

# Rotating Coil / Helmholtz Coil Magnetic Measurement System Using Lock-in Amplifier Method

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## 1. Introduction

Measurement of integrated magnetic flux is an important part of construction of insertion devices (ID.) Flipping coil [1] is normally utilized to characterize the integrated multipole components of the device, a requirement of which varies from one storage ring to another. Helmholtz coil system is used to determine a magnetization vector of each magnet piece. Both systems are designed to measure integrated magnetic flux to deduce quantities using known relationship. We have developed an unconventional system having continuously rotating mechanism which allows the use of lock-in amplifier instead of integrator or voltmeter. Concise descriptions of the equipment are given in the following sections.

## 2. Rotating Coil System

Conventional flipping coil system employs multi-turn coils whose output goes to an integrator or programmable voltmeter for integration. The coil usually has a limited range of rotation angle so that integration must be done within this range. As a consequence all the frequency components of the output voltage from the coil must be included and noise filtration becomes a major obstacle.

It is known that one of the most effective means for noise reduction is to limit the bandwidth of the measurement. In order to apply this type of method to a flipping coil system, one needs a connector which enables the rotation of the coil while maintaining electrical connection. A rotary connector (Mercotac Model 205) fulfills this condition by having mercury as an interface medium.

Another advantage of using lock-in amplifier is that both normal and skew components of the first integral can be measured simultaneously as two quadratures. The first integral  $I_y$  and  $I_x$  could be derived from the following equation;

$$V = \text{const} (I_y \sin \omega t + I_x \cos \omega t) = A \cos (\omega t - \phi) \quad (1)$$

where  $V$  is the induced voltage and  $w$  is the angular frequency of rotation. The amplifier indicates  $A$  and  $\phi$ .

The second integral could be calculated as follows [2];

$$\theta_x = -\phi_x / \Theta + L \cdot I_x \quad (2)$$

where  $Q = d / L$ ,  $d$ : whole width of the coil,  $L$ : a half

length of the coil and  $\phi_x$  is the coefficient of sin component of integrated flux.

Figure 1 shows a schematic of the system layout. Two stepping motors (Oriental Motor UPK-569-NAC) would rotate the coil and the motor controller (Tsuji Denshi Flip-Coil-Controller) which ensures a synchronization of movement of two motors within less than 0.1 degree. A absolute rotary encoder (K+R CE-65-P) has 3600 division per turn and a minimum step is 0.1 degree. The multi-turn coil is made of Teflon<sup>®</sup> coated tungsten wire of 0.1 mm diameter. Copper wire is deemed to be inappropriate as rather high tension (1 kgf / wire) is required to maintain a constant width of the coil during the rotations of five turns per second. We could observe a steady increase of the output voltage during the measurement due to elongating coil when 0.2mm diameter enamel coated copper wire was used. A lock-in amplifier (Stanford Research SR850) with a DSP has an advantage of having very low detectable frequency (1 mHz.) It also has very high dynamic reserve compared to a conventional analog type so that a use of electrical noise filter could be avoided.

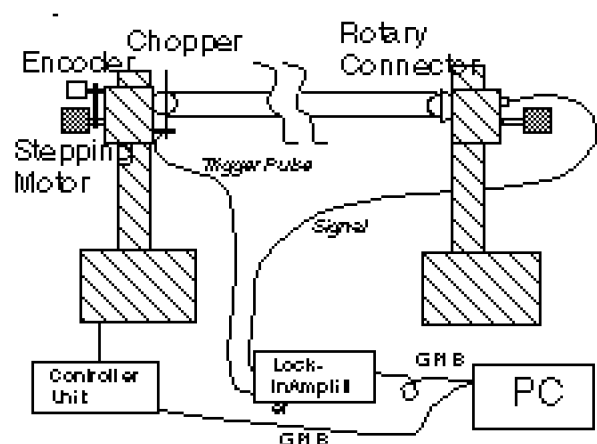


Fig. 1. The schematic of SPring-8 rotating coil device

## 2. Helmholtz Coil System

Like the rotating coil system, our Helmholtz coil scheme employs a lock-in amplifier in order to improve signal to noise ratio. It uses an inverter motor (Sumitomo Heavy Industry, CNHM02-4085-AV-6)

instead of a stepping motor as synchronization of multiple motors was unnecessary. The encoder unit (Nikon RNJ10800) was chosen to warrant 0.1 degree resolution. However, unlike the rotating coil, this one also has a conventional integrator method for an alternative method. The reason for this duality is as follows: Unlike integrated multipole measurement, one could expect reasonably big signal on certain circumstance, for instance, with a large magnet block. In addition, a symmetry of rotation is not always guaranteed. If not symmetric, high speed rotation generates vibration which results in extra noise. Measurement data are taken through GPIB interface to a PC in which a software written in Microsoft C runs. A simplified picture of the system is given in Fig. 2.

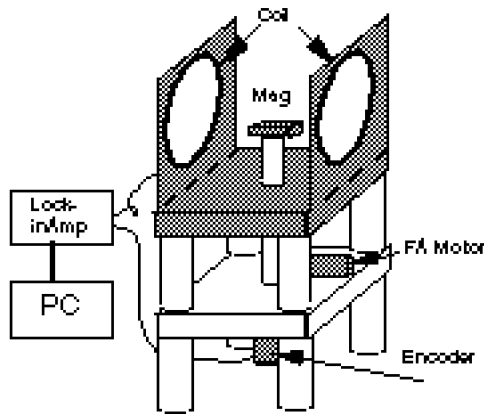


Fig. 2. A simplified picture of SPring-8 Helmholtz coil system.

### 6. Measurement

Figure 3 shows a measurement result of multipole components of a SPring-8 insertion device (#4 - BL09) at a gap of 8 mm by the rotating coil system. The result of nine consecutive measurements indicate that repeatability of the measurement within half an hour is approximately 1 Gcm.

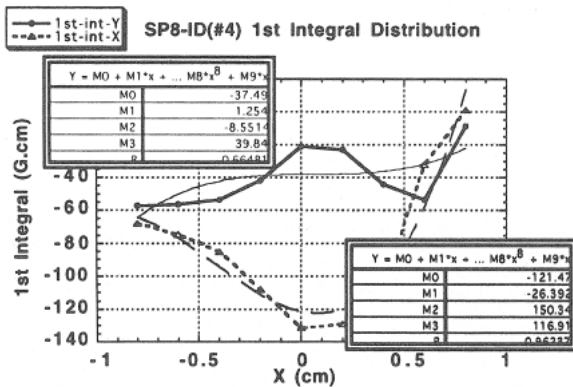


Fig. 3. The first field integral distribution and multipole components for SPring-8 ID (#4 - BL09.)

### 7. Conclusion

With a continuously rotating mechanism, a rotating coil / Helmholtz coil systems using a lock-in amplifier have been developed. This type of measurement is particularly suitable for integrated multipole measurement of magnets, the signal from which is inherently small.

### References

- [1] See for example, R. P. Walker "Magnetic Measurement," Synchrotron Radiation Sources, World Scientific (1994)
- [2] D. Frachon et al., "Magnetic Measurements of the Elliptical Multipole Wiggler Prototype," ANL/APS/TB-22 (1995)