DESIGN AND DEVELOPMENT A MEASUREMENT SYSTEM FOR MAGNETIC TUNING OF UNDULATOR MAGNETS

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Abstract

The permanent-magnet in-vacuum undulator technique is critical for the Taiwan Photon Source(TPS) at the National Synchrotron Radiation Research Center(NSRRC). Before installing the magnet arrays in the vacuum chamber, the phase error of the undulator is optimized by adjusting the magnetic field. Optimizing phase errors is a complex and time-consuming task. The conventional measurement method involves using Hall probes to measure the magnetic field and a stretched-wire(SW) to measure the integral field of the undulator. In this work, we propose a method for tune the local magnetic field by utilizing the correlation between the gap and the magnetic field. We have demonstrated that using gap sensors allows us to more effectively determine whether to tune the magnetic field of the upper or lower magnet array. Additionally, we have demonstrated for the first time the use of the pulsed wire measurement (PWM) method for magnetic sorting. Finally, we used the magnetic finger method to minimize the multipole components.

INTRODUCTION

A permanent-magnet in-vacuum undulator technique is critical for the Taiwan Photon Source (TPS) at the National Synchrotron Radiation Research Center (NSRRC). To achieve high brightness, an undulator with multiple magnet periods is required. Due to variations in geometry, magnetization direction, and magnetic strength, an optimal arrangement is required to construct a high-performance undulator. Phase error is a key parameter in constructing a high-performance undulator. Excessive phase error can reduce brightness. It arises from non-identical magnets at each pole, causing imperfect interference between wave packets[1]. In addition to phase error, the multipole components of the first and second field integrals in an undulator must also be minimized. This can be achieved through magnet sorting[2]. Establishing a high-precision magnetic field measurement system and applying it to magnet sorting is essential. In this work, we designed and constructed a measurement system that includes (1) gap sensors to measure the undulator gap, (2) PWM and Hall probe magnetic field measurement systems to perform magnet sorting, and (3) the SW system to measure the first and second field integrals and conduct multipole analysis. We used this system to complete the magnetic field optimization of the undulator.

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SYSTEM DESIGN

Figure 1 shows the overall construction of the field measurement system, which comprises a Hall probe measurement bench, a stretch wire measurement system, a pulsed wire measurement system, and a gap sensor measurement system. This multi-function field measurement system is designed for magnetic field measurement of undulators. The Hall probe measurement system utilizes a two-axis Hall probe from SENIS, known for its consistently high accuracy and repeatability[3]. For the first time, a gap sensor measurement system and a Hall probe measurement system are integrated to enable simultaneous measurement of the undulator gap and magnetic field. The stretch wire system is used to measure the first and second integral field of the undulators[4]. The pulsed wire measurement system is used for immediate and fast local magnetic field, the first and second integral field measurement of the undulator[5]. Utilizing the fast and high-precision measurement capabilities of the pulsed wire measurement system, it can be applied to measure the magnetic field during the magnet-sorting process. We designed a magnet-sorting process and a magnetic finger method to optimize the phase error and minimize the multipole components of the undulator, respectively. In the following sections will detailed description of the subsystems and the measurement process.

Hall Probe Measurement System

Based on *in-Situ* Hall probe measurement system[3], the system contains a laser interferometer system, a position sensitive detector (PSD) system, and a Hall probe vehicle moving system on granite platform. This system will be used for final inspection of magnet-sorting results and comparison with pulsed wire measurement results. A laser interferometer is used to detect the distance between Hall probe vehicle and origin position. The laser beam is divided into the detection and reference light. The detection light is reflected by the corner cube mirror on the vehicle, then reflected by the 50/50 beam splitter and finally received by the light receiver. The reference light enters the receiver after reflecting by the 50/50 beam splitter. We used the differential signal of laser interferometer technology to trigger the data acquisition. A Hall probe mounted on the center of ceramic plate and two pinhole holder mounted on both side of ceramic plate. The ceramic plate is installed on the XY motorized translation stage through the adapter plate. Finally, the XY motorized translation stage is installed on a platform pulled by a combination of stainless steel rope and rotary motor. Before magnet field measurement, the Hall probe (Type I3A, SENIS AG) is calibrated with reference to the nuclear

