DESIGN AND DEVELOPMENT OF A SYSTEM OF HYBRID TYPE TO MEASURE THE MAGNETIC FIELD OF A CRYOGENIC UNDULATOR

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Abstract

Cryogenic permanent-magnet undulators (CU) have currently become the most important scheme serving as sources of hard X-rays in medium-energy facilities worldwide. One such set (length 2 m, period length 15 mm) is under development for Taiwan Photon Source (TPS). To obtain a magnetic-field distribution of the cryogenic undulator after it is cooled to an operating target temperature below 80 K, a device of hybrid type combining a Hall probe and stretched-wire method has been designed and developed, to perform the field measurement at low temperature and in an ultra-high vacuum environment. The Hall probe is used to measure the field on axis in the transverse and vertical directions; the stretched wire is utilized to measure the field integral in the vertical and horizontal directions in the horizontal plane. Unlike a conventional field-measurement system in air, this innovative system must be located in an ultra-high vacuum environment with limited clearance. This paper describes mainly the entire system, including kernel components, control systems and preliminary test results in detail.

INTRODUCTION

To obtain great brilliance within the hard X-ray region from an accelerator facility of medium beam energy, approximately 3 GeV, an approach with a cryogenic permanent-magnet undulator (CU) places magnet arrays of short period inside a vacuum chamber [1], which enhances the peak magnetic field strength around 20% compared with an in-vacuum undulator (IU). The deflection parameter (K) is thus kept consistent with an undulator of type out of vacuum. After the entire machine was assembled with the vacuum chamber, the scheme resulted in a difficulty of taking data through a conventional device for field measurement. Many solutions have thus been proposed to solve this problem: BNL designed a customized rectangular vacuum chamber or rectangular port of which one side can be used for access [2, 3]; ESRF adopted a specific dedicated chamber for field measurement [4]; SPring8 has a SAFALI system, and so on [5, 6]. Considering not taking off the main vacuum chamber and using standard vacuum components, NSRRC developed a set of field-measurement system in situ for an undulator in vacuum. It was applied to verify the magnetic field on axis of several undulators in vacuum, but had facilitated only an atmospheric environment [7]. To fulfill a further requirement for the measurement of a cryogenic permanent-magnet undulator in the near future, the device must be able to accommodate to an ultra-high vacuum surrounding without contamination and interference. This paper presents the current efforts of a new design and development of a CU field-measurement system.

SYSTEM REQUIREMENTS

To characterize the magnetic performance of CU15 in operating conditions at low temperature, the field-measurement devices must be placed in a narrow clearance space of the ultra-high vacuum environment around a vacuum chamber, magnet array and a nearby cooling system. Adjacent components in the vicinity of the magnets and the field-measurement device must neither interfere with each other nor perturb the signal source. As stated above, a compact design is a crucial and essential element of the system development. The movement requirements of the measurement system are listed in Table 1. To avoid an accidental collision due to loss of control resulting in component damage or system failure, interlock protection devices must also be taken into account.

Table 1: Movement Requirements of Each Method

Method	**Stretch Wire**	**Hall Probe**
Stroke range		
Vertical	±1 mm	±5 mm
Transverse	±22 mm	±1 mm
Longitudinal	-	2.4 m
Scanning Speed	10 mm/s	3 mm/s

System Composition - Hardware

Figure 1 displays the overall construction of the system to measure a magnetic field. The free space between vacuum chambers is used to accommodate the measured undulator. According to the functions of the system, the field-measurement equipment of hybrid type can be divided into two portions, a Hall probe and a stretched wire.

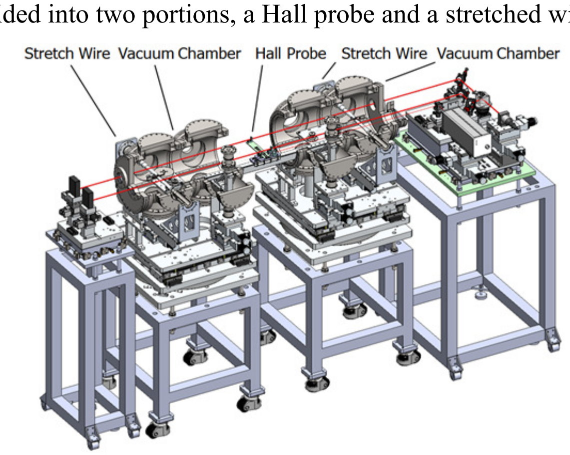

Figure 1: Overview of the measurement system.

