FIELD MEASUREMENT SYSTEM FOR A CRYOGENIC PERMANENT MAGNET UNDULATOR IN TPS

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Abstract

Short period in-vacuum, permanent magnet undulators operating at cryogenic temperatures are being developed worldwide to serve as brilliant and coherent light sources for medium energy storage rings. A hybrid cryogenic permanent magnet undulator (CU) with PrFeB magnets has now been designed and constructed at NSRRC [1]. To characterize the performance and to determine magnetic field errors after cool down poses some technical challenges compared to room temperature undulators. A new system combining a Hall probe and a stretched wire has been designed to measure the field integrals, trajectory, phase errors, and *K* value under low temperature and vacuum conditions. Field measurements in this cryogenic undulator will be performed around 77 K as well as at room temperature, making temperature dependent calibration of the Hall probes necessary. The main features and improvement of the measurement and calibration system are presented.

INTRODUCTION

At NSRRC we have developed an in-situ field measurement system for in vacuum undulators [2]. Recently this system has been upgraded to measure also a new 2-meter long cryogenic undulator [3] for which the magnetic field specifications are listed in Table1. To check these specifications, the system should include a stretched wire bench to measure the first and second magnetic field integrals and a Hall probe bench to perform magnetic field measurements.

Table 1: Magnetic Specifications of the Cryogenic Undulator

Items	Specifications
Period length	15 (mm)
Number of periods	133
Magnetic structure	Hybrid
Max. Peak field	1.32 (T)
Gap range	4-40 (mm)
R.M.S Phase Errors	< 3^o
Vertical and horizontal first field integral on axis	≦100 (Gauss-cm)
Vertical and horizontal second field integral on axis	≦2000 (Gauss-cm^2)
Multipoles for ｜x｜ ≦15mm Quadupole Sextupole Octupoles	 ≦±50 (Gauss-cm) ≦±100 (Gauss/cm) ≦±100 (Gauss/cm^2)

Figure 1 shows the measurement system (schematic) with the CU frame designed and made by the company NEOMAX. All components, such as the Hall probe, carriage, and rails are installed inside a vacuum chamber except for the laser position monitor systems. The vacuum should be pumped down to high-vacuum level during field measurement. Components installed inside the vacuum are ultra high vacuum compatible and non-magnetic to avoid contamination and influence of magnetic field.

HALL PROBE SYSTEM

A Hall probe system should provide accurate, reproducible, and efficient measurement for an undulator. To reduce measurement errors, the Hall probe is calibrated against an NMR probe and its readings need to be corrected.

The scan is done 'on-the-fly' to obtain smooth probe motion and to diminish measurement time, starting from a precise home position and acquiring data in specified intervals. The voltages of the Hall probe are sequentially sampled by a Digital Multi-Meter (DMM) that is externally triggered by a laser scale signal and temporarily stored in a DMM buffer. Then the voltage data are downloaded and processed with calibrated field readings.

Although the cryogenic undulator is a planar undulator, imperfect magnet blocks usually generate transverse magnetic fields, and the thermal radiation from magnetic arrays will cool down the probe temperature. Therefore, the Hall probe should consist of a two-axis Hall sensor and a temperature sensor to measure the vertical and transverse magnetic fields and to calibrate the field strength against temperature.

To achieve and maintain a reliable measurement of the transverse fields, the influence of the planar Hall reading from the high vertical field should be minimized. The planar Hall voltage resolution of the new generation Senis probe [4] is smaller than 0.01%.

Improvement of Signal Wires Collecting

In previous versions, signal wires are fixed on the Hall probe carriage and the feedthrough pins, and the signal wires are collected by a rotating pulley, which cause an entanglement problem of these signal wires during measurement, as shown in the Fig. 2. To solve this problem, one end of the wires should be free. In the new design, this end is attached to a slip ring, which can transmit signals and rotate the pulley without entangling wires by gold spring wires. This slip ring is custom-made with reliable signal transmission, extremely low electrical noise, very low contact resistance (0.005 Ohm), and long service life.

