# A Simple Magnet Multipole Measurement System

T.C.Fan, C.S. Hwang, P.K. Tseng
Synchrotron Radiation Research Center
No.1,R&D Road VI, Hsinchu Science-Based Industrial Park, Hsinchu 30077, Taiwan, R.O.C.

*Abstract*

A magnet multipole measurement system (MMMS) purchased from Scanditronix AB, Sweden (Scx) has been improved by the engineers locally. We used this system to measure all the quadrupole magnets and the sextupole magnets to be installed into the storage ring of SRRC. The MMMS consists of a rotating coil assembly with a stepper motor and a subsystem incorporating electronics for signal handling and analysis. The rotating coil is centered relative to the magnet with conical taper rings pressed against the poles at the ends of the magnet easily. Some technical aspects of the MMMS will be discussed. The results of the measurement are to be compared with the ones using the homemade Hall probe system.

## 1. INTRODUCTION

Generally, the rotating coil is the best choice for measurements of series of magnets. It is useful in diagnosis of accelerator magnets [1]. The theory and the instrumentation have been developed considerably [2]. Some comprehensive measurement systems based on rotating coil are commercially available. The fancy DANFYSIK MMMS, model 692 is one of them. For some reason, we don't have any of them in the construction of the electron storage ring.

At the stage of the prototype construction, we developed a Hall probe system with high reliability [3]. We made use of the system to map the two or three dimensional magnetic field in order to learn the detail of the relation between the field performance and the mechanical error of the magnets. While in series production of the storage ring magnets, our strategy is to use the Hall probe system to acquire only a set of data at the main excitation current of quadrupole magnets and sextupole ones. Then, for saving time and cross check, the simple MMMS was used to get the harmonic content at a series of excitation/trim currents, the relation of the field and current was established as well.

SRRC purchased the MMMS from Scx in 1991. Except the coil dimension, the system is identical with the one used by Scx for measurement of the quadrupole magnets for the Booster Synchrotron, constructed by Scx for the SRRC. It was of simple structure, easy to operate and inexpensive one. The MMMS while delivered consisted of a self centering rotating coil, a stepper motor with driver; a CPU coupling electronics for signal handling, signal analysis and communication. The mechanical layout of the rotating coil assembly is shown in Fig. 1, the simple positioning and alignment method of the rotating coil is impressive. The positioning pipe is centered relative to the magnet just with conical rings pressed against the pole at the ends of the magnets.

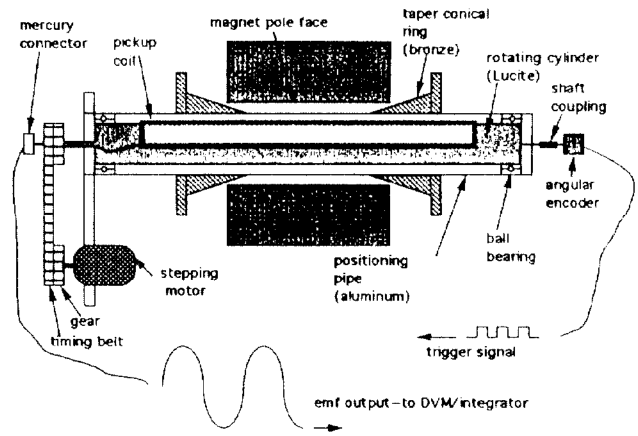


Figure 1. The layout of the rotating coil assembly.

In the position pipe, a rotating cylinder made of Lucite serves as the coil support. The coil configuration is of the simplest type, i.e. wiring along the side of the cylinder and coming back along the rotation axis, as shown in Fig. To achieve the higher signal-to-noise ratio, for the quadrupole magnet with a yoke aperture diameter of 76 mm and the sextupole one of 80 mm, the effective coil radius was designed to be 33 mm and positioning pipe 37 mm.

The accuracy and reproducibility of the whole system is of the order of 1/1000 peak value which was sufficient to the measuring of the Booster ring magnets but not of the storage ring magnets. While measuring the sextupole magnet without any variation in mechanical configuration after positioning, with the average of 100 times per run, the system presented a $2*10^{-4}$ reproducibility. However, as the rotating coil was removed and re-installed, the reproducibility dropped to $5*10^{-3}$. The result could not be compared with the one derived from the Hall probe system of SRRC. So we tried to improve it step by step.

## 2. THE ELECTRICAL ASPECTS

### *2.1 Getting a higher resolution*

The CPU contains a TMS9995 microprocessor and an ADC. Since the resolution of the ADC was only 12-bit and dependent upon rotating speed, we replaced the CPU by an HP 3458A DMM with a PC as the controller. The resolution had been improved but the reproducibility got worse.

