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DESIGN AND MANUFACTURE OF SOLENOID CENTER DEVIATION MEASUREMENT DEVICE*

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Abstract

The solenoids are widely used both in conventional magnets and superconducting magnets in the particle accelerators. The longitudinal fields along longitudinal direction of the solenoids are usually measured with the Hall probe measurement system. However, in some cases, the deviation between magnetic center and mechanical center of solenoid is another important parameter and has to be measured accurately. In this paper, a device is designed and developed to measure the center deviation of the solenoid, which can be both used in conventional magnets and superconducting magnets. After the device is finished, some tests are made in the solenoid to check whether the data is correct. For the numerical simulation and analysis of the magnetic field inside the solenoid, the TOSCA code was chosen right from start. The results of the analysis are compared to the result of the tests. Index Terms—Solenoid, Center deviation, TOSCA code, Measurement device, CSNS.

INTRODUCTION

The China Spallation Neutron Source (CSNS) [1-3] is composed of an H-linac and a proton rapid cycling synchrotron (RCS). It is designed to accelerate proton beam pulses to 1.6 GeV, striking a metal target to produce spallation neutrons for scientific research. The magnetic fields of all the magnets should be measured before they are installed. A hall probe measurement system was built to calibrate all the DC magnets of CSNS [4].

When the hall probe measurement system finished the measurement task of the CSNS magnets. We modified the system to measure the center deviation of the solenoid. Usually we measure the longitudinal field first with the Hall probe. Then we fiducialize the solenoid with the rotating coil. Both measurements check for mechanical problems with the solenoid. The solenoid is fiducialized so that its properties in the beam are correct, namely, so that it doesn't have transverse fields which would steer the beam.

STRUCTURE OF SOLENOID CENTER DEVIATION MEAS-UREMENT DEVICE

Overview of the Device

Figure 1 shows the main structures of the center deviation measurement device. The device includes the following three parts: the coupling, the slip ring motor and the rotating lever. The measurement device adopts one-piece design and the internal is movable structure. It can be used to measure the magnetic fields in different positions along the Z direction.

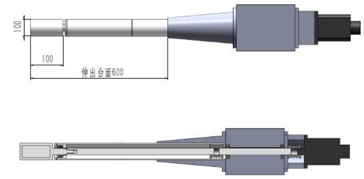

Figure 1: The sketch drawing of center deviation measurement device.

Principle of Measurement

The key point of center deviation measurement is that the short coil does not give a signal from the longitudinal field and only gives a voltage from the local transverse field. In the center of the solenoid we get a transverse field from pitch and yaw of the solenoid. We can use this to take out pitch and yaw by moving the measurement device until the coil voltage goes to zero. At the ends of the solenoid, we get a transverse field locally if the coil is not on the magnetic axis. We can move the coil to the magnetic axis by watching the coil voltage go to zero as we move the coil. Fig. 2 shows the schematic of the principle of the center deviation measurement device [5, 6].

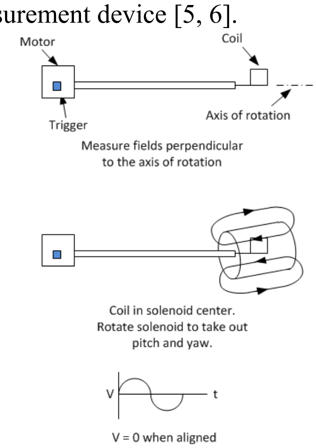

Figure 2: The principle of the center deviation measurement.

The Numerical Calculation of the Project

We calculated the magnetic axis deviation in three cases:

1. When the angle of solenoid axial deviation in the case of 0.015°:

$$\Phi = BS = \sin 0.015° * Bc * S \quad (1)$$

$$\Phi = 2.618e\text{-}4 * 4000 * 10e\text{-}4 * 0.1 * 0.1 = 1.0472e\text{-}6 \quad (2)$$

$$V = Nc d\Phi/dt = (200 * 1.0472e\text{-}6)/0.25 = 0.83mV \quad (3)$$

When the Φ is magnetic flux, B is the max magnetic field, S is the area, V is the induced voltage. And we set the

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rotate speed is 1 circle per second. The calculated results showed that the induced voltage was 0.83 mV.