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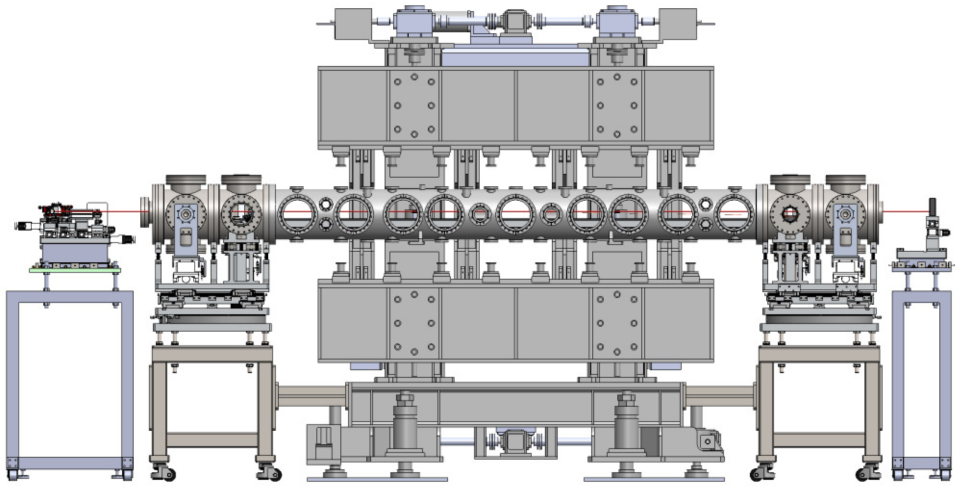

Figure 1: Illustration of the measurement system with cryogenic undulator frame (schematic).

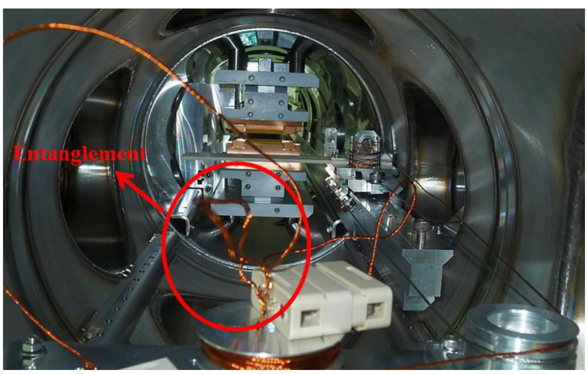

Figure 2: Picture of the Hall probe system.

Magnetic Measurements

An important parameter of a CU is its peak field enhancement at low temperatures. At the ESRF NdFeB materials were used and it was found that the temperature for maximum field and strength did not quite occur were numerical simulations predicted [5]. At Spring-8 they also discovered that the optimum operating temperature was not the same as what was expected from single-piece measurements and it is speculated that the reason is the difference in the permeability coefficient [6]. Since our CU uses PrFeB material, it will be interesting to compare the average peak field with RADIA calculation results at different temperatures.

A temperature gradient along the magnetic arrays induces a gap tapering that induces r.m.s. phase errors, which may increase by one degree while cooling down from room temperature to operating temperature. In addition, bellows operating temperatures increase rapidly in case of a temperature gradient of about 3 K/m [5]. If the temperature gradient reaches our design goal of 0.5 K/m (± 0.25 K/m), we can expect better phase error performance at low temperature.

Due to the change of the magnet susceptibility at low temperatures, the field integral at each end of the magnetic arrays may change significantly. The trajectory in the horizontal plane is dominated by this end field change while no significant deviations occur in the vertical plane [5, 7]. We will examine this trajectory variation with the Hall probe system.

STRETCHED WIRE SYSTEM

Like any other measuring device, noise is an important concern of the Hall probe performance. A stretched wire system is also available to double check the on-axis first and second integrals obtained with the Hall probe, and to measure integrated multipole errors within ±15mm of the axis. The normal and skew multipole field integral errors will be calculated by fitting with a fourth order polynomial. If necessary, the multipoles of the field integrals will be further corrected using magic fingers located at the ends of the magnet arrays.

Previous versions [8] of the stretched wire, as used to measure the elliptically polarizing undulators, was made from ten turn Litz wire and an integrator (Metrolab PDI5025) to acquire the induced voltages. To improve the spatial resolution, a single beryllium copper wire with a diameter of 0.125 mm will be used here. However, the signal from a single wire is smaller than the noise level of the integrator [9]. If, for example, the wire moves 4 mm [e.g. $\Delta x = 4$ mm] and we want a 2 G cm reproducibility [8], the integrated voltage is expected to be given by Eq. (1).

$$\int V\ dt = \Delta x \int_0^L B_x\ dz = 8\ \times 10^{-9}\ Vs \tag{1}$$

The sample time for each point should be longer than a power line cycle and considering the moving speed and number of desired sampling points, each measurement will take 0.133 seconds, generating a voltage of 60 nV. Therefore, a nano-voltage meter is needed to perform this measurement.

