOP COIL SYSTEM FOR INSERTION DEVICE MAGNET MEASUREMENT

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Abstract

The "dynamic scan" and "static scan" measurement methods, using the long loop coil system, have been designed for magnetic field measurements of the elliptically polarizing undulator (EPU) as well as any other insertion device magnet. The basic design concept is to build a reliable and high speed measurement system for characterizing the two transverse magnetic field components. The main features of this system are its high speed of measurement, high precision and accuracy. This system can perform the multipole field measurement within ten minutes by the " static scan" method, and in one minute by the " dynamic scan" method.

1 INTRODUCTION

Several thousands of magnet blocks and the different kind of insertion devices need to be characteristized. Therefore, a fast speed and high precision long loop coil measurement system is deemly necessary for the field measurement. The long loop coil measurement system performs three major tasks : (1) measuring the integral field distributions of the NbFeB blocks to provide for the magnet sorting, (2) measuring the multipole field component as a function of gap and phase for the multipole shimming, (3) to double check the Hall probe measurement results. The integral field distribution, viz. $\int B_x \, dz$ and $\int B_y \, dz$, of each block surface can be measured by the "dynamic scan" method to reduce the time consumption and the whole insertion device will be measured by the "static scan" method.

This system is am automatic measurement and data acquisition system which was developed on the LabView application program. It can quickly measure the magnetic fields of the magnet block and analyze the field homogeneity features. The measurement speed and accuracy of the integral field are much higher than the 3-D Hall probe measurement system[1]. However, the measured data of this system can not be used for trajectory and spectrum shimming. Finally, the long loop coil system and its precision and data analysis algorithm are described in this report.

2 LONG LOOP COIL MEASUREMENT SYSTEM

The long loop coil system consists of two groups x-y-z stages to position and translate the coil. Each group of x-y-z table has a rotor to rotate the long loop coil. For the synchronization of rotation and translation, one driver controls two groups of X and Y axes, while the other driver controls two groups of Z and R (Rotor) axes[2]. The coil is fixed by the coil fixture[2]. When the coil is installed on the coil fixture, the coil center automatically become concentric to the rotating center of the two rotors.

The PC was selected as the main control unit, wherein two stepping motor control cards (PC-STEP-4A-CL), one Digital I/O board (NI-PC-DIO-24), and one NI-AT-GPIB card were installed to perform the remote control and data acquisition[2]. The software was developed on the LabView application program[2]. Before the magnetic field measurements, the NI-PC-DIO-24 sends a signal to reset the integrator (Metrolab PDI5025) and starts to integrate the magnetic flux change. Meanwhile, the rotor begins to flip the coil (in the static scan) to the preassigned positions of 0°, 90°, 180°, 270° and then measures the integral flux at these four positions individually, or translate the coil (in the dynamic scan) along the transverse axis.

The system consists of a predefined home position and limit switch, and uses the photo-detector switch to find the home position and to avoid exceeding the limit position of the rail. The data acquisition method is to perform the value which is cumulated from the start of the measurement and it is stored in the memory at the end of each integration interval. At the end of a run, the number of available data is identical to the number of integration periods. Consequently, the data in the integrator buffer are in ASCII format, which are then transferred to the PC via GPIB interface to be saved in the hard disk memory to perform further data analysis. The six translation axes and two rotators can be moved in individual mode or in synchronized mode. This system can thus be operated in perform two measurement modes, viz. the "static scan" and "dynamic scan". These two measurement modes can also be alternated easily to perform the different measurements. The trig mode can either be external trig mode (from position control) or internal trig mode (from the integrator timer).

3 MEASUREMENT AND ANALYSIS ALGORITHM

Since there are several thousands of magnet blocks which need to be measured for assembling the insertion device

magnet, a high speed measurement system for obtaining multipole integral fields is desirable to reduce time consumption. Therefore, this system can be operated in two measurement modes, (1) "static scan" with flipping coil, and (2) "dynamic scan" with translating coil.

