Research of Reproducibility of Dipoles for CSRm

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***Abstract*—The measurement method and principle of dipole magnet reproducibility for Cooling-storage-ring are introduced. How the position and number of steel sheet affect the reproducibility of magnet is investigated. In the end, the reproducibility of CSRm dipoles reaches to less than $\pm 2\times10^{-4}$, which can meet the acquirements of CSR. In addition, the measurement repeatability and the sources causing errors are also analyzed.**

***Index Terms*—shim, integral coil, reproducibility, standard deviation**

I. Introduction

THE main ring of HIRF-CSR system [1] is a synchronous accelerator. While ions are accelerated in the system, they are restricted in orbit by the magnets. In other words, the change of magnet field must be synchronous. For considering more factors in magnet field synchronization, the control system for power supply would become very complicated. The problem can be solved in the condition that all the 17 dipoles (including a reference magnet) in the effect of deflection are connected in series with one power supply. However there is unavoidable deviation in the process of batch manufacture of magnets. The value of reproducibility shows the degree of deviation. So the main problem during the manufacturing of dipoles is dispersion control.

TABLE I
THE PARAMETERS OF CSRM DIPOLE

Type	H
Field range(T)	0.1–1.6
Bending radius(mm)	7600
Bending angle(degree)	22.5
Pole width(mm)	220
Air gap(mm)	80
Field uniformity	$\pm 2.0\times10^{-4}$
Current(A)	3000
Steel Length(mm)	2906
Effective aperture(mm^2)	170×60

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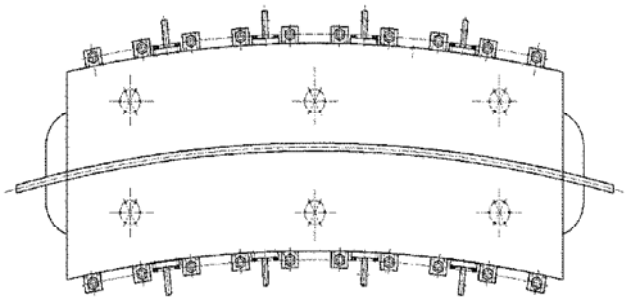

Fig. 1. Overview of dipole for CSRm

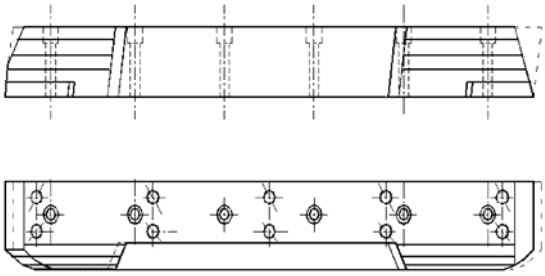

Fig. 2. Overview of steel slice on dipole pole

II. The Introduction of CSRm Dipole Magnet

The shape of CSRm dipole magnet adopts H type. The iron body is laminated by 0.5mm thick high induction cold rolled isotropy electro-technical steel sheet [2]. To adjust the equivalent length of magnet in the process of measurement and reduce the reproducibility of the 17 dipole magnets (16 measured magnet and 1 reference magnet), the demountable pole end structure has been adopted. Adding or taking out 0.5mm silicon steel slice can adjust the equivalent length of magnet. Main parameters of dipoles of CSRm are shown in table 1.The looking down figure of dipole of CSRm is shown in fig.1. Main structure of the demountable pole end is shown in fig.2.

III. The Principle of Reproducibility Measurement in Integral Magnet

Ramping current was adopted to change the magnetic flux during the measuring of magnet reproducibility [3]. If absolute measurement is adopted using only one coil, the value of $\int B(0)dl$ must be very large, as well as it hardly obtains the precision of 10^{-4}. If relative measurement is adopted using two coils, it means an easy way to reach high precision. That is two magnets are reverse connected in series with a power supply, and the value of $\Delta\int B(0)dl$ will be measured directly.

