HALL ELEMENT RELATIVE POSITION AND ANGLE CALIBRATIONS FOR THE CRYOGENIC PERMANENT MAGNET UNDULATOR

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Abstract

A three dimensions Hall probe has be manufactured for characterizing the magnetic performance of Cryogenic Permanent Magnet Undulator (CPMU) of Chinese High Energy Photon Source (HEPS) at Institute of High Energy Physics (IHEP). The positional and angular misalignment errors of the Hall sensors play an important role in the measurement accuracy of CPMU. In order to minimize the misalignment errors, a method of calibrating relative displacements and assembly angles of a 3-D Hall probe is carried out. In this paper, details of the calibration procedures and the data processing are presented.

INTRODUCTION

Chinese High Energy Photon Source (HEPS) is a 6 GeV third generation synchrotron radiation facility with ultralow emittance and extremely high brightness [1] [2]. In the straight sections, several Cryogenic Permanent Magnet Undulator (CPMU) will be installed to deliver a high-performance X-ray [1]. The CPMU is a full scale in-vacuum undulator with a period of 12 mm and a magnetic length of 1.6 m. With a gap of 5 mm and cryogenic temperatures of 83 K, the target peak field achieved will be more than 0.8 T.

Since the RMS phase error and the field integrals of CPMU have a strong influence on the spectral flux and the closed orbit. The precise measurement of the magnetic quantities is essential to characterize magnetic errors [3]. A Hall bench used to measure the CPMU magnetic field are under development. Table 1 shows the specifications of the in-vacuum Hall probe bench.

Table 1: Specifications of the in-vacuum Hall probe bench

Parameter	Value
Reproducibility on the peak field measurement	2×10^{-4} T
Reproducibility on the RMS phase error computation	0.3 °

As the gap is limited to 5 mm and the operating environment is vacuum condition, a new three dimensions Hall probe has been manufactured instead of the old one which is used in atmospheric environment. The Hall probe is shown in Figure 1. The overall dimension is 170 mm* 30 mm *1.5 mm. The three Hall sensors are welded on a ceramic printed circuit board. The adjacent two sensors are perpendicular to each other with a distance 10 mm. In order to accurately measure the three real field components of CPMU, the relative position and angle between the sensitive areas of the Hall sensors should be calibrated and readjusted exactly.

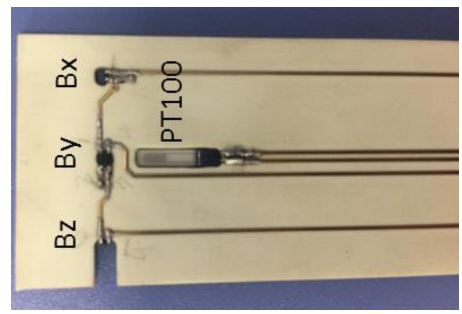

Figure 1: The three dimensions Hall probe, from top to bottom is B_x sensor、 B_y sensor and B_z sensor.

RELATIVE POSITION BETWEEN HALL SENSORS

In the ideal conditions, the sensitive areas of the three Hall sensors are overlapped. However, in the actual manufacturing, the three Hall sensors have to be placed apart due to the fabrication and welding. Figure 2 shows the relative position between sensitive areas of Hall sensors. The a sensor is used to measure B_y magnetic field, the b sensor is used to measure B_x magnetic field, and the c sensor is used to measure B_z magnetic field. The B_y sensor is defined as a reference sensor. The relative position between B_x sensor and B_y sensor is Δxba、Δyba and Δzba. The relative position between B_z sensor and B_y sensor is Δxca、Δyca and Δzca.

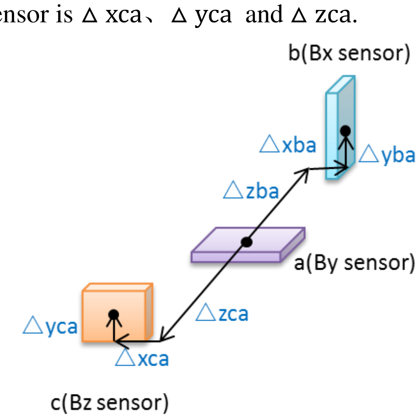

Figure 2: The relative position between sensitive areas of Hall sensors, the B_y sensor is the reference sensor.

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The relative position between Hall sensors are calibrated by a two dimensional undulator section which is shown in figure 3. The magnetic field of the two dimensional undulator can be expressed as $\mathbf{B}(x', y', z') = (0, B_y(y', z'), B_z(y', z'))$ which should satisfy the Maxwell's equations [4] [5]:

$$\nabla \cdot \vec{B} = 0 \quad (1)$$

$$\nabla \times \vec{B} = 0 \quad (2)$$

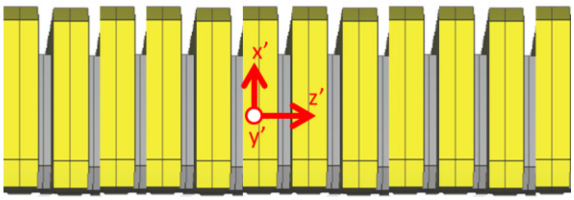

Figure 3: View of the two dimensional undulator section model.

