ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-TUPG64

INTEGRATED HALL PROBE AND STRETCHED WIRE MEASUREMENT SYSTEM FOR AN IN-VACUUM UNDULATOR

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Abstract

The Taiwan Photon Source (TPS) is a 3 GeV synchrotron light source at the National Synchrotron Radiation Research Center (NSRRC) in Taiwan. Several in-vacuum undulators are expected to be installed before the end of 2024. Before installation in the storage ring, the magnetic field of an in-vacuum undulator has been measured at operational gaps. To assess the performance of the in-vacuum undulator, we integrated two measurement methods in the vacuum chamber: the SAFALI (Self Aligned Field Analyzer with Laser Instrumentation) system for measuring the magnetic field, and the stretched wire system for measuring the magnetic field integral. In this work, we designed a stretched wire measurement system integrated with the SAFALI system inside the vacuum chamber. This measurement system was applied to the in-vacuum undulator with a period of 22mm and a magnetic length of 2m. Details of the automated measurement system is presented in this paper.

INTRODUCTION

The in-vacuum undulators technique is critical for TPS in NSRRC. The magnetic field of the undulator has been measured before installation in the storage ring. Typical methods to measure the magnetic-field performance of undulators are Hall-probe and stretched-wire measurement systems [1-4]. The *in-situ* Hall-probe measurement system has great accuracy in measuring local magnetic fields [1,2]. A stretched-wire measurement system was set up to measure the first and second magnetic-field integrals [3,4]. In 2007, T. Tanaka et.al. used a SAFALI system to measure the magnetic-field of cryogenic permanent magnet undulator(CPMU) prototype [1]. The insertion-device group of ESRF designed a Hall-probe measurement system and installed in special vacuum chamber to measure the magnetic-field of in-vacuum undulator. A stretched-wire bench was also designed to connect with both ends of the undulator to measure the magnetic-field integrals [5].

In our previous research, we designed a hybrid type system to measure the magnetic field of an in-vacuum undulator [6]. In this early system, the two-axis moving wire stage was located outside the vacuum chamber, resulting in the need for a relatively larger installation space and a complex installation process. When the stretched wire is actuated, its holder interferes with the optical path in the SAFALI system. In this work, we have designed an *in-situ* stretched-wire measurement system and integrated it with an *in-situ* Hall-probe measurement system. The *in-situ* Hall-probe measurement system consists of a laser interferometer system, a Hall probe position detection-correction system, and a Hall probe vehicle moving system. The *in-situ* stretched-wire measurement system consists of the two-axis vacuum piezo translation stage, a wire fixed holder, and a data acquisition system. Ultimately, the system achieves easy installation and high measurement repeatability.

SYSTEM DESIGN

Figure 1 shows that the overall construction of the system installed on an in-vacuum undulator contains a SAFALI system and a stretch wire measurement system. This system is designed for magnetic field measurement of in-vacuum undulators. The SAFALI system uses Hall probe to measure local magnetic field of in-vacuum undulators. In past studies, the SAFALI system has high accuracy and repeatability [2]. The stretch wire system is to measure the first and second integral field of the undulators. This system uses the metal wire to quickly cut the magnetic flux to induce a voltage that is received by an integrator [4]. We designed a measurement processes(Labview™) to complete the system for automated magnetic field measurement. In the following sections will detailed description of the subsystems and the automation measurement process.

In-Situ Hall Probe Measurement System

Based on past SAFALI system [2], the system contains a laser interferometer system, a Hall probe position detection-correction system, and a Hall probe vehicle moving system. We have improved the measurement system to achieve high accuracy. Before measurement, the aluminum rail installed in the vacuum chamber. The Hall probe mounted on the center of ceramic plate and a pinhole holder mounted on one side of ceramic plate. The material of vehicle is copper. The ceramic plate, another pinhole holder, a corner cube retroreflectors holder and a Hall probe signal (D-sub) connector installed on the vehicle. The front and rear of the vehicle is tied with the same stainless steel wire to form a circle, which is mounted on the pulley block and driven by a vacuum rotary motor (VSS 57, Phytron GmbH). In the continuous measurement operation mode, the vacuum rotary motor has the disadvantage that it is not easy to dissipate heat. In our system, we added a reducer with a reduction ratio of 1:8 to the vacuum rotary motor. Due to increased torque, we reduced the vacuum rotary motor operating current to 0.75 A to prevent the motor coil overheat.

