A NOVEL MAGNETIC MEASUREMENT SYSTEM FOR CRYOGENIC PERMANENT MAGNET UNDULATOR

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Abstract

A standardized magnetic measurement system exists for evaluating the field characteristics of conventional insertion devices, including in-vacuum undulators designed for NSLS-II, which utilize a rectangular measurement window. However, in the case of cryogenic permanent magnet undulators (CPMUs), each facility employs a distinct design, and no commercially available measurement system currently exists. At NSLS-II, we intend to retain a side-mounted rectangular window for room-temperature characterization. An in-vacuum magnetic measurement system (IVMMS) suitable for 1.5 m long CPMUs was developed during the NSLS-II project. A newly developed in-vacuum Hall probe system, capable of accommodating devices longer than 1.5 m, has been designed to interface with this window. This paper presents a preliminary design of the in-vacuum Hall probe measurement bench, designated IVMMS-II, developed to characterize a 3 m long CPMU planned for the NEXT-III (NSLS-II Experimental Tools III) project beamline, High Resolution Powder Diffraction (HRD).

INTRODUCTION

For the characterization of insertion devices, two categories of magnetic field measurement systems are required. One is a field mapping apparatus, typically employing a three-dimensional Hall probe. The other is a field integral measurement system, commonly utilizing either a single-wire configuration or a multi-turn coil. Our group has previously developed a field integral measurement system based on an in-vacuum flip coil [1] which is applicable to CPMUs. During the NSLS-II project, an in-vacuum Hall mapping system, referred to as In-Vacuum Magnetic Measurement System (IVMMS), was developed and optimized for 1.5 m long CPMUs. This measurement system was validated using a 20 cm long Prefab CPMU at the vendor's facility, as illustrated in Fig. 1. The new beamline for the NEXT-III (NSLS-II Experimental Tools III) project, designated as High Resolution Powder Diffraction (HRD) [2], requires a radiation source incorporating a 3.0 m long CPMU. A concise summary of the device specifications is provided in Table 1.

Table 1: HRD-CPMU Parameters

Item	Specification
Magnet Core length (including magic fingers)	3.0 m
Period Length	18.0 mm
Min. Vertical Physical Aperture	4.50 mm
Min. Operational Vertical Physical Aperture	5.97 mm
Max. Operational Magnetic Gap	25.0 mm
Min. Fully Open Gap (with vacuum chamber, with transitions)	40.0 mm
K_{eff} at 5.97 mm vertical aperture@77 K*	> 1.795

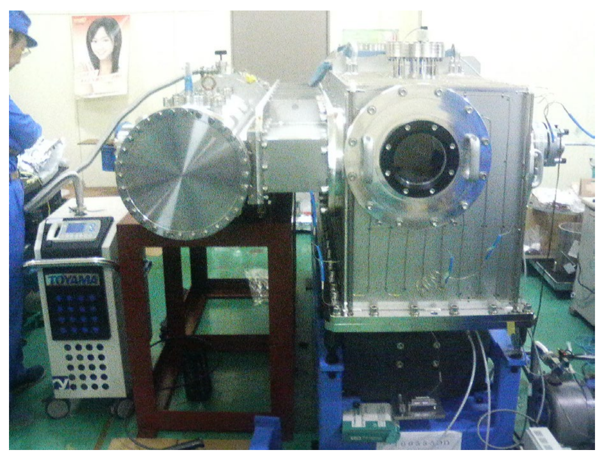

Figure 1: IVMMS measuring a 20 cm long prefab undulator with liquid Nitrogen cooling.

DESIGN CONCEPT

The IVMMS employed the concept of incorporating a compact granite bench within the vacuum environment. However, extending this approach to accommodate longer devices has proven to be prohibitively expensive. The existing IVMMS allows adjustment only in the X, Y, and Z directions, as well as roll (rotation about the X-axis). A newly developed system should provide full six-degree-of-freedom adjustment, encompassing X, Y, Z translations and pitch (T_x), yaw (θ_y), and roll (θ_z) rotations. Figure 2 illustrates the definitions of these parameters. The Z-direction corresponds to the longitudinal axis, extending up to 4000 mm.

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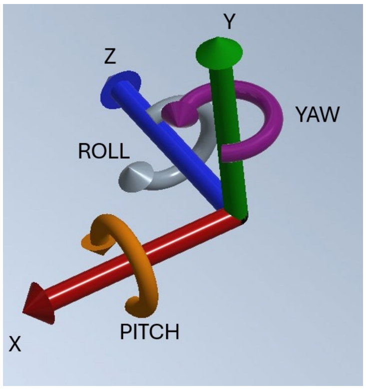

Figure 2: Our coordinate definitions. Z axis is for the long travel along the device.

