DEVELOPMENT OF IN-SITU FIELD MEASUREMENT SYSTEM FOR KOREA-4GSR IN-VACUUM UNDULATORS

G. Choi†, Korea Basic Science Institute, Daejeon, South Korea
Y. G. Choi, B. J. Kim, G. Hahn, Y. Jung, D. E. Kim, W. Lee
Pohang Accelerator Laboratory, Pohang, South Korea

Abstract

Precise magnetic-field characterization of in-vacuum undulators is essential for achieving stable beam dynamics in synchrotron light sources. This work presents an in-situ measurement platform that integrates a SAFALI-based Hall probe scanner with a stretched-wire measurement system. The Hall probe unit measures the local magnetic-field distribution along the undulator, achieving micrometer-level positioning accuracy through laser interferometry and optical feedback. In parallel, the stretched-wire system enables reliable determination of the first and second magnetic-field integrals. To minimize magnetic distortion, most mechanical structures are fabricated from low-permeability materials. The system is designed to characterize in-vacuum undulators with magnetic lengths of up to 3 m, allowing comprehensive field mapping without removing the vacuum chamber. The integrated platform is currently under construction for application to in-vacuum undulators at the Korea-4GSR Facility and is expected to improve phase-error reproducibility while providing direct verification of undulator magnetic performance.

INTRODUCTION

Several advanced accelerator laboratories worldwide have developed and successfully operated in-situ magnetic field measurement systems for undulators. However, no equivalent system has yet been established in Korea. In the framework of the Korea 4th Generation Synchrotron Radiation Facility (Korea-4GSR) project, an in-situ magnetic field measurement system for in-vacuum undulators (IVUs) is being developed at Pohang Accelerator Laboratory (PAL). The fundamental design concept draws reference from the SAFALI (Self-Aligned Field Analyzer with Laser Instrumentation) system at SPring-8, Japan [1], and the in-situ measurement system at the National Synchrotron Radiation Research Center (NSRRC), Taiwan [2].

Given that the measurement system operates in close proximity to magnetic structures, minimization of magnetic interference is a primary design consideration. Low magnetic permeability materials were therefore adopted for all major structural and fastening components. The mechanical and optical subsystems were further designed to ensure stable alignment and motion accuracy over the full measurement range.

Prior to full-scale fabrication, prototype assemblies — comprising the carriage, rail, optical alignment subsystem, and wire tension control mechanism — were manufactured and experimentally evaluated. The prototype aimed at identifying potential mechanical instabilities, bearing contact issues, optical alignment limitations, and structural constraints relevant to 4 m translation performance.

Based on the outcomes of prototype evaluation, a series of design improvements are currently being implemented, targeting enhanced carriage stability, improved optical alignment reproducibility, refined wire tension control, and overall system reliability in view of future deployment on Korea-4GSR IVUs.

CONCEPT AND DESIGN

Figure 1 shows the overall schematic layout of the in-situ magnetic field measurement system developed for Korea-4GSR IVUs. The fundamental design concept follows that of the in-vacuum cryogenic undulator measurement system at NSRRC, incorporating a wire-driven Hall probe carriage, an optical alignment subsystem, and a stretched-wire measurement configuration within a unified measurement platform [2, 3].

Hall Sensor Actuating System

The Hall probe carriage is driven along a 4 m rail structure with high positional repeatability. The translation mechanism comprises a stepper motor and pulley assemblies, with stainless-steel wire connected to both ends of the carriage; bidirectional motion is achieved through rotational actuation of the stepper motor.

The carriage and rail assembly form the primary mechanical guide structure of the system. The carriage accommodates the Hall probe sensor, retroreflector, optical pinholes, and associated mechanical fixtures. To minimize magnetic interference during measurements, all major fastening components on the carriage were fabricated from 316L stainless steel.