3.1 Static scan mode

When the coil is flipping around the rotating center, the induced voltage e due to the variation of magnetic flux - $Nd\Phi/dt$ will be created in the coil. The geometrical structure of the long loop coil operating in the "static scan" mode is shown in Figure 1, where Φ is the magnetic flux linkage and $N =10$ is number turns in the coil. Since the coil flips around the longitudinal axis, the induced voltage e can be expressed as

$$e = -N\frac{d(\vec{B}\cdot\vec{A})}{dt} = N(Bl)X\sin\theta\frac{d\theta}{dt}. \qquad (1)$$

where B is the magnetic field strength, $l=5.5$ m and $X=0.5$ cm are the coil length and width of the long loop coil, respectively. The induced voltage can be integrated in the integrator when the coil is flipping. Therefore the integral value, I , can be obtained by integrating the induced voltage with respect to time integral in the integrator

$$I = \int_{t1}^{t2} edt = N\,B_{x,y}\,X\int_{\theta1}^{\theta2}\sin\theta d\theta = 2NX\,B_{x,y}. \qquad (2)$$
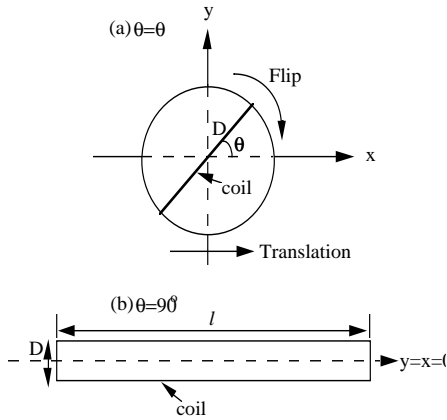

Figure 1: Schematic view and geometry structure of the long loop coil is on the "static scan" method. (a) Front view on the longitudinal axis, coil located at any angle θ, (b) Side view on the horizontal plane, coil located at θ=90°.

If the θ is changed from 0° to 180°, the vertical field integral $B_y = B_y(\theta = 0^o) - B_y(\theta = 180^o)$ will be obtained and if θ is changed from 90° to 270°, the integral value of horizontal field $B_x = B_x(\theta = 90^o) - B_x(\theta = 270^o)$ will be obtained. Therefore Eq.(3) gives us the field integral strength in $G\cdot cm$ unit

$$B_{x,y}(j) = C + \frac{I(j)\cdot 10^{-8}}{2NX} = C + 0.1\cdot I(j)\cdot 10^{-8}. \qquad (3)$$

where C is the zero field offset, which can be calibrated by measuring the earth's field. For increasing the precision of the "static scan" mode, data acquisition can be performed when the coil flips backward to the original location, and averaged with the measurement of forward flip.

3.2 Dynamic scan

When the coil is translating along the transverse axis, the induced voltage e due to the variation of magnetic flux - $Nd\Phi/dt$ will be created in the coil. The geometrical structure of the long loop coil operating in the "dynamic scan" mode is shown in Figure 2. By the same reasoning as in 3.1, the induced voltage e due the coil translation can be expressed as

$$e = -N\frac{d(BA)}{dt} = -N\frac{d(Bl\cdot X)}{dt}. \qquad (4)$$

The induced voltage can be integrated in the integrator by moving the coil along the transverse axis. Therefore the integral value, I , can be obtained by integrating the induced voltage with respect to time integral in the integrator

$$I = \int_{t1}^{t2} edt = -N\cdot B_{x,y}\int_{x1=0}^{x2=x}dx. \qquad (5)$$

Therefore, the integral field strength at certain position can be obtained as

$$B_{x,y}(j) = C + 0.2\cdot I(j)\cdot 10^{-8}. \qquad (6)$$

where C is the zero field offset which can be calibrated by measuring the earth's field strength. If the coil is fixed at $\theta = 0^o$ and translated from x_1 to x_2, B_y will be obtained and if the coil is rotated to be $\theta = 90^o$ and then translated back to the original location from x_2 to x_1 (at the original position), B_x will be obtained. Eq.(6) gives the field integral strength in $G\cdot cm$ unit. However, since the effective sensitive area of the coil is different for the "static scan" and "dynamic scan" modes, the calibration factor is to be changed to $0.1991\cdot I$ from $0.2\cdot I$.

In the dynamic measurement mode, the electric drift and the reference field strength offset should be corrected by calculating $(I_f - I_i)$ and $(I_{fs} + I_{is})$, and the field strengths of I_f and I_i should also be calibrated in order to obtain the exact electronic drift. Hence the electronic drift compensation values $I_{d,y}(j)$ and $I_{d,x}(j)$ at j-th position can be expressed as

$$I_{d,y}(j) = \frac{[(I_{f,y} - I_{i,y}) + (I_{fs,y} + I_{is,y})]\cdot j}{n}, \qquad (7)$$

$$I_{d,x}(j) = \frac{[(I_{f,x} - I_{i,x}) - (I_{fs,x} + I_{is,x})]\cdot j}{n}. \qquad (8)$$