Assuming the misalignments between the three sensors are ignored, magnetic field measured with the Hall probe must fulfil equation (1) and (2). Derive the differential equations for B_y and B_z as following:

$$\frac{\partial B_y}{\partial y} + \frac{\partial B_z}{\partial z} = 0 \quad (3)$$

$$\frac{\partial B_y}{\partial z} - \frac{\partial B_z}{\partial y} = 0 \quad (4)$$

One defines function:

$$f^2(y,z) = \left(\frac{\partial B_y}{\partial y} + \frac{\partial B_z}{\partial z}\right)^2 + \left(\frac{\partial B_y}{\partial z} - \frac{\partial B_z}{\partial y}\right)^2 = 0 \quad (5)$$

When the Hall probe scans along the z′ axis and y′ axis of undulator section, in a scanning range of rectangular area (s), define function:

$$\tau = \sqrt{\frac{\int_s f^2(y,z)ds}{s}} \quad (6)$$

The parameter τ is minimized by optimizing △xba △yba, △zba, △xca, △yca and △zca with adequate data processing technique.

In order to obtain △yba and △zba, the coordinate of the Hall probe should be correspond to the coordinate of the undulator section. The magnetic field of a rectangular area is achieved by scanning the Hall probe along the z′ axis and y′ axis of the undulator section, shown in the figure 4. Then, the △yba and △zba can be calculated by optimizing the function τ.

When the Hall probe scans as the second and third case, shown in figure 5 and figure 6, we can calculate the remaining positions △xba、△xca、△yca and △zca.

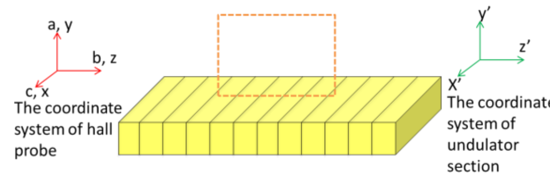

Figure 4: The first case, the B_y sensor is used to measure $B_y{}'$ field and the B_z sensor is used to measure $B_z{}'$ field.

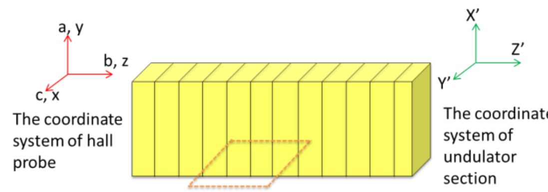

Figure 5: The second case, the B_x sensor is used to measure $B_y{}'$ field and the B_z sensor is used to measure $B_z{}'$ field.

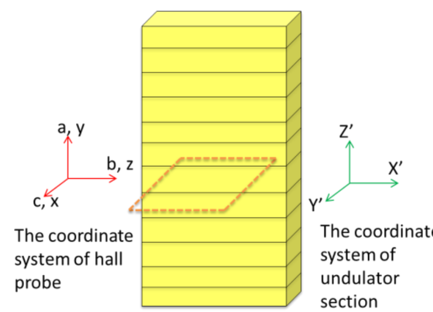

Figure 6: The third case, the B_x sensor is used to measure $B_y{}'$ field and the B_z sensor is used to measure $B_x{}'$ field.

To date, the Hall probe has been fabricated. The calibration experiment will begin immediately as soon as the laboratory rebuilding is completed. The data processing program with MATLAB has been completed. The accuracy of relative position calibration between Hall sensors is within ±5 μm.

RELATIVE ANGLE BETWEEN HALL SENSORS

The three Hall sensors are welded on a ceramic printed circuit board orthogonal to each other. Due to the error of manual welding, there exists orthogonal angular errors (θxy, θxz and θyz) between each sensor, which should be calibrated [6]. The calibrating is realized by a dipole magnet and a Hall bench. The Hall probe is laid in the centre of a dipole magnet which can supply single direction and uniform magnetic field. Table 2 summaries the parameters of dipole magnet. Figure 7 shows the Hall bench and table 3 shows the parameters of the Hall bench.

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Table 2: The parameters of dipole magnet will be used to do angular calibration of Hall probe.

Parameter	Value
Effective length	2.1 m
Maximum field	0.981 T
Good field region	260 mm
Quality of good field	0.1%

Figure 7: The Hall bench will be used to do angular calibration of Hall probe.

Table 3: The parameter of Hall bench will be used to do angular calibration of Hall probe

Parameter	Value
Resolution of rolling	2″
Accuracy of rolling	30″
Repeatability of rolling	2″
Resolution of pitch and yaw	9″
Accuracy of pitch and yaw	±30″
Repeatability of pitch and yaw	±6″

The calibration of the relative angle between Hall sensors consists of following four steps.

Firstly, adjust the plane of the B_y sensor parallel with the magnetic field direction. Tune the rolling and pitch angle of bench until the field strength of B_y sensor is as close to zero as possible, and then the probe is rotated 90 degrees around z axis of the Hall probe. The B_y sensor is then perpendicular to the magnetic field. Record the reference marks.

Secondly, tune the pitch angle of bench until the field strength of B_x sensor is as close to zero as possible. Then record the pitch angle as angle θxy.

Thirdly, tune the hall probe back to the position of the first step. And then tune the rolling angle of bench until the field strength of B_z sensor is as close to zero as possible. Record the rolling angle as angle θyz.

Lastly, the probe is rotated 90 degrees around the x axis. The B_z sensor is then perpendicular to the magnetic field. Tune the pitch angle of bench until the field strength of B_x sensor is as close to zero as possible. Then record the rolling angle as angle θxz.

We plan to go to CSNS magnetic measurement lab to do the angle calibrations experiment. Based on this method, the accuracy of relative angle calibration between Hall sensors can achieve 10" theoretically.

CONCLUSIONS

HEPS is developing a high performance CPMU. In order to test its performance, a high precision vacuum hall measurement system is required. To adjust to the vacuum and the small gap conditions, we manufacture a new three dimensions Hall probe. This paper gives the relative position and angle calibration procedures and the data processing of the 3D hall probe. The accuracy of relative position and angle calibration between Hall sensors is ±5 μm and 10". The data acquisition system has also been finished. The experiment of Hall element relative position and angle calibrations is on the schedule.

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