*2.2 The instability of the trigger period*

The stepping motors rotate stepwise. The drive current is a series of square waves with one at each step. As a result, the process of a accelerating after a decelerating at each step makes the speed of rotating unstable. In the vibration test, it turns out to be the main vibration source of the whole mechanical assembly. We did a simple experiment to see how the induced voltage is influenced by this vibration.

We adopted a stepping motor with 200 steps per turn coupling an angular encoder with 1000 angle resolution per turn. The output of the encoder is to trigger the DVM to take 5 data at each step. Since the induced voltage from the pick-up coil is proportional to the speed of rotation, we can observe the speed variation from the output of the DMM indirectly. Fig. 2 is an example to describe it, a section of the output voltage was selected while the coil was flying through one of the pole faces. One can see the speed of rotation varies periodically. After fitting, we found a 0.3% deviation in speed and the uncertainty of the induced voltage will be of the same level.

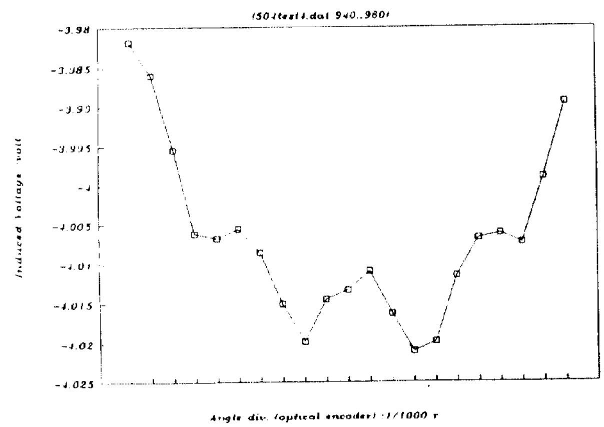

Figure 2. The induced voltage affected by unstable rotation of the rotating coil.

*2.3 Digital integrator*

If the angular encoder quality is perfect, the use of a voltage integrator connected to the measuring coil makes it possible to eliminate the velocity dependence.

We have a bipolar V/F converter (16V1201-P1) purchased from LBL. Before each measurement, we calibrated it by Detron 4808 Calibrator and Iwatsu 7204 counter. After 2 hours warm-up of these three instruments, the drift of the V/F converter is smaller than $10^{-5}$ per hour.

## 3. THE MECHANICAL ASPECTS

*3.1 The mechanical transmission error*

However, even the periods of the rotating angle are not uniform. In an experiment, we mounted an encoder with a resolution of 200 angles per turn. The periods were measured by a counter. Fig. 3 shows the results. One can see a 2 % variation between periods. The precision of the angles are surely to be concerned. But some periodical behavior shows that the transmission mechanism is more critical. If the measurement are performed by one clockwise rotation followed by one counterclockwise rotation of the coil, the periodicity has different behavior, the high harmonic terms re-distributes as well, Table 1 is one of these examples.

As Fig. 1 shown, the torque to rotate the rotating cylinder is transmitted by two gear wheel coupled by a timing belt. The encoder was mounted on the other end connected to the rotating cylinder by a shaft coupling. All these elements should be mounted and aligned carefully. Take shaft coupling for instance, radial displacement, angular displacement or backlash shall make the rotation speed unstable. The coupling of the rotation transmission of two ends will make it more complicated.

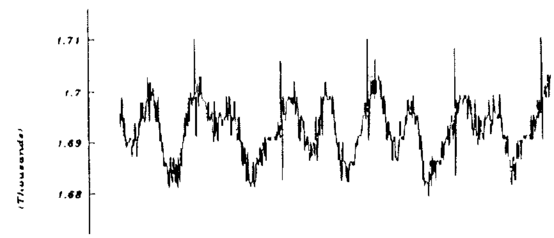

Figure 3. A measurement of the duration period at each angular encoder angle. The most sharp peaks are happened to be the marks of the starting points of each rotation.

*3.2 Conical taper rings*

Since the installation of the taper rings need to be pressed by external force, some damage of the taper are unavoidable due to the hard edge of the magnet pole. We tried some material like copper films and Teflon thin layers to be intervened the pole face and the taper as a buffer but find it just make the mechanical tolerance more complicated.

We had carried out an reproducibility test by removing the taper rings and re-mounting by rotating it with various angles, then observed the shift of the target mounted on one end of the positioning pipe by theodolite. We found a 0.2 mm displacement of the target with random direction. With the coupling of two taper ring, an offset and a tilt of the positioning pipe shall emerge.

*3.3 The sag of the rotating cylinder*

Since the rotating cylinder is made of Lucite and the rigidity is somewhat poor, the sag is unavoidable. It is meaningless to measure the concentricity and the straightness while suspended by two ends. So we observed the sag by auto level meter and got an average 0.5 mm at the middle of the cylinder which is comparable with the theoretical calculation.