A laser interferometer is used to detect the distance between Hall probe vehicle and origin in the vacuum chamber. The laser beam is divided into the reference and detection light. The reference light enters the receiver after passing

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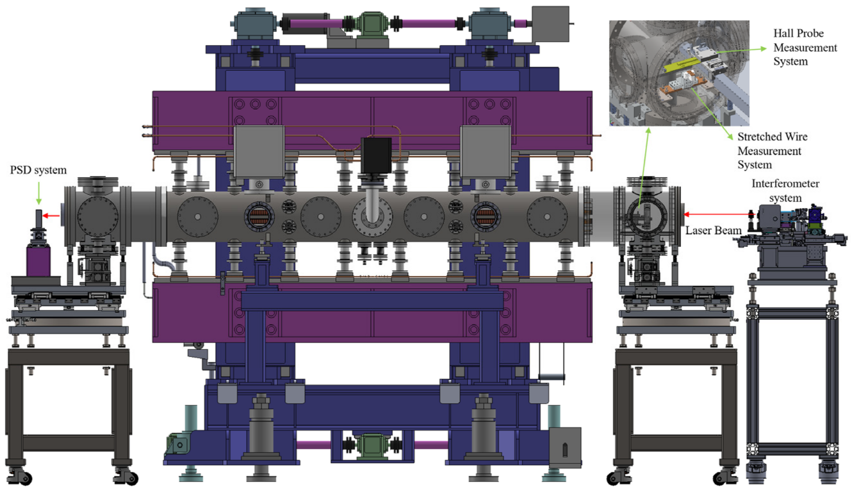

Figure 1: The overall construction of the systems installed on an in-vacuum undulator.

through the beam splitter. The detection light is reflected by the corner cube retroreflectors on the vehicle and then enters the light receiver. We used the laser interferometer technology to trigger the data acquisition.

A Hall probe position detection-correction system is used to detect the vertical and horizontal positions of the hall probe during measurement. We used a solid-state laser with a wavelength of 633 nm. The laser beam passes through the beam splitter and splits into two beams. The two laser beams passes through the pinhole on the ceramic plate and the pinhole on the vehicle and receives by the position sensitive detector (PSD, On-Trak PSM2-10, OT301), respectively.

The Hall probe (Type I3A, SENIS AG) is calibrated with reference to the nuclear magnetic resonance (NMR) probe. The calibration error of the magnetic-field strength is less than 0.02 % in a temperature-dependent calibration system [7].

Figure 2: In the stretched wire measurement system, the assembly diagram of one side platform group.

In-Situ Stretched Wire Measurement System

The stretch wire measurement system provide three kinds of magnetic field information in accelerator magnets or 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 lattice magnets to obtain the multipole errors. The stretch wire measurement system consists two translation stage groups and mounted on both sides of the magnet. Each translation stage system consists two vacuum piezo stages for horizontal (Smaract, CLS-3282) and vertical CLS-3252). A polyetheretherketone (PEEK) wire holder is mounted on vertical piezo stage as shown in Fig. 2. The wire is fixed on the holder with PEEK screws. The wire is connected to the integrator (Metrolab Technology SA, FDI2056) through the Vacuum Feedthrough. The wire between the Vacuum Feedthrough and the holder is covered with PEEK to insulate it and prevent contact with the vacuum chamber wall.

Design of the Auto-Measurement Procedure

To prevent interference between the two systems and ensure the accuracy of measurements, it is necessary to establish an automated measurement procedure. Once the measurement system is installed on the insertion devices, the automated measurement program can be initiated. When the hall probe measurement system is in operation, the stretched wire measurement system positions itself beneath it. This approach helps prevent the stretched wire measurement system from interfering with the interferometer system and PSD system necessary for the operation of the hall probe measurement system. When the wire in the stretched wire measurement system reaches the gap center of the undulator, the hall probe measurement system must be moved outside the stretched wire measurement system.

MEASUREMENT RESULTS

This integrated measurement system is used to measure the magnetic field of an in-vacuum undulator (period 22 mm, magnetic length 2 m, IU22). The installation and alignment processes for the SAFALI system were successfully conducted in previous research. In this paper, we focus on the stretched wire measurement system. In the scenario where the center of the magnetic field is unknown, we align the wire with the predetermined magnetic field center. The predetermined magnetic center is marked on

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the vacuum chamber during the fabrication process. We used a theodolite to align the wire horizontally and a spirit level to align it vertically. Before securing the wire, we use a load cell(LRK-100N, NTS Technology Co., LTD.) to fix the wire tension at 6N. When both the Hall probe and the wire are aligned with the predetermined magnetic field center, we first use the Hall probe to identify the actual magnetic field center, and then align the wire with the found magnetic field center as well. In the stretched wire measurement system, we used a copper zirconium(CuZr) wire with a diameter of 100mm and a length of 3.3m. The advantages of CuZr wire include high tensile strength and high conductivity. when used on a long undulator, wire with high tensile strength will reduce the maximum sag [8].

