A Low-Temperature-Dependent Calibration of Hall probes for CPMU

C.W. Chen, Y.Y. Hsu, Y.L. Chu, H. Chen, C.K Yang and J.C. Huang

National Synchrotron Radiation Research Center, Hsinchu Science Park, Hsinchu 30073, Taiwan

Abstract

A cryogenic permanent-magnet undulator (CPMU) with period 18 mm and magnetic length 2 m is being constructed for Taiwan Photon Source. The CPMU (gap 5.5 mm) can generate effective magnetic field 1.18 T at 170 K. When the field is measured, the temperature of a Hall probe decreases at a cryogenic temperature; a calibration of the field strength and a thermostatic control system for the temperature is hence necessary. The calibration range of the field strength of a home-made dipole electromagnet is from ±0.00055 to ±1.5T. A two-axis compact Hall probe (SENIS) is mounted on a home-made copper plate in a vacuum chamber. The system to control temperature consists of a cryocooler, a sensor (PT100) and a heater to control temperature of the Hall probe. A higher-order polynomial surface fit is applied to analyze the data measured from the calibration system. The maximum error of field strength is less than 0.2 G at the fitted surface. Details of the temperature-dependent calibration system are presented in this paper.

Introduction

A calibration dependent on temperature of a Hall probe is an important issue for the measurement of a magnetic field of a cryogenic permanent-magnet undulator (CPMU), which is an insertion device in a synchrotron for radiation to provide high brilliant X-rays. In this work, we set up an automated temperature-dependent calibration system of a Hall probe. We combined a dipole electromagnet and high-precision current supply to provide magnetic fields of varied strength. The nuclear magnetic resonance (NMR) and electron spin resonance (ESR) probes were used to scan and to measure magnetic fields. We designed and installed a Hall probe holder and temperature-control system inside a vacuum chamber. Software (Labview and Matlab) served to control the calibration system and to analyze the data to generate a fitting function.

System Design

The setup of a calibration system dependent on temperature of a Hall probe as shown in fig.1.

Figure 2 shows the home-made holder has two types in one to hold a Hall probe (SENIS) for field calibration in directions *x* and *y* and for determination of the planar Hall coefficient.

Figures 2(a,b) show the calibration mode of the field in direction *y*. The Hall probe is placed on XZ surface in the dipole electromagnet system. In the calibration mode of the field in direction *x*, the Hall probe passes through a hole in the bottom copper block and is mounted in the rectangular groove of the front surface of the holder, as shown in figures 2(c,d).

Figures 3 show Five NMR probes, two ESR probes and a teslameter (Metrolab, PT-2025) are used to calibrate the Hall probe. The meter reading is displayed in Tesla with resolution 1 mG.

Figure 4 shows the system to control temperature, consisting of a temperature sensor (PT-100) installed on the surface of a copper plate near a Hall probe; a sandwich structure is mounted over the Hall-probe holder. The sandwich structure has three layers consisting of two copper plates for the top and bottom layers; between them is an all-polyimide thermofoil heater (Minco, HAP6945). The holder is connected to a cryo-cooler system.

Figure 1 Calibration system including (a) vacuum chamber, (b) dipole electromagnet, (c) five-axis motorized stage, (d) pumping station, (e) temperature-control system, (f) NMR meter and (g) power supply