A drift of the induced voltage and a time dependent variation of harmonic distribution were observed. After checking all the electrical instruments we believed they are not mainly due to the electronic drift. A sag related model is to be proposed. We can describe this by Fig. 4. After positioning, the rotating cylinder distortion reaches an equilibrium with gravity within two hours and has a maximum sag at the middle of the cylinder, as Fig. 4 (a). While rotating, a "relaxation" effect shall re-deform the cylinder back to its original shape, as Fig. 4 (d). The pickup coil will return to straight line shape. The amplitude of the induced voltage will reduce in case (a) and increase in case (b), but make no difference in case (c).

The observation of the drift and the harmonic re-distribution shows a consistency with the model.

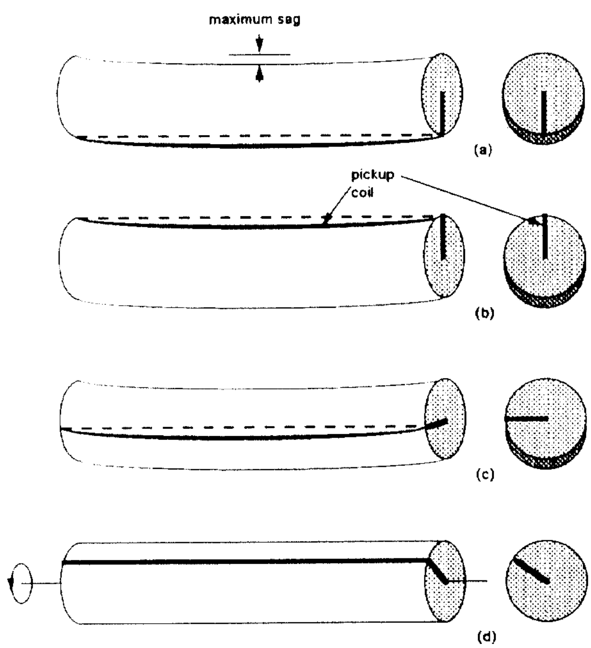


Figure 4. The sag of rotating cylinder due to gravitation. The dashed lines are the positions of the pickup coil after a period of rotation or without sag.

## 4. COMPARISON WITH THE RESULT OF THE HALL PROBE SYSTEM

Comparing with the result of the measurement of the Hall probe system, the most obvious error is the bigger dipole term of the quadrupole magnets or the bigger quadrupole harmonic of the sextupole magnets. For quadrupole magnet, take Table 1 for example, if the CCW data is normalized at 30 mm, there shall be a 0. 525% dipole. Then a 0.421 dipole error occurs. It is equivalent to a misalignment of 0.16 mm which is consistent with the result of survey data mentioned in section 3.2.

All the high harmonic terms are within the tolerance. The terms of harmonic number 6, 10 and 14 are in excellent agreement with the Hall probe data.

Table 1
An example of measurement result of quadrupole magnet

| Harmonic number | Hp3458A | CW @33 mm | CCW | Hall probe @30 mm |
|---|---|---|---|---|
| 1 | 0.330 | 0.477 | 0.490 | 0.104 |
| 2 | 100.00 | 100.000 | 100.000 | 100.000 |
| 3 | 0.170 | 0.060 | 0.096 | 0.022 |
| 4 | 0.388 | 0.024 | 0.012 | 0.012 |
| 5 | 0.022 | 0.001 | 0.002 | 0.004 |
| 6 | 0.019 | 0.008 | 0.011 | 0.012 |
| 7 | 0.005 | 0.009 | 0.003 | 0.003 |
| 8 | 0.006 | 0.001 | 0.002 | 0.003 |
| 9 | 0.004 | 0.003 | 0.008 | 0.006 |
| 10 | 0.081 | 0.028 | 0.030 | 0.039 |
| 11 | 0.004 | 0.003 | 0.006 | 0.005 |
| 12 | 0.006 | 0.002 | 0.005 | 0.004 |
| 13 | 0.004 | 0.004 | 0.005 | 0.007 |
| 14 | 0.048 | 0.013 | 0.013 | 0.016 |
| 15 | 0.003 | 0.002 | 0.007 | 0.008 |
| 16 | 0.002 | 0.004 | 0.003 | 0.012 |

Excitation current: 186 Amp., Series number: Q44
Quadrupole length = 350 mm

## 5. CONCLUSION

After the renovation and some adjustment, the simple MMMS convenient and useful for quality control in series production. The accuracy in measuring the harmonic content and the field strength depends directly on the angular precision of the rotating coil. The linkage of the rotation transmission should be set up carefully. The multipole errors due to the intrinsic mechanical error from the simple structure need to be further improved.

## 6. ACKNOWLEDGMENTS

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## 7. REFERENCES

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