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Hall-probe field-measurement equipment The carriage of the optical components and the Hall probe is dragged with a circulating loop of stainless-steel wire and driven with a rotary stepping motor. The rotational motion of the stepping motor is transferred from air into the vacuum with a magnetic rotary feed-through. During the sliding actuation, the carriage is guided with a Y-shaped rail and moves in the longitudinal direction. Figure 2 shows that the configuration arrangement of the wheels of the carriage is distributed to fit three surfaces -- the upper side and both inclined sides of the Y-shaped rail. One inclined side of the wheel assembly is equipped with a flat spring; its purpose is to constrain the freedom of the carriage in the vertical and transverse directions, but it could also prevent the carriage from skipping due to wire dragging. To obtain a highly accurate position of the probe sensor within a long travel stroke, a He-Ne laser scale (Agilent 5517C laser head, beam splitter, corner-cube reflector and photon detector, resolution 0.01 μm) is built in; the reflector is mounted on the carriage inside the vacuum chamber.

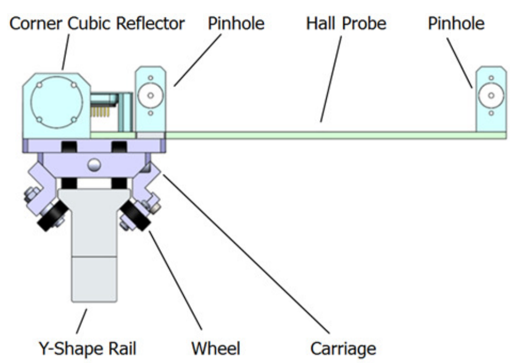

Figure 2: Hall probe carrier.

Because of an excessive slenderness ratio of the geometric profile of the guiding rail, fabrication with high precision of this part was difficult. Moreover, considering the self-weight of the rail and only two or three supporting locations for the rail (length 2.5 m) and carriage, deformation of the rail will result in wander from its course during a field measurement. To diminish the deviation and to improve the centering accuracy in both vertical (*Y*) and transverse (*X*) directions, a position-measurement technique would be introduced to monitor the extent off-axis of the probe sensor and to correct the error in real time. A solid-state laser spot of light becomes expanded to a beam of diameter 3 mm with a beam expander before the light travels to a beam splitter. Of the light intensity, half would be directly reflected toward the pinhole near the rail; the other half would penetrate the beam splitter to the next reflector and thus be reflected to the pinhole far from the rail. These two pinholes are mounted on both sides of the probe sensor, as shown in Fig. 2. The position of the Hall probe sensor is related to the distribution configuration of these pinholes. After the light travels to the pinhole, a portion of the light becomes intercepted by the pinhole; the residual light would be allowed to pass through the pinhole (1.5 mm). The actual bi-directional position of the holes of the pinhole is altered on following the carriage moving along the guiding rail. Two beams of penetrating light would eventually be received by two sets of quadrant detectors settled on two axes of a moving stage individually; the real position coordinate of the probe sensor could be determined immediately. Furthermore, it could simultaneously be used to compensate for the deviation through each of two axes of the moving stage to support the rail located at both ends and, or, the middle position.

To solve the storage of the signal wire and for usage in a vacuum condition with no influence on the accuracy of the carriage movement, the method of a reel drum that deploys a constant torque spring is proposed. One end of the signal cable is fixed on the carriage and connected to sensors; the other end is stored on winding around the reel drum. During a field measurement, the signal wire accompanying a restoring force would be smoothly relaxed or retracted through the mechanism of the reel drum.

Stretched-wire field-measurement equipment A Litz wire made on twisting eight wires and a series connection of all taking advantage of increasing the ratio of signal to noise would be adopted to measure the integral field measurement. The cable passes a horizontal central plane across a pair of magnet arrays and is then fixed on the cable fixture at both ends. The pre-tension mechanism of the cable shown in Fig. 3 is proved to tighten the cable and to decrease the sag of the cable to lessen systematic deviation. The cable scanning within a desired range in vertical and horizontal directions must be performed with both ends of the two axes of the moving stage.

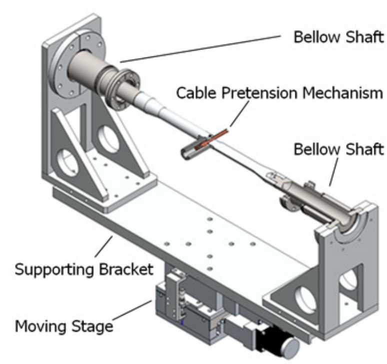

Figure 3: Section view of stretched-wire mechanism.

Control and Data Acquisition System

Figure 4 shows an architectural diagram of the entire control and data acquisition system. The laser scale generates "A quad B" signals. The controller (Galil) uses these signals to determine the longitudinal positions of the Hall probe and triggers a voltmeter at particular intervals. As the core of the control system, a computer monitors the *x-y* positions of the Hall probe through two quad-cell PSD and corrects them with two rail-supported *x-y* stages. It also controls the movements of the *x-y* stages of the stretched-wire movement and the Hall probe rotary stepping motor. After measurement, this computer reads data of a voltmeter and a digital integrator and plots the measurement results.