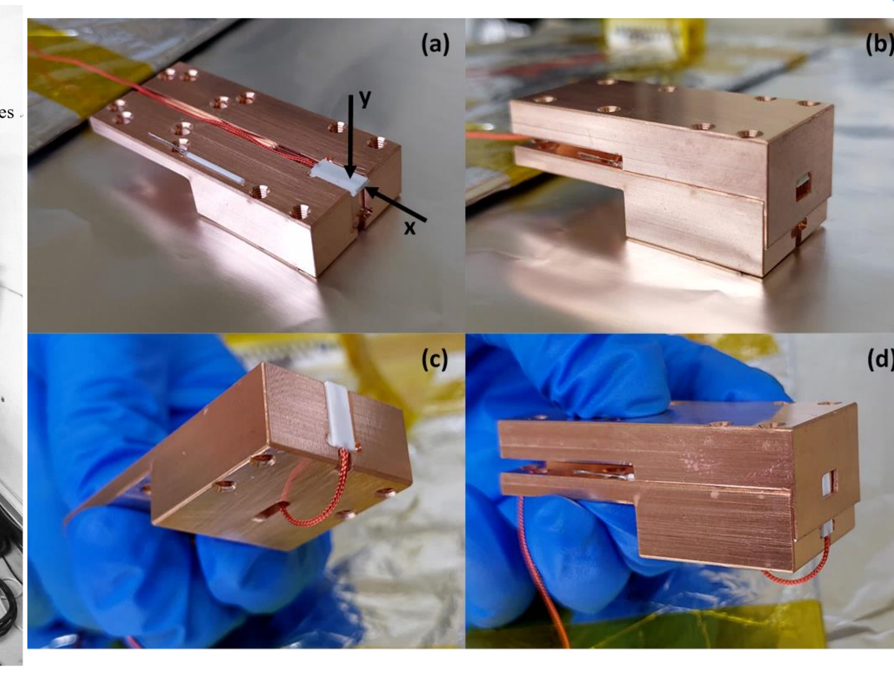

Figure 2. Two types in one to hold a Hall probe for the calibration mode of the field in (a,b) direction *y* and (c,d) direction *x*

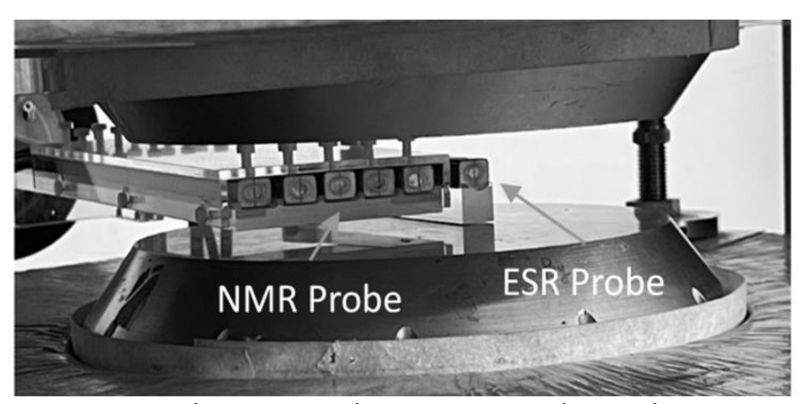

Figure 3. The ESR probe is mounted on a home-made single holder and fixed at the dipole electromagnet system.

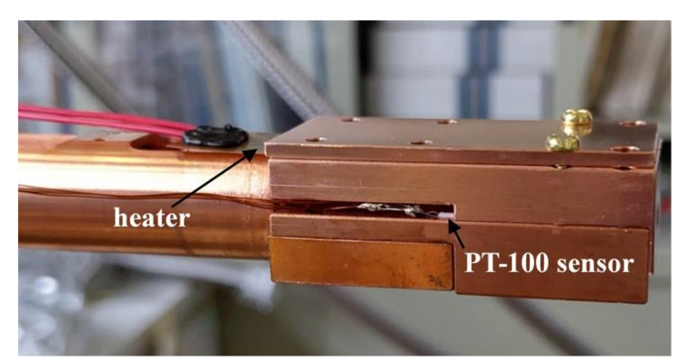

Figure 4. Temperature control units are a temperature sensor and an all-polyimide thermofoil heater

Design of the auto-calibration procedure

Software (Labview) is used to program the calibration automation.

1. the NMR probe to discover the center position of the magnetic field of the dipole electromagnet.
2. used long travel motorized stage to move the vacuum chamber to the gap center of dipole electromagnet and near the NMR probe in the X direction. Figure 5 shows that the distance between the Hall probe and the NMR probes is less than 1.5 mm in the X direction.
3. used the motorized stages of the vacuum chamber system and the data-acquisition system to micro-adjust the position of the Hall probe.
4. using software (Matlab) to fit the calibration data.

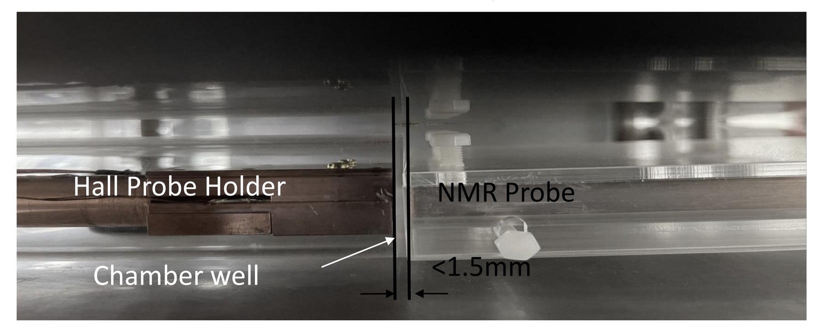

Figure 5. Distance between Hall probe and NMR probe is less than 1.5 mm in the horizontal direction.

