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DESIGN OF A SYSTEM AT NSRRC TO MEASURE THE FIELD FOR AN IN-VACUUM CRYOGENIC UNDULATOR WITH PERMANENT MAGNET

C. K. Yang, Y. Y. Lin, C. H. Chang, J. C. Huang, C. S. Hwang and T. Y. Chung, NSRRC, Hsinchu, Taiwan

Abstract

A cryogenic undulator with a permanent magnet (CPMU) is an important insertion device now under construction at NSRRC. For an undulator of this kind, the distribution of the magnetic field must be measured along the axis; the phase error, trajectory and photon flux must be calculated after the magnetic arrays are installed in the vacuum chamber and cooled to cryogenic temperature. We developed a Hall-probe system to measure the magnetic field in an evacuated environment; this system uses lasers and stages to monitor and to correct dynamically the positions of the Hall probe. All components installed inside the vacuum chamber are compatible with an environment of high vacuum and low temperature. The details of the design and completed fabrication are presented in this paper.

INTRODUCTION

Since 2005, undulators with a short period and a small gap have been installed in medium-energy facilities for synchrotron radiation to produce energetic photons. For an undulator of a given length, increasing the number of periods increases the brightness of the radiation. For short periods requiring stronger and more stable magnets, cooling the magnets to cryogenic temperature was proposed to achieve this objective.

SPring-8 first built a CPMU [1] and developed a system of measurement to test the magnetic performance [2]. Thereafter, many facilities built CPMU of various types. ESRF [3] built two $Nd_2Fe_{14}B$ CPMU in 2008. SOLEIL [4], UCLA [5] and BNL [6] built and tested $Pr_2Fe_{14}B$ CPMU prototypes.

At NSRRC for Taiwan Photon Source in phase I, we are building five beamlines equipped with undulators in vacuum and with period 22 mm; we developed a system to measure the field *in situ* to verify the performance of the magnetic field after magnetic arrays are installed inside the vacuum chamber [7-8]. For beamlines of phase II, NSRRC will design and fabricate a CPMU. We must also test the magnetic performance after the CPMU is evacuated and cooled, but not all components are suitable for emplacement within a vacuum chamber. We therefore redesigned and modified the measurement system to be completely compatible in a high-vacuum environment and made some improvements to simplify the alignment and to enhance the reproducibility of the system.

DESIGN

Figure 1 is a schematic illustration of this system, which comprises four subsystems -- for positioning and for actuation of the Hall sensor, and systems to correct the position and to collect signal wires. To place all parts inside the vacuum chamber is difficult and expensive. Most components are left outside except the Hall sensor, rail, signal wires, pinholes and some homemade parts. All homemade parts are designed at NSRRC and made of aluminium machined free of oil, with computer numerical control (CNC) to control the machining precision, and sprayed with pure alcohol to protect a fresh surface from any ambient contamination with oil [9]. Components produced according to this method are proved compatible for use in an evacuated environment.

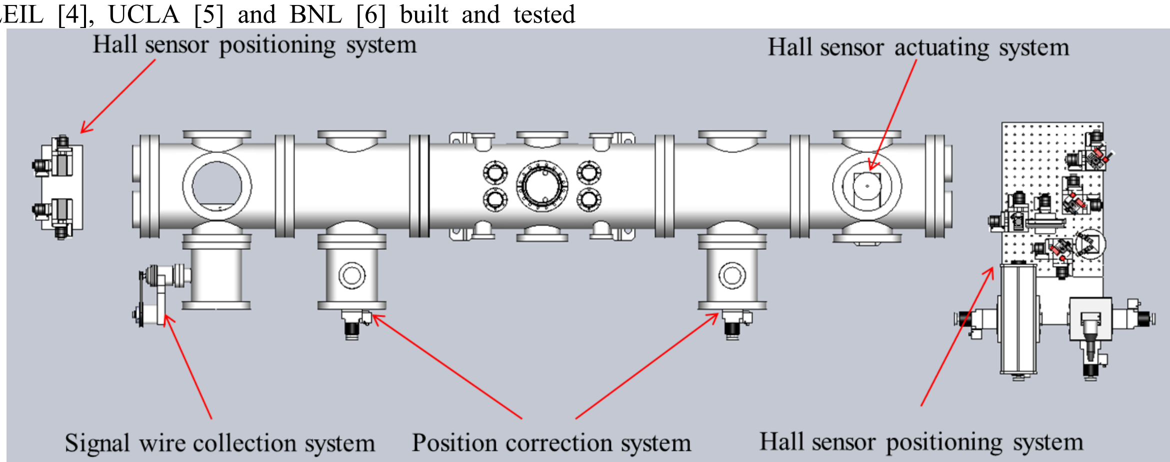

Figure 1: Schematic illustration of the measurement system.

yang.ck@nsrrc.org.tw

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System to Actuate the Hall Sensor

Figure 2 shows the system to actuate the Hall sensor so as to move it in a longitudinal direction. The stainless-steel wire connects to two ends of the carriage and is arranged along pulleys to form a closed loop. This wire is cleaned in an ultrasonic bath with acetone and pre-baked in a vacuum environment.