2. When the displacement deviation between mechanical centre and magnetic center in the case of 0.1 mm:

$$V = N_c d\Phi/dt = (200*0.9063e-6)/0.25 = 0.72\text{mV} \quad (4)$$

When the Nc is the number of turns of the measurement coils. The calculated results showed that the induced voltage was 0.72 mV.

3. When the displacement deviation between mechanical centre and magnetic center in the case of 0.1 mm: we calculated the magnetic field on the edge of the solenoid.

If we can measure the induced voltage and the difference of magnetic field, we can measure the deviation of solenoid axial.

FINITE ELEMENT ANALYSIS OF THE SOLENOID AND PROGRAMMING OF THE MEASUREMENT DEVICE

FE Model of the Solenoid

The Finite Element Model of the solenoid is created in the TOSCA 3D Post-Processor. And the center magnetic field is about 4200 Gs.

First information of the analysis result is the distribution of center magnetic fields. Figure 3 shows the distribution of center magnetic fields of the solenoid. The maximal magnetic field of the model is about 4240 Gs. The right curve shows the distribution of magnetic fields along longitudinal direction of the solenoid about 100 mm.

Figure 4 shows the distribution of magnetic fields on the edge when the displacement deviation between mechanical centre and magnetic center in the case of 0.1 mm. We can use hall sensor to measure the difference of magnetic field on the edge to measure the deviation.

Figure 5 shows the distribution of magnetic fields in radial direction. And the center is 0.1 mm off. The magnetic field is 645.2 Gs and in the other side is 648.4 Gs.

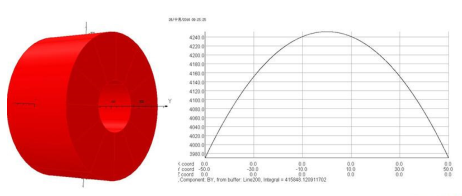

Figure 3: The distribution of center magnetic fields.

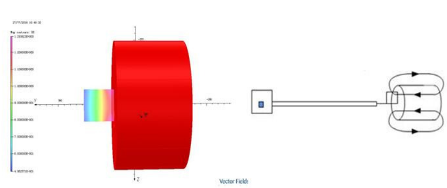

Figure 4: The distribution of magnetic fields on the edge.

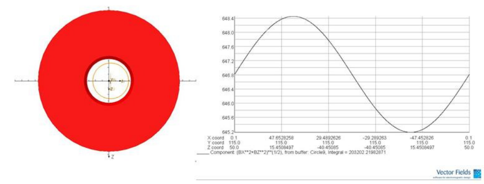

Figure 5: The distribution of magnetic fields in radial direction.

Programming of the Measurement Device

The measurement control program is programmed by labview code. The program has the basic control function modularization, can automatic measure. Figures 6 and 7 show the flow chart of the program and the interface of the program.

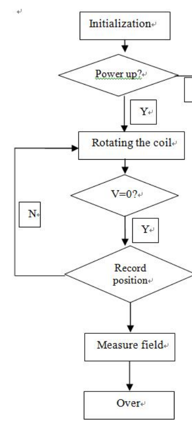

Figure 6: The flow chart of the program.

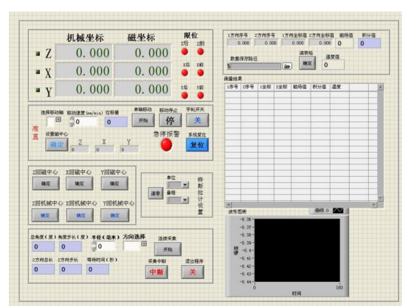

Figure 7: The interface of the program.

MANUFACTURE OF THE MEASUREMENT DEVICE

Rotation Lever

We use the hall measurement system as the foundation to build the deviation measurement device. The accuracy of the hall probe system is shown in Table 1.