The Z-axis motion (aligned with the electron beam direction) is driven by an in-vacuum linear motor (C12-1 with Delta phase connection by Allied Motion), a configuration analogous to that employed in the IVMMS. The remaining five degrees of freedom are provided by an in-vacuum hexapod (SMARPOD 110.45 by Sarat, Inc.) with the following operating ranges: X: 11 mm; Y: 20 mm; pitch: 38°; yaw: 25°; roll: 22°. Rather than mounting the linear motor on a granite base within a separate vacuum chamber, it is positioned vertically at the edge of an enlarged vacuum chamber opening.

The IVMMS previously utilized an in-vacuum motor (AIREX LMC-P16), now produced by Alient. A primary challenge associated with in-vacuum motors is thermal management, as the absence of convective cooling significantly limits heat dissipation from the coils. Given the substantially reduced load in the present system relative to the IVMMS, the LMC-C12 model has been selected [3]. The Hall probe element will be calibrated in a measurement laboratory maintained at a controlled temperature of 25.5 °C.

Thermal analysis was conducted using ANSYS®. Heat sources include the ambient vacuum chamber at room temperature, the linear motor coil, the hexapod assembly, and the bias current supplied to the MV2 Hall probe. Radiative heat transfer from the magnet arrays is also incorporated into the model.

Figure 3 presents a three-dimensional layout of the system with a 1 m long configuration; the rails and backplate can be extended or shortened as required. The assumption for the thermal analysis is shown in Fig. 4. The resulting temperature distribution across the structure—assuming a volumetric heat load of 1.38×10^6 W/m³ and a thermal conductance of 100 W/m²/°C for the bearings—is illustrated in Fig. 5. In this analysis, the carriage stands still with necessary current for the motor to move. The Hall probe arm is assumed to be fabricated from aluminium; however, in the actual implementation, Macor is expected to be employed.

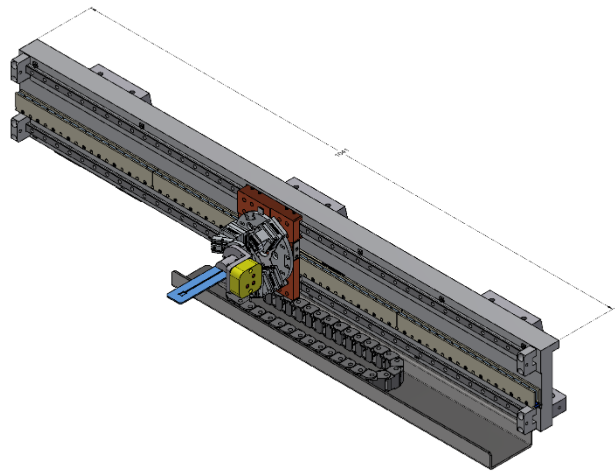

Figure 3: 3D-CAD rendering of the IVMMS-II.

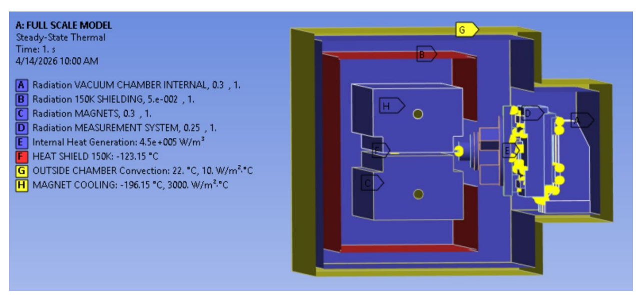

Figure 4: Assumed parameters for the ANSYS thermal analysis.