In past research, we have developed integrated field measurement procedures in the stretched wire measurement system using LabVIEW^{TM} [4]. From Fig. 3 that it can be observed that when the gap of the IU22 is 6mm, the standard deviations of the first and second order integrated field measurements in the vertical magnetic field direction of the stretched wire measurement system can reach 1.2 G-cm and 200 G-cm^2, respectively.

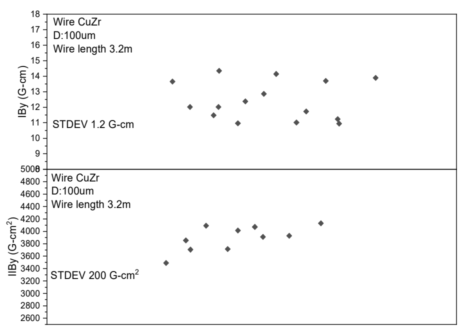

Figure 3: the measurement results in the vertical magnetic field direction of the stretched wire measurement system.

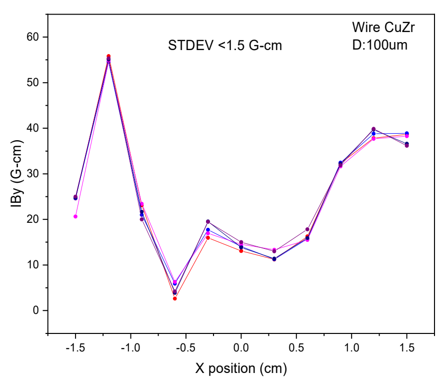

Figure 4: The integrated field along the horizontal direction.

Figure 4 shows we measure the integrated field along the horizontal direction, achieving a repeatability of less than 1.5 G-cm. We also obtain the integral multipoles of the IU22 using the elliptical scanning measurement method [9]. The magnetic field is expressed in polynomial expansions as follows:

$$B_y + iB_x = \sum_{n=1}^{\infty}(b_n + ia_n)(x + iy)^n \tag{1}$$

The index n is the order of the multipole; n = 1 is a dipole field and the units is gauss (G); n = 2 is a quadrupole field and the units is G-cm^{-1}; n = 3 is a sextupole field and the units is G-cm^{-2}; and so on. The b_n and a_n are the normal and skew coefficients, respectively. We designed an elliptical trajectory with semi-major and semi-minor axes of 15 mm and 1.5 mm, respectively, to measure the integral field. The reproducibility of the coefficients for normal and skew are shown in Fig. 5(a) and 5(b), respectively. A comparison of the results shows that harmonic items are in the same order.

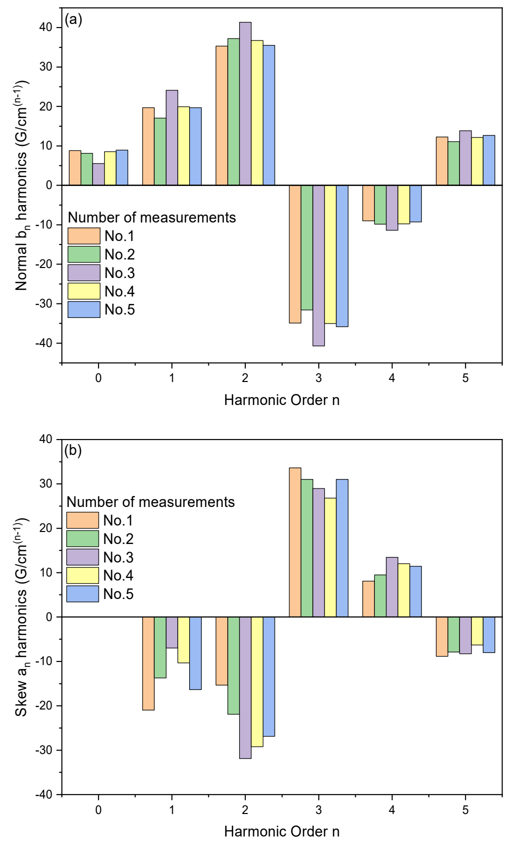

Figure 5: The reproducibility of the coefficients for (a) normal and (b) skew.

CONCLUSION

We successfully integrated Hall probe and stretched wire measurement systems inside the same vacuum chamber for measuring the magnetic fields of in-vacuum undulators. This integrated system design simplifies installation and enhances usability, while also yielding highly reproducible experimental results. The measurement results demonstrate that the minimum standard deviation of measurements for *in-situ* stretched-wire measurement system can reach 1.2 G-cm. We also verified the measurement and analysis of elliptical scanning for integrated fields and multipole errors measurement of the undulator. This system can be applied in the future for magnetic field measurements of superconducting undulators and cryogenic permanent magnet undulators.

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