Calibration and measurement Results

Figures 8 show the results of the calibration of By at varied temperature with the Hall probe. The fifth-order polynomial coefficients can be calculated from equation (1). The fitted surface is shown in grey; the solid circle shows the measurement results.

$$B_{dm}(B_v, T) = \sum_{i=1}^{n} a_i p_i(B_{vi}, T_i) \qquad (1)$$

$B_{dm}(B_v, T)$ is the strength of the magnetic field of the dipole electromagnet, B_v is the Hall Probe voltage, T is the Hall-probe temperature and a_i are the coefficients to be determined by the least-squares method. We used the Hall probe to measure the magnetic field at 20 points for a random temperature in range 0 - 20^{o}C and compared the measurement results with the NMR probe, as shown in fig. 9. From the measurement results, the maximum difference between the Hall-probe measurement and the NMR-probe measurement was less than 0.2 G.

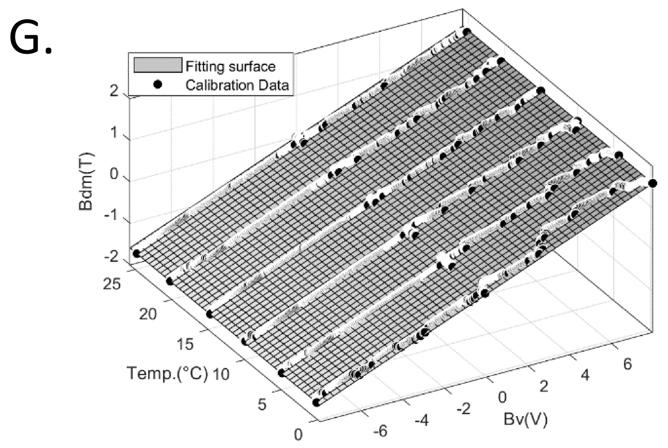

Figure 8. Hall-probe calibration results of By at varied temperature

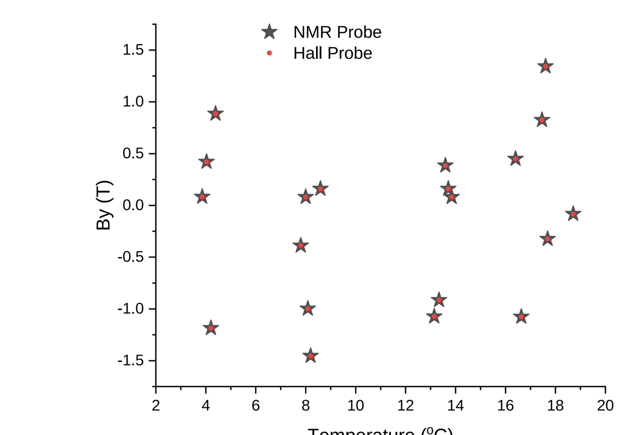

Figure 9. Comparison of results of measurements with Hall probe and NMR probe

Figure 10 Results of field measurement of a CPMU with various Hall-probe calibration methods. (a) polynomial surface fitting (to correct the error of field measurement); (b) polynomial fitting (no correct the error of field measurement). (c) During measurement, the error of the magnetic field increased as the temperature decreased.

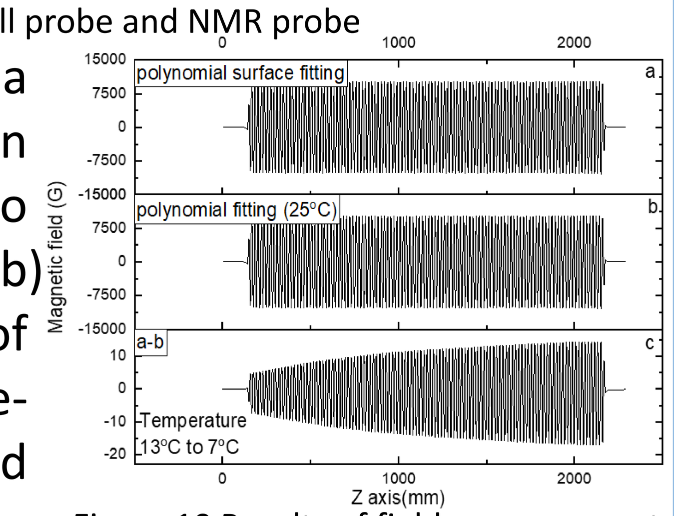

Figure 10 Results of field measurement of a CPMU

Conclusion

A temperature-dependent auto-calibration of a Hall-probe system includes an auto-tuning temperature-control system, a home-made Hall- probe holder, a cryo-cooler system, a non-magnetic vacuum chamber with adjustable position system, NMR and ESR probe systems and a dipole electromagnet system. With a polynomial surface-fitting method to fit the temperature-dependent calibration data, we obtained a highly accurate strength of the magnetic field on the fitted surface. The calibration error of the magnetic-field strength is less than 0.2 G on the fitted surface.