HALL PROBE CALIBTATION SYSTEM

Experience at other facilities tells us that the temperature of the Hall probe may drop several degrees during a measurement around 140 K [5, 6]. However, our cryogenic undulator will operate at lower temperatures, around 77 K, which may cause even a larger temperature drop. In addition, cooling down to this temperature may take about 6 hours [7], and the Hall probe temperature will likely change by a few degrees due to thermal radiation cooling, making field calibrations at low temperatures necessary.

Figure 3 shows this calibration system, consisting of a standard dipole magnet, a cryocooler, a goniometer, a rotating stage, a vertical stage, a heater, and a Pt100 temperature sensor. Details of each component are described below. The maximum field strength of the standard dipole magnet is 1.5 T at a current of 80 A. The good field region ($\Delta B/B$<0.01%) is ±4 mm and ±6 mm from the axis in the vertical and horizontal plane.

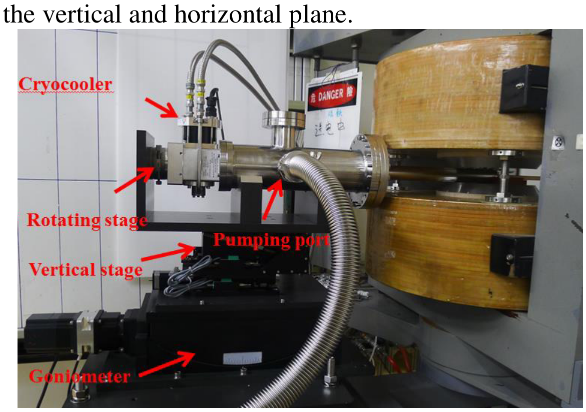

Figure 3: Hall probe calibration system

Angle Adjustment Scheme

Hall probes are sensitive to angular alignment, and therefore the same angular positions for undulator measurements and probe calibration should be preserved carefully and the real angles of the axis with respect to a reference surface need to be determined. A goniometer and a rotating stage are used to determine these angles. The resolutions of the goniometer and rotating stage are better than 10 μrad and 0.3 mrad. The goniometer is rotated by a motor and a reducer to increase the inertia torque and resolution, while the rotation stage is operated manually.

New Senis Hall Probe

A new two-axis Senis Hall probe is used to measure the CU [4]. The probe assembly is electrically insulated, non-magnetic, rigid, with good thermal conductance, and a thermal expansion coefficient similar to that of silicon, and is suitable to operate at a lowest temperature of -55 ℃. The dimensions are 8 mm by 4 mm by 0.9 mm, which is small enough to fit into the minimum undulator gap of 4mm. This new generation of integrated Hall devices features a voltage-related magnetic sensitivity of 5 V/T with low flicker noise. A temperature sensor, integrated on the Hall probe chip, allows the Hall probe to sense temperature and to do temperature compensation.

Low Temperature System

While for a CU measurement the temperature calibration down to zero degree may be sufficient, this system is also ready for calibrations of superconducting insertion devices. Therefore, a two stage cryocooler (Sumitomo RDK-101D) is used to cool down the whole measurement system. The cooling power of the first stage is 0.1 W at 4.2 K and 5 W at 60 K for the second stage.

The field strength will be calibrated at specified temperatures and it is expected that the temperature fluctuations are small (smaller than ±0.2 degree) to minimize temperature calibration errors. A Pt100 temperature sensor is used to measure the temperatures and a 30W non-inductance resistance provides heat. A Lakeshore 330 temperature controller receives temperature readings from the Pt100 and applies current to the resistance heater for temperature control.

CONCLUSION

A new in-vacuum field measurement system is now under construction for a CU at NSRRC. A new design of the signal wire collecting system will be adopted to solve the entanglement problem. The stretched wire system is still under construction and a single turn Be-Cu wire with a multimeter acquiring data is expected to improve the spatial resolution and signal reproducibility. A low temperature field calibration system based on a Hall probe is ready to be calibrated at low temperatures to determine the planar Hall coefficient and angular accuracy of the sensor.

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