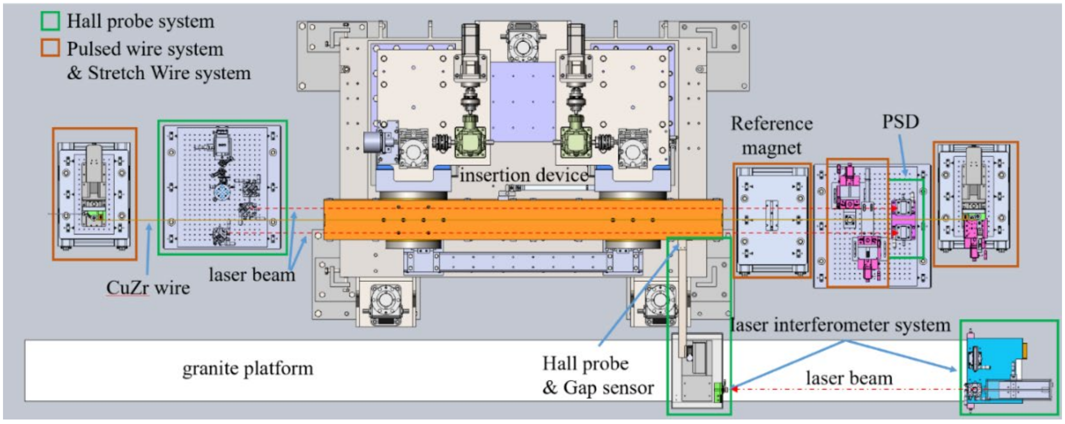

Figure 1: The overall construction of the field measurement system

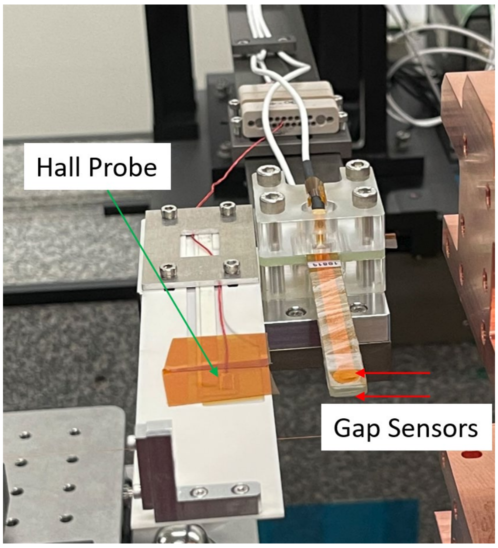

Figure 2: The installation of gap sensors and the Hall probe on the same measurement platform

magnetic resonance (NMR) probe. The calibration error of the magnetic-field strength is less than 0.02 %[6]. A PSD system is used to detect the vertical and horizontal positions of the hall probe holder during measurement. We used a solid-state laser with a wavelength of 633nm. The laser beam passes through the 50/50 beam splitter and splits into two beams. The two laser beams passes through the pinhole of 2mm in diameter at the both sides of Hall probe holder. Finally, the two laser beams are received by the PSD (On-Trak PSM2-10, OT301).

Gap Sensor Measurement System

The gap sensor measurement system consists of two very thin capacitive non-contact gap sensors(HPS-5509-7906, capacitec) and a signal amplifier(220-SLC, capacitec). The thickness of the sensors is less than 0.11 mm. The gap sensors are installed on both sides of a ceramic plate with a known thickness (d). During the measurement process, the upper gap sensor measures the distance to the upper magnet array (dup), while the lower gap sensor measures the distance to the lower magnet array (ddown). Finally, the gap width is determined as dup+d+ddown. Figure 2 shows the installation of gap sensors and the Hall probe on the same measurement platform. Static testing confirms that the measurement signals from the Hall probe and gap sensors do not interfere with each other, even when placed in close proximity.

Stretch Wire Measurement System

The stretch wire measurement system provide three kinds of magnetic field information in insertion devices. One is for measuring the first field integral to obtain the electron beam angle deviation. The second is for measuring the second field integral to obtain the electron trajectory. The third is for measuring the harmonic field components of insertion devices to obtain the multipole errors. The stretch wire measurement system consists two translation stage groups and an integrator (Metrolab, PDI-5025). The translation stage groups are shared with the pulsed wire measurement system and each group consists two motorized stages for horizontal (OptoSigma, OSMS26-200) and vertical (OptoSigma, OSMS26-100). A polyetheretherketone (PEEK) wire holder is connected the tensionmeter (LRK-100N, NTS Technology Co., LTD.) and mounted on vertical stage. The wire is fixed on the holder with PEEK screws. The tensionmeter is mounted on a motorized stage (TAMM100-50C, OptoSigma) to control the wire tension. This system uses a 100µm diameter CuZr wire to rapidly cut the magnetic flux to induce a voltage that is received by an integrator.

Pulsed Wire Measurement System

In previous studies, we have developed a complete PWM system based on a Lorentz force and a general traveling wave. In this PWM system, we share the CuZr wire with the SW system. A wire-displacement detection system at one side of the undulator. The wire displacement detection system includes a vertical and a horizontal optical-sensor pair. Each optical-sensor pair is composed of a photodiode (SM05PD1A, Thorlabs) and a diode laser (LNC-13MMC, 633 mm, Schäfter+Kirchhoff GmbH), mounted on a 2D motorized stage. The wire-displacement detection method is used a laser beam to focus on the wire and a photodiode is used to detect the light intensity that is not blocked by the wire. We used the linear range to detect the wire displacement. The current-to-voltage amplifier

(PDA200C, Thorlabs) is used to receive the current from the photodiode and output to an oscilloscope (MSO44, Tektronix). The reflected waves constitute noise in the PWM system. The oil dampers will be to weaken the reflected wave. The current pulse circuit generates a current pulse width and frequency in the range of 0~1s and 1~1kHz, respectively.