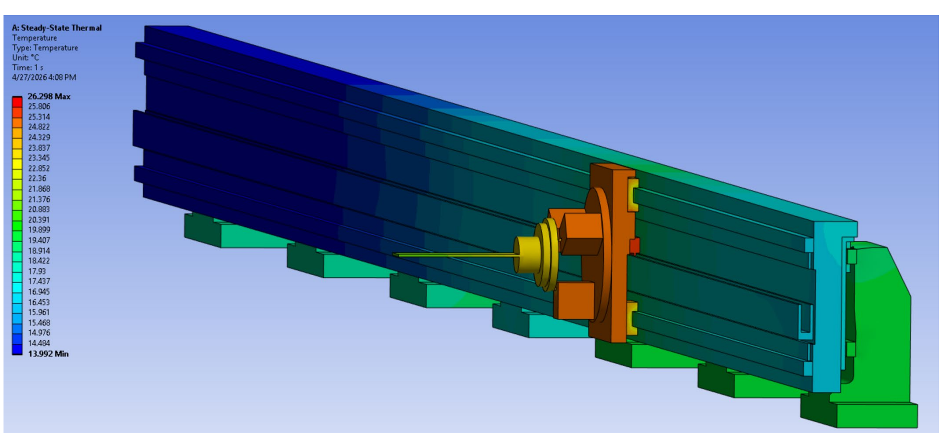

Figure 5: Estimated temperature distribution of full length IVMMS-II.

PROBE POSTIONING ERROR DETECTION

In contrast to a conventional Hall probe bench, which ensures the flatness of the granite surface, the present system cannot maintain the required straightness of ±5 μm without supplementary position monitoring instrumentation. A triple-beam laser interferometer (SP 5000 TR) by SIOS, Inc. [4, 5] can be employed to monitor the angular deviations of the Hall probe carriage. The X and Y positions of the probe are measured using two position-sensitive detectors (PSDs), analogous to the approach implemented in the Self-Aligned Field Analyzer with Laser Interferometer (SAFALI) system developed at SPring-8 [6]. The SP 5000 TR and the laser source for the PSD (TBD) are located outside the vacuum chamber and mounted on floor-based supports.

HALL PROBE

The MV2 Hall probe [7] has been selected due to its capability for digital signal output. Rather than transmitting signals through long analog cables, the probe converts measurements into digital form, thereby mitigating susceptibility to electrical noise. By incorporating a Bluetooth transmitter, data acquisition can be achieved without the need for extended cabling. The bias current may also be supplied via a battery to further minimize cable usage. Nevertheless, a cable tray remains necessary to provide power to the linear motor and the hexapod. Layout of MV2 control hardware for Digital acquisition and transmission over Bluetooth or USB is illustrated in Fig. 6. Figure 7 shows Metrolab breakout board with supplied Arduino Uno to interface MV2 chip. This setup will be used for calibration and analog/digital noise comparison.

CONCLUSION

A preliminary design of the in-vacuum Hall probe measurement bench, designated IVMMS-II, intended for the characterization of a 3 m long CPMU planned for the NEXT-III project beamline, High Resolution Powder Diffraction (HRD), is presented. Unlike the original IVMMS, the new system does not incorporate an independent support structure anchored to the ground. Consequently, the probe trajectory must be continuously monitored and compensated to ensure accurate positioning of the Hall probe elements. A vacuum-compatible hexapod is employed to provide X and Y translations, as well as pitch (θ_X), yaw (θ_Y), and roll (θ_Z) rotations. A triple-beam laser interferometer is utilized to monitor Z-axis motion, as well as pitch and yaw. Position-sensitive detectors, in conjunction with parallel laser beams, are used to monitor X and Y displacements and roll. A shorter prototype will be constructed to evaluate the functionality of the system in the coming months.

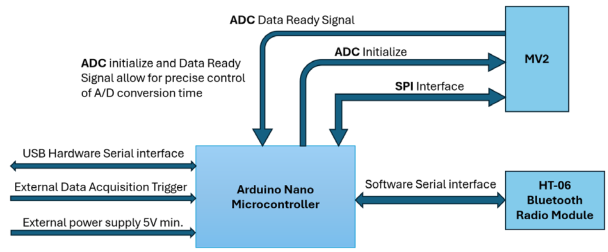

Figure 6: Layout of MV2 control hardware for Digital acquisition and transmission over Bluetooth or USB.

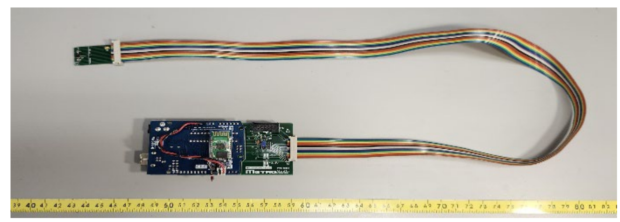

Figure 7: Metrolab breakout board with supplied Arduino Uno to interface MV2 chip.Setup being used for calibration and analog/digital noise comparison.

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