Magnet 1(measured magnet) and magnet 2(reference magnet) are connected in series. Two integral long coils are put in the center of the pole width and air gap. Coil 1(measurement coil) and coil 2(reference coil) are reverse connected in series.

The Magnetic flux crossing the section of coil can be described in the formula following [4]:

$$\Phi = NW\int B(0,l) = NWBL. \tag{1}$$

Here, NW is the coil constant (N is the number of coil circle, W is the width of coil), L is the length of integral coil. The difference of the integral magnet field between measurement coil and reference coil can be gotten from the following formula:

$$\Delta\Phi = \Phi_M - \Phi_R. \tag{2}$$

Then the reproducibility can be defined in the following formula:

$$\xi = \Delta\Phi / \Phi_R = \Delta BL / BL. \tag{3}$$

Because of tolerance of manufacture and so on, there is unavoidable difference between the designed value and the genuine value of NW. However the coil radius is 7.6m and the length of bowstring is 3.4m. It is difficult to find symmetrical dipole magnet field to emendation the real NW value accordingly. The absolute value of $\Delta\Phi$ cannot be gotten [5]. The method of exchanging the two coils should solve the problem. Magnetic flux can be gotten by changed the current. The Magnetic flux (putting the reference coil into reference magnet) is Φ_{RR} and the Magnetic flux (putting the measurement coil into the measured magnet) is Φ_{MM}.

$$\Phi_{RR} = (BL)_R(NW)_R. \tag{4}$$

$$\Phi_{MM} = (BL)_M(NW)_M. \tag{5}$$

The difference of magnetic flux between reference coil and measurement coil can be described in the following formula.

$$\Delta\Phi_1 = \Phi_{MM} - \Phi_{RR} = (BL)_M(NW)_M - (BL)_R(NW)_R. \tag{6}$$

Then exchanged the two coil, it means putting the measurement coil to the reference magnet (Magnetic flux is Φ_{RM}) and putting reference coil to the measured magnet (Magnetic flux is Φ_{MR}).

$$\Phi_{RM} = (BL)_R(NW)_M. \tag{7}$$

$$\Phi_{MR} = (BL)_M(NW)_R. \tag{8}$$

The difference of Magnetic flux between reference coil and measurement coil can be described in the following formula.

$$\Delta\Phi_2 = \Phi_{RM} - \Phi_{MR} = (BL)_R(NW)_M - (BL)_M(NW)_R. \tag{9}$$

So

$$\begin{aligned}&(\Delta\Phi_1 + \Delta\Phi_2)/(\Phi_{RR} + \Phi_{RM})\\ &= ((BL)_R - (BL)_M)/(BL)_R = \xi.\end{aligned} \tag{10}$$

The coil constant NW become a variable irrelevant with ε.

IV. The Process and Conclusion of Measurement

A. The measuring reproducibility at different current state

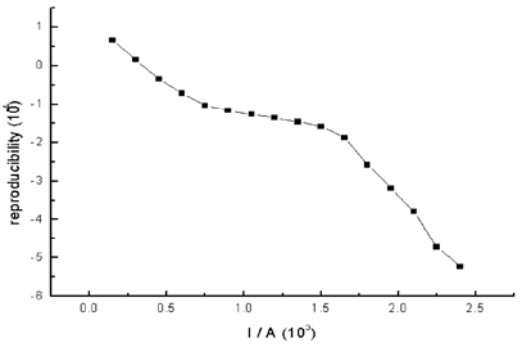

Fig. 3. Curve of the reproducibility with current

In the process of measuring reproducibility, we adopt the method as follows: starting from the minimum output of supply power, and ramping step is 150A, holding 3 seconds at each step. step by step, when the current increased to 2400A (about 1.45T), getting 16 reproducibility value, the results in the Fig.3. From the figure, the reproducibility of magnet is lower 0.8× 10-4 at 150A, but at 1500A, it ascends to 1.6×10-4. At this segment, the reproducibility of magnet decreased gently. When

the current increases from 1500A to 2400A, the reproducibility reaches to 5.5×10-4. Its variety is steeper than the first segment. So for the same magnet, its reproducibility is different at different current. Here, we can optimize the reproducibility about on 0.5T by increasing or decreasing iron sheet.