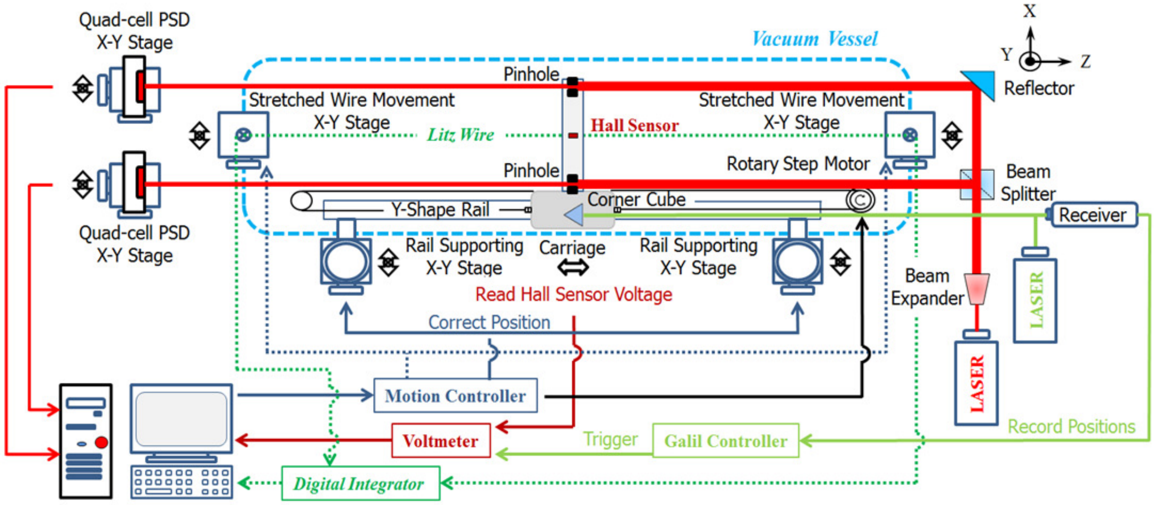

Figure 4: Diagram of the control and data acquisition system.

VERIFICATION OF RESULTS

To verify the function and performance of the system under the vacuum-sealed condition at 10^{-4} Pa, a couple of magnet arrays (length 0.2 m) of period length 22 mm and a gap fixed at 7 mm would be dedicated to testing, as shown in Fig. 5. Figure 6 shows that the reproducibility of Hall probe system is better than 0.2° in RMS phase error, which indicates that this system is reliable to examine an undulator in a vacuum environment.

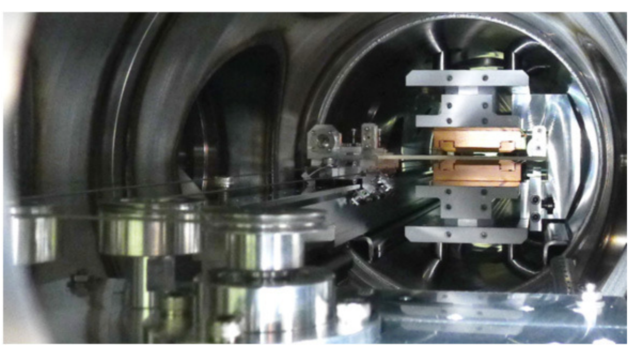

Figure 5: Magnetic-field measurement of IU22 with 0.2 m long.

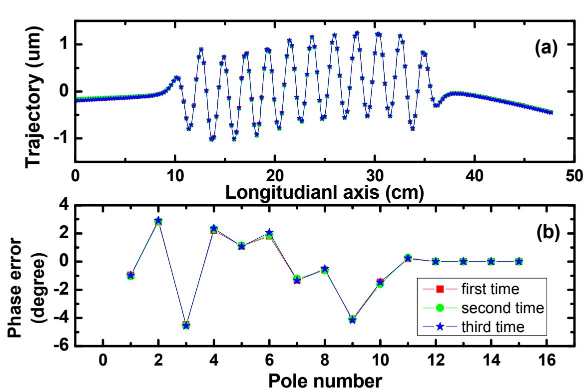

Figure 6: Result of measurement of the magnetic field.

CONCLUSION

The design of a system of hybrid type to measure the magnetic field of a cryogenic permanent-magnet undulator is proposed. The fabrication of Hall-probe components has been accomplished; some significant experiments of the system have been performed at room temperature and in a vacuum environment. The test results confirm that the engineering architecture enables collection of information about the magnetic field. Calibration of the Hall probe at varied temperature and testing of the reliability at cryogenic temperature are required. The stretched-wire parts are under fabrication and will also be tested.

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