Where n is the total number of sampling, I_f and I_i denote the integral field values (unit is $Vs\cdot cm$) at the final and initial positions, I_{fs} and I_{is} are the absolute integral values (unit is $Vs\cdot cm$) at the final and initial positions. Herein, I_{fs} and I_{is} can be obtained by flipping the coil at the final

and initial positions resembling the "static scan" mode. Finally, the integral multipole field strength $I'_{x,y}$ at j-th position can be calculated as

$$I'_y(j) = I_y(j) - I_{i,s} - I_{d,y}(j), \qquad (9)$$

$$I'_x(j) = I_x(j) - I_{f,s} - I_{d,x}(j). \qquad (10)$$

Eqs.(9) and (10) can be inserted into Eq.(6) to calculate the integral field strength. Therefore, the field calibration can be obtained by Eqs. (3) and (6) which based on the coil geometry dimension and the integrator features.
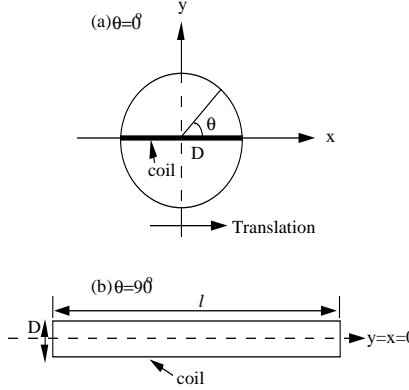

Figure 2: Schematic view and geometry structure of the long loop coil is on the "dynamic scan" method. (a) Front view on the longitudinal axis, coil located at any angle $\theta=0^o$, (b) Side view on the horizontal plane, coil located at $\theta=90^o$.

4 SYSTEM PRECISION AND ACCURACY

Measurements of the magnetic field were performed by flipping the long loop in the "static scan" and "dynamic scan" methods along the x-axis of the APU magnet, and recording the integral field of B_y, and B_x which are as a function of transverse position[2]. These measurements yield multipole integral field profile and the system precision and accuracy were surveyed. The precision and accuracy of the measurements of vertical and horizontal field integrals are shown in Table 1 which also has indicated the measured speed and field offset of the long loop coil and Hall probe system. A Hall probe measurement system was also used to measure the multipole integral field distribution under the same conditions, to compare with the results of the long loop coil measurement system[2]. This "static scan" method of the long loop coil can complete the multipole field measurement within ten minutes in the range of ±52 mm per 4 mm. Under the same measurement conditions, the three-orthogonal Hall probe system need 1.5 hours to complete the multipole integral field strength measurements of the 1 m long insertion device. Moreover, the measurement speed of the "dynamic scan" has been improved, and it completes the multipole component measurement of magnet block within one minute, which is ten times fastest than the "static scan" method.

Table 1: Precision, accuracy and measured speed of the long loop coil and Hall probe system.

	ΔB_{p-p} (G·cm)	ΔB_{rms} (G·cm)	speed (minute)	Accuracy (%)	Offset (G·cm)
Static	±10	5	10	0.5	30
Dynamic	±25	15	1	0.5	30
Hall probe	±25	10	90	---	-100

However, from the results in Table 1, the precision of the "dynamic scan" method is three times worse than the "static scan" method. After the effective area modification, the maximum absolute field error between these two methods is within the field deviation range. The crucial issue of system accuracy depends on careful elimination of electric drift, high frequency noise, and coil vibration. The electric drift can be canceled by means of data analysis, while the high frequency noise can be filtered by using low pass filter circuits. To obtain high accuracy, the sag and diameter of the coil should be as small as possible. The optimum values for sag and coil diameter are 0.5 mm and 0.5 cm, respectively, to avoid the field error induced due to the fringe field, inhomogeneous field and the coil sensitive area error.

5 CONCLUSION

The precision of the system presented here is enough for characterizing the field quality of insertion device magnets or magnet blocks. The system's rms. precision is about 5 $G\cdot cm$ in the "static scan" method, and 15 $G\cdot cm$ in the "dynamic scan" method. Essentially, the accuracy of this system lies well within 0.5%. The measurement speed as well as the precision of the long loop coil system are faster and much more accuracy than the Hall probe measurement method. It was found that the calibration value differs by 130 $G\cdot cm$ difference between the long loop coil system and three orthogonal Hall probe measurement system[1].

6 ACKNOWLEDGMENTS

7 REFERENCES

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