B. The effect for reproducibility which shimming on downside or upside

1 ~ 5 pieces of iron sheets are shimmed on its upside and downside at the same time. According to this, we obtained ten results. The reproducibility is a curve, and the shape of everyone is conformable with fig.3. Fig.4 is shown the result of reproducibility at 1050A with adding sheets number.

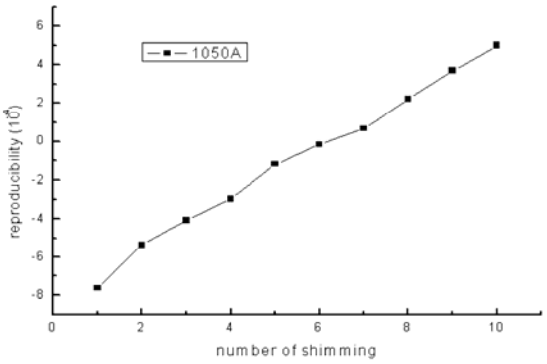

Fig. 4. Curve of the reproducibility with number of shimming

It is drawn that whether shimming on upside or downside, its impact on effective length is equivalent. However, it would produce some effect on multi-pole and the position of median plane of field. So the method is chosen which shimming on the magnet symmetrically.

According to this, we got all the 16 dipole final result of reproducibility. They are shown in the Fig.5.

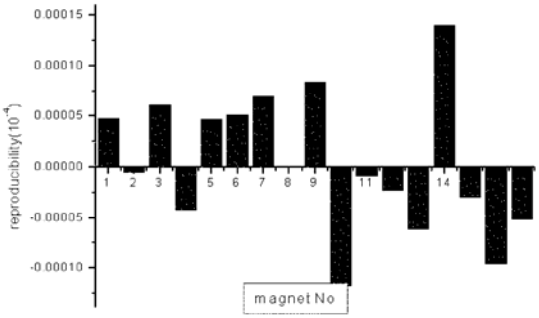

Fig. 5. The reproducibility of dipoles for CSRm

V. THE REPEATED MEASUREMENT

Before shimming, one magnet was measured ten times on its reproducibility. From the experiment, the error of the measurement system is obtained. It can check whether the error satisfies the requirement or not.

Through analyzing the repeating test data, the average and standard deviation of reproducibility of ten times were gotten. The results are shown in the fig.6. At 900A, the measurement error is about 7×10^{-5} which occupy one third of the reproducibility (about $\pm 2 \times 10^{-4}$). It can be realized that the measurement error is satisfied the requirement of CSR.

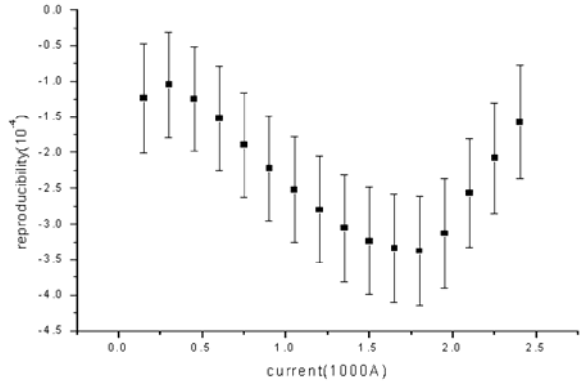

Fig. 6. The error of measurement repeatability for measurement system

VI. CONCLUSION

Through the analysis of the measurement results and errors, a conclusion can be drawn that shimming for integral effective length is possible, but a certain current must be chosen firstly. During the manufacture process, the trim size and weight of the magnet and the symmetry of the upside and downside are the ingredients which effect the magnet reproducibility. By

shimming on the magnet, we may make the reproducibility of CSRm dipoles meet the acquirement of CSR project. In order to enhance the measurement precision, we should manufacture alignment equipment about orientation which limits integral coils when exchanging coils. The remanence diversity of magnet should be also considered in the total magnetic flux.

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