As the current measurements are planned under out-vacuum conditions, vacuum-compatible treatment procedures — such as lubricant removal from stepper motor assemblies and carriage bearings — were not applied at the present prototype stage. Nevertheless, the overall mechanical structure was designed with future applicability to in-vacuum measurement environments in mind.

To improve translation stability, a dedicated wire tensioner mechanism (Fig. 2) was developed to maintain approximately constant wire tension throughout carriage motion. In the absence of adequate tension stabilization, fluctuations in wire tension can induce longitudinal oscillation and vibration during measurements. The tension control mechanism therefore plays a critical role in suppressing

†ghee1107@kbsi.re.kr

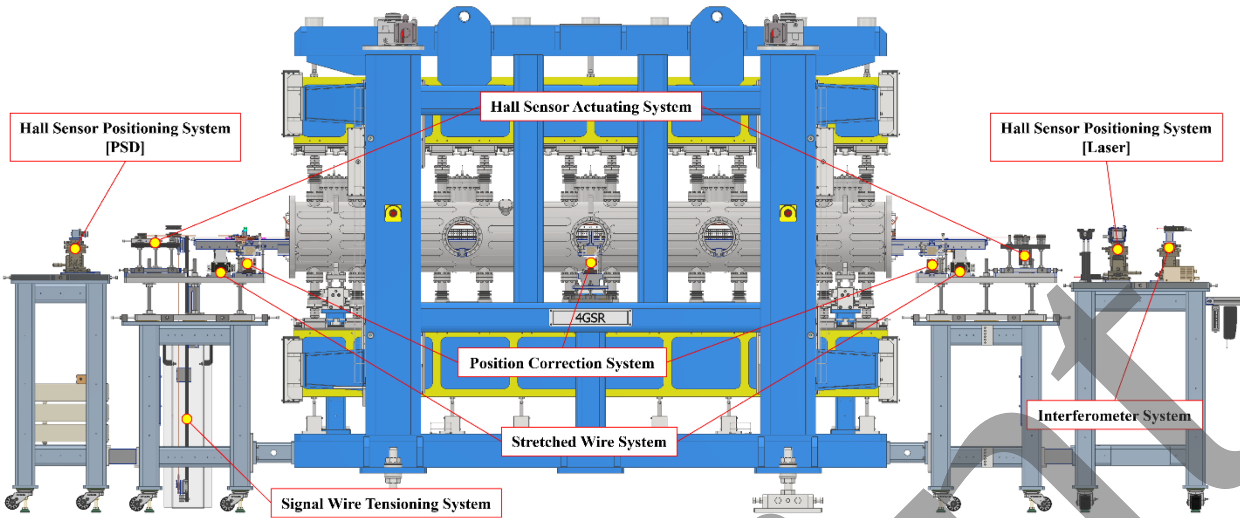

Figure 1: Schematic illustration of the in-situ field measurement system.

carriage vibration and minimizing Hall probe oscillation during magnetic field measurements.

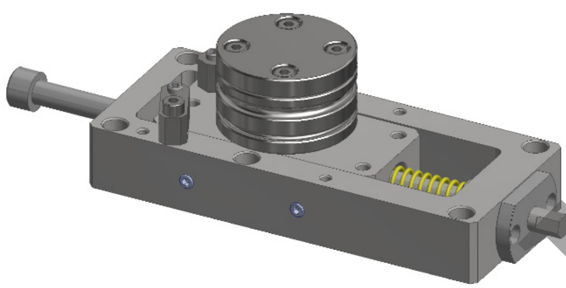

Figure 2: Stainless steel wire tensioner.

Optical Alignment System

The fundamental concept of the optical alignment subsystem is to establish a stable optical reference axis using a single laser source and to utilize this reference for real-time alignment correction. The emitted laser beam is divided into two paths by a beam splitter, and the resulting beams are subsequently redirected by mirrors [4]. Each beam is guided through optical pinholes mounted on the carriage and detected by a position-sensitive detectors (PSDs), which provides quantitative beam position information.