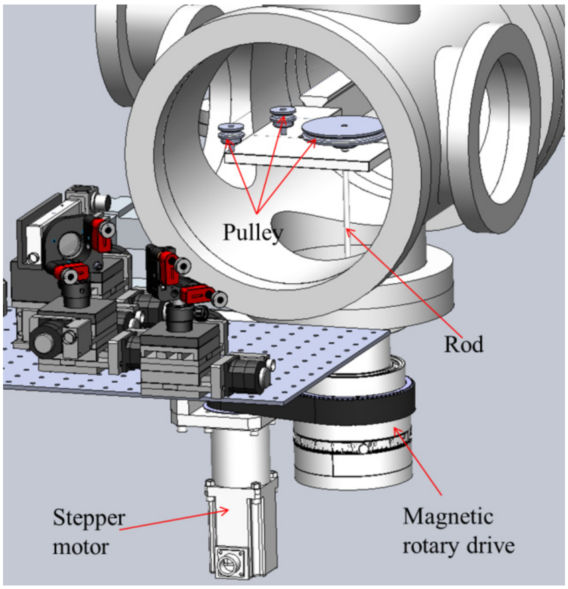

Figure 2: System to actuate the Hall sensor.

Because the stepper motor has, for lubrication, oil that would contaminate the vacuum chamber, it is mounted outside that chamber, and drives the pulley through a magnetic rotary-drive system.

System to Position the Hall Sensor

Figure 3 is a top view of the positioning system. A laser interference system and a corner cube moving with the Hall sensor serve to monitor its longitudinal position.

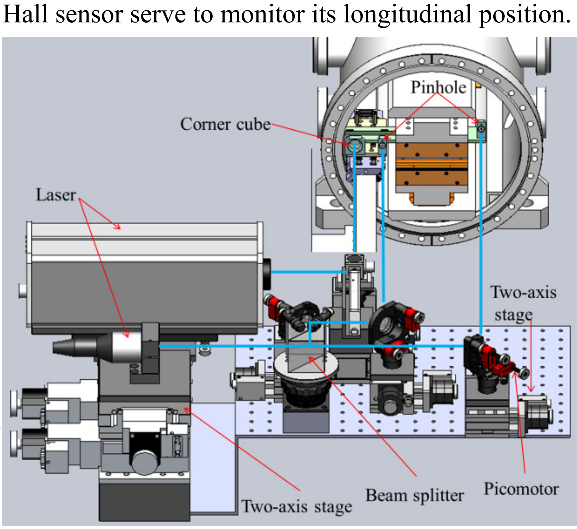

Figure 3: System to position the Hall sensor.

A solid-state laser with a beam of uniform profile split into two beams measures the transverse and vertical positions. All optics except a corner cube and two pinholes are located outside, and laser beams emit into the vacuum chamber through two view ports. We removed the holder, which is unsuitable for vacuum, from a corner cube and mounted it on our homemade holders. Pinholes are also replaced with non-coated ones.

System to Correct the Position

To correct the positions of the Hall sensor in transverse and vertical directions, there are three two-axis stages. In a previous version, stages connected directly to plates that loaded the rail and carriage with the Hall probe, but the stages cannot be placed inside the vacuum chamber.

In this version, these stages are installed outside the vacuum chamber and move the plates through transfer rods, as shown in figure4. Two rods connect the plate at one end and connect to a bellows at the other end. The stage moves the bellows fixed to it to correct the positions. The bellows provide an adjustable space. If two ends of a bellows are not fixed, the bellow becomes compressed after evacuation and the force is too large to overcome. The function of the upper bellows is to balance the force, so that the stages can move the plates easily.

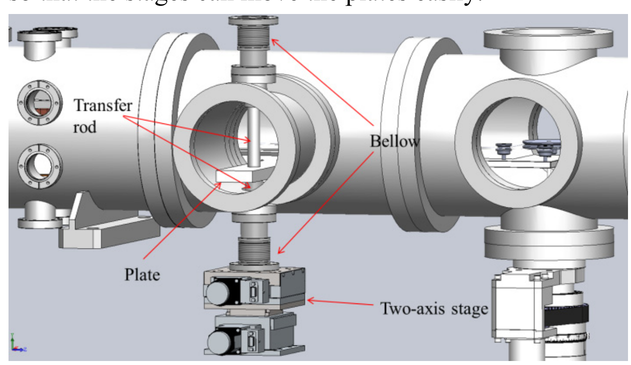

Figure 4: System to correct the position.