MAGNET SORTING RESULTS

Before the undulator magnet array is installed into the vacuum chamber, magnet sorting is performed to optimize its phase error, first field integral, and second field integral. In this work, we use multiple bellows-link rods to connect the undulator magnet array to the mechanical frame[3]. This magnet array has a total length of 2 meters and is composed of hybrid permanent magnet blocks with an 18 mm period. First, we use a theodolite and a leveling instrument to align the Hall probe in the measurement system with the mechanical center of the undulator magnet array. Then, we use the Hall probe measurement system to determine the magnetic center position. The first step in magnet sorting is to use gap sensors and a Hall probe to simultaneously measure the undulator gap and magnetic field, identifying the correlation between their variations. Observations indicate that at the magnetic center, a smaller gap results in a stronger magnetic field, whereas a larger gap leads to a weaker magnetic field. We use gap sensors and bellows-link rods to adjust the gap error between the upper and lower magnet arrays and the gap error to within 10 μm. After the adjustment, a Hall probe is used to measure the phase error. After the first step of localized magnetic field adjustment, the second step of magnet sorting involves using the PWM system to measure the first field integral of the undulator and calculate its error-storage(%) and field-storage (G-cm)[2]. The error storage and field storage are given by[2]

$$ES = \sum_{m=1}^{n} \left(\frac{|I_n| - \langle I \rangle}{\langle I \rangle} \right)_m , \quad FS = \sum_{m=1}^{n} \frac{I_n - (-1)^n \langle I \rangle}{\langle I \rangle} \quad (1)$$

where the I_n represents the first field integral of the nth pole. Previous studies have demonstrated that these two functions are effective in magnet sorting for optimizing phase error.

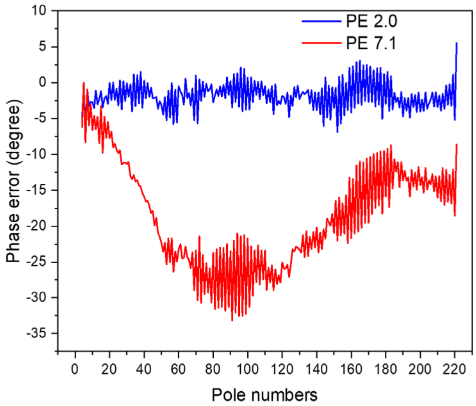

Figure 3: The results of magnet sorting

Figure 3 shows the results of magnet sorting, where the phase error is optimized to 2.0 degrees at a 5 mm gap of the undulator. Next step, we used the magnetic finger method to minimize the multipole components. For this case, the first field integral must be less than ±100 G-cm, and the second field integral must be less than ±10,000 G-cm². Figure 4 shows the results of the first and second field integrals in the horizontal direction before and after optimization using magnetic fingers. Next, we analyze these results to determine the multipole components. In this undulator, the multipole components including dipole, quadrupole, sextupole, and octupole terms are all within ±100 G-cm.

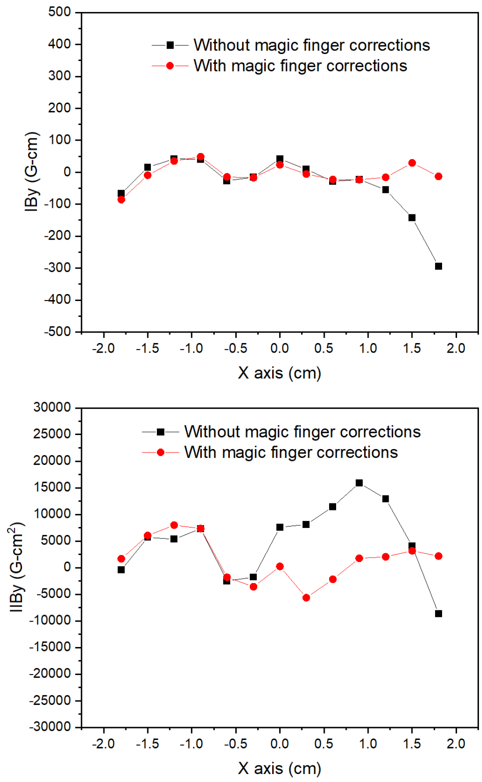

Figure 4: The results of the first and second field integrals in the horizontal direction before and after optimization using magnetic fingers

CONCLUSION

We developed a measurement system to efficiently perform magnet sorting for the undulator magnet array. We demonstrated that a gap sensor combined with bellows-link rods can be used to adjust the local magnetic field while simultaneously verifying the field using a Hall probe. For the first time, we used the PWM system for magnet sorting and ultimately verified its reliability using the Hall probe measurement system. The SW system is used to measure the first and second field integrals of the undulator and analyze its multipole components, while a magnetic finger is employed to optimize the field integrals. After magnet sorting, the resulting phase error is 2.0 degrees. The first field integral shows values less than ±100 G-cm, and the second field integral shows values less than ±10000 G-cm².

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