The PSD signals serve as feedback for closed-loop alignment correction. Based on the measured deviation of the beam position from the reference axis, three two-axis motorized stages adjust the lateral and vertical position of the rail structure accordingly. Through this continuous correction process, the position of the carriage — and consequently that of the Hall probe mounted on it — is actively maintained in alignment with the optical reference axis over the full measurement length, thereby improving both measurement accuracy and repeatability.

In the initial design, two independent laser sources were employed. However, prototype revealed that even between nominally identical laser units, slight inter-unit variations in optical specifications introduced discrepancies in the PSD signals across the two channels. These inconsistencies increased alignment complexity and degraded positioning reproducibility.

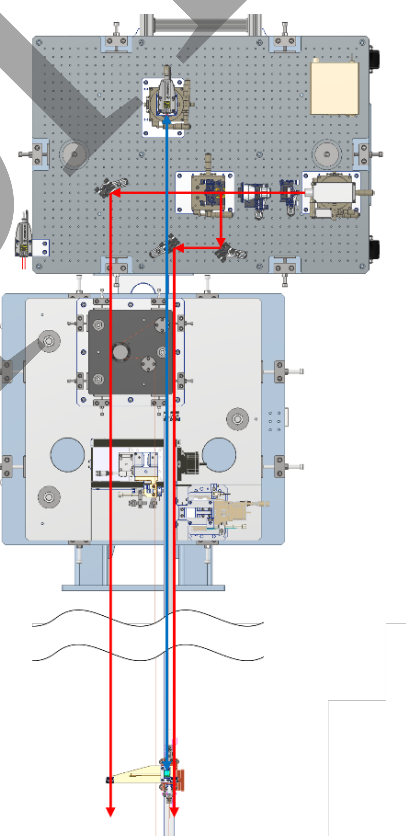

Figure 3: Laser beam path for alignment system.

To address this issue, the optical configuration was revised to adopt a single-laser beam-splitting architecture (Fig. 3). This modification simplifies the alignment procedure and is expected to significantly enhance the stability and reliability of the overall positioning correction system.

IMPROVEMENT PLAN

Based on the prototype evaluation, several mechanical and optical improvements are being implemented to enhance system stability, alignment accuracy, and overall measurement reliability.

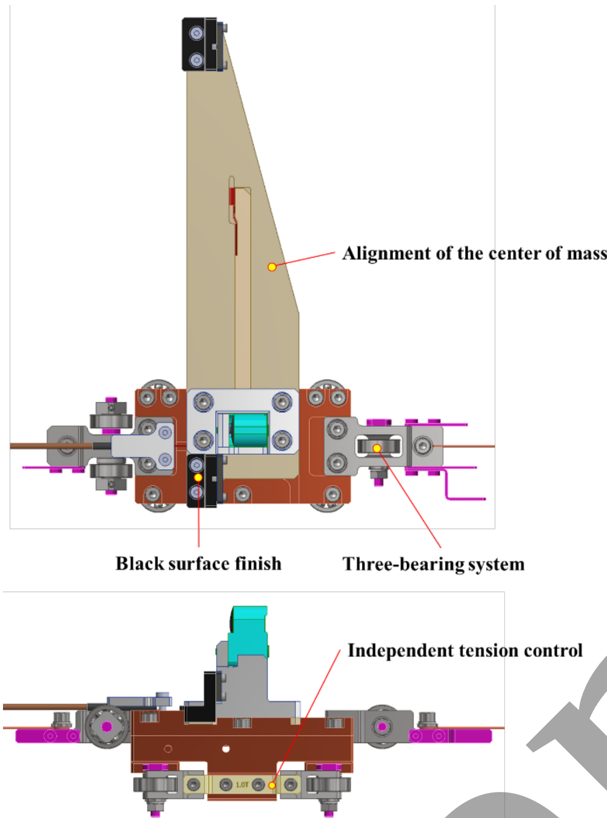

Figure 4: Carriage modification plan.