System to Collect Signal Wires

As the Hall sensor moves along the rail, signal wires are collected with a pulley assembly. Figure 5 shows this system without the vacuum chamber.

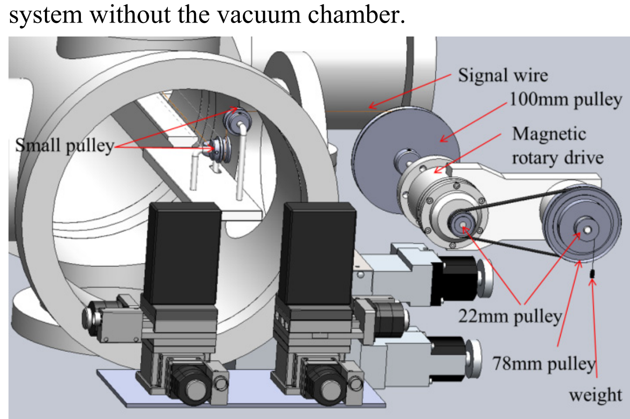

Figure 5: System to collect signal wires (without the vacuum chamber).

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The signal wires first have their directions changed with two small pulleys, and are then rolled with a larger pulley (diameter 100 mm). Here we use also a magnetic rotary drive to rotate the large pulley outside the vacuum. Instead of a stepper motor, we use a weight and another pulley assembly to operate the magnetic rotary drive. On the central axis of this drive is mounted a timing pulley (diameter 22 mm) that is connected to another timing pulley (diameter 78 mm) with a timing belt.

A weight pulls a further timing pulley (22 mm) that is fixed on the same rod with the timing pulley (78 mm). With these pulleys the weight requires a falling distance only about 60 cm to collect signal wires of length 4 m.

IMPROVEMENTS

According to our experience of measuring undulators in vacuum, we undertook some improvements of the components to align the laser and the carriage for the Hall sensor to expedite the alignment and to simplify the reproducibility of the measurement.

Components for Laser Alignment

As lasers and optics are used to monitor the positions of the Hall sensor, they must be aligned precisely to assure the measuring positions. Because of the drift of the laser beams, alignments should be done daily. As the optical components are manually adjusted, aligning the laser beam quickly is not easy. To simplify the alignment, motorized two-axis stages and picomotors, shown in figure 3, are added to adjust the positions of optical components and angles. An algorithm is being developed to complete alignment automatically through control of these stages and the picomotors with software.

Carriage of the Hall Sensor

In a previous version, we found that the wheel surfaces of the carriage were not parallel to the rail surface. As the wheels were made of stainless steel and the rail material was aluminium, the wheels scraped the rail surfaces, which caused vibrations when the carriage passed through.

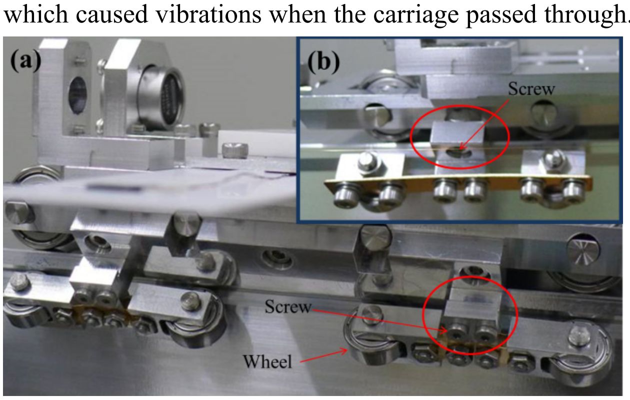

Figure 6: Carriage of the Hall sensor.

Another drawback is that only one screw, shown in figure 6(b), served to fix two wheels on the carriage, resulting in instability and rotation of the wheel axle. Figure 6(a) shows the revised version of the carriage. We used two screws to fix the wheel axle tightly, and finely milled the rail surfaces and adjusted the wheel angle to make wheels normal to the rail surfaces.

With these modifications, the reproducibility of this system is improved. The standard deviation of the phase error is decreased from 0.2^{o} to 0.13^{o}, and that of the first integral from 13.4 to 9.4 G cm.

CONCLUSION

A system to measure the magnetic field has been developed and applied to verify the magnetic field after magnet arrays were installed inside a vacuum chamber. To measure the magnetic performance of a CPMU, the system should be installed in a cryogenic and evacuated environment. To avoid contaminating the vacuum chamber, only several parts that carry and monitor the Hall sensor are placed inside the chamber; these parts are well cleaned before use. The driving system and the system to position and to correct the Hall sensor are mounted outside the vacuum chamber.

We also redesigned the carriage and optical components to improve the reproducibility of measurement and to decrease the duration of optical alignment. We shall test this system first in a vacuum chamber (70 cm) with magnetic arrays (30 cm) inside to ensure that this system is reliable and compatible with high vacuum.

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