Table 1: Accuracy of Hall Probe System

Iterm	X-axis	Y-axis	Z-axis
Distance (mm)	500	400	3500
Velocity (mm/s)	1 ~ 50	1 ~ 50	1 ~ 200
linearity (μm)	≤ ± 5	≤±5	≤ ± 10
Position resolution (μm)	0.1	0.1	0.1
Positional Accuracy (μm)	± 5	± 5	± 10
Repositioning resolution (μm)	± 1	± 1	± 2

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We design a rotating coil in the front of the lever to get the induced voltage. The rotating accuracy of the coil is 0.02 mm. And we get the voltage with NI PCI/PXI-4462 (NI 446x) Dynamic Signal Acquisition (DSA) devices [7]. In order to get a large stiffness, the lever is made with aluminium alloy which have large stiffness and light mass.

The lever has six degree of freedom: three rotating degree of freedom and three translation degree of freedom. The accuracy of the rotation lever is shown in Table 2. Figure 8 shows the final manufacture of the rotation lever.

Table 2: Accuracy of Rotation Lever

Iterm	X-rotation	Y-rotation	Z-rotation
Rotation angle (°)	5	5	360
Velocity (360°/s)	0.1 ~ 5	0.1 ~ 5	0.1 ~ 5
Rotation Positional Accuracy (°)	0.005	0.005	0.005
Rotation angle resolution (°)	0.001	0.001	0.001

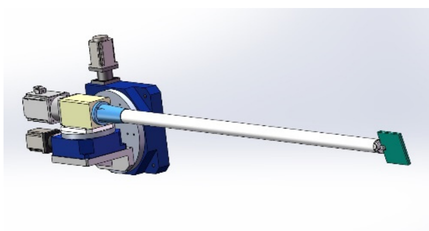

Figure 8: Final manufacture of the rotation lever.

Other Hardware

The other hardware including the induction coil framework, the data acquisition equipment. The induction coil framework is made of G10, and the wire is winding on the groove of the framework. The size of the groove is 100 mm*100 mm. See in Fig. 9.

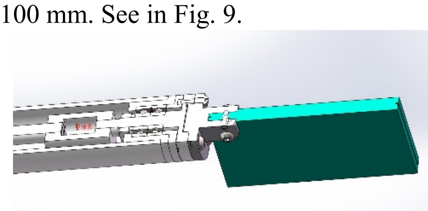

Figure 9: The induction coil framework.

We use the Agilent 34411A digital multimeter and the Group3 digital teslameter to acquire the induced voltage and magnetic fields. See in Fig. 10.

Figure 10: The data acquisition equipment.

SOME ISSUES ABOUT THE DEVICE

During manufacturing the solenoid center deviation meas-urement device, we found that the Rotation Positional Accuracy is unstable. The range of fluctuation is about 0.05 mm which is higher than we requested. Figure 11 shows how we test the rotation positional accuracy. We use the micrometer gauge to get the fluctuation of the groove.

After eliminated many possible situations such as machining accuracy, we found that the stiffness of the groove is the cause. So when change the groove to a large stiffness one, the phenomenon of fluctuation is almost gone. Figure 12 shows the final design of the groove.

Figure 11: Test the fluctuation of the groove.

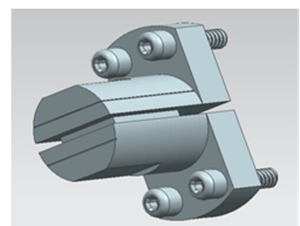

Figure 12: Final design of the groove.

The magnetic conductivity of the lever's surface is another key issue for the measurement device. The solenoid center deviation measurement device measure the small magnetic fields, so when the magnetic conductivity of the lever's surface has magnetic field. It will make a big difference. The supporting structure was made of stainless steel at first, but the stainless steel has magnetism when tested. So aluminium alloy was replaced, and it passed the test of magnetism.

CONCLUSION

In summary, we present the design and manufacture of solenoid center deviation measurement device. A new rotating coil magnetic field measurement device built base on hall measurement system had successfully been developed to measure the solenoid center deviation both in conventional and superconducting solenoids. The precision of the device is good enough to meet the measurement requirements. Some key issues were solved in the process.

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