From a mechanical standpoint, modifications are focused on improving carriage motion stability and contact consistency with the rail (Fig. 4). The current four-bearing configuration exhibited incomplete rail contact during translation; accordingly, an alternative three-bearing configuration will be evaluated to ensure stable and continuous contact with the rail surface. In addition, an independent tension adjustment mechanism for the side bearings is under development to improve lateral contact performance and to prevent inclined bearing contact arising from excessive tension at the side spring plate. The geometry of the Hall probe support plate is also being redesigned to better balance the center of mass between the carriage and rail, thereby reducing dynamic instability during motion.

To address wire-driven translation issues, the spring-based tensioner mechanism is being refined to deliver more stable and consistent wire tension throughout carriage travel. This is expected to suppress longitudinal oscillation of the carriage and minimize Hall probe vibration during magnetic field measurements.

From an optical standpoint, several measures are being introduced to improve alignment stability and reduce signal noise. To suppress spurious laser reflections from metallic surfaces, pinhole holders and selected structural components will be treated with a black anodized or matte surface finish. Furthermore, as described in the preceding section, the optical alignment system has been redesigned from a dual-laser to a single-laser beam-splitting architecture. This modification eliminates inter-unit laser variability and improves alignment reproducibility by deriving both optical paths from a common source.

These improvements are currently under implementation and will be validated through systematic testing of the full-scale 4 m measurement system.

CONCLUSION

An in-situ magnetic field measurement system for Korea-4GSR IVUs is currently under development to enable precise magnetic characterization under installed operating conditions. The proposed system integrates a wire-driven Hall probe translation mechanism with a laser-based optical alignment and correction subsystem, achieving stable and repeatable measurements over a 4 m travel range.

Prototype fabrication and testing confirmed the overall feasibility of the system concept, while simultaneously revealing several mechanical and optical limitations — including bearing contact instability, insufficient wire tension control, and alignment inconsistencies associated with the initial dual-laser configuration. These findings provided essential feedback for systematic design refinement.

Based on the prototype evaluation, key improvements have been implemented: optimization of the carriage bearing configuration, enhancement of the wire tension control mechanism, reduction of spurious optical noise, and adoption of a single-laser beam-splitting alignment architecture. These modifications are expected to collectively improve alignment stability, measurement repeatability, and overall system reliability.

Future work will focus on the fabrication and experimental validation of the full-scale 4 m measurement system, followed by its integration into the Korea-4GSR IVU measurement environment.

REFERENCES

[1] H. Kitamura, T. Seike, and T. Tanaka, "In-situ Undulator Field Measurement with the SAFALI System", in *Proc. FEL'07*, Novosibirsk, Russia, Aug. 2007, paper WEPPH052, pp. 468-471.

[2] C. K. Yang, C.-H. Chang, T. Y. Chung, J. C. Huang, C. S. Hwang, and Y. Y. Lin, "Design of a System at NSRRC to Measure the Field for an In-vacuum Cryogenic Undulator with Permanent Magnet", in *Proc. IPAC'14*, Dresden, Germany, Jun. 2014, pp. 2041-2043. doi:10.18429/JACoW-IPAC2014-WEPRO045

[3] C.W. Chen, C.S. Yang, H. Chen, C.K. Yang, and J.C. Huang, "Integrated Hall Probe and Stretched Wire Measurement System for an In-Vacuum Undulator", in *Proc. IPAC2024*, Nashville,TN, USA, May. 2024, paper TUPG64, pp. 1398-1401. doi:10.18429/JACoW-IPAC2024-TUPG64

[4] C. H. Chang, S. D. Chen, J. C. Huang, C.-S. Hwang, and C. K. Yang, "Design and Development of a System of Hybrid Type to Measure the Magnetic Field of a Cryogenic Undulator", in *Proc. MEDSI2016*, Barcelona, Spain, Sep. 2016, paper TUPE41, pp. 251-253.
doi:10.18429/JACoW-MEDSI2016-TUPE41