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NEW SUPERCONDUCTING UNDULATOR MAGNETIC MEASUREMENT SYSTEM FOR THE ADVANCED PHOTON SOURCE UPGRADE*

M. Kasa†, E. Anliker, Y. Shiroyanagi, and Y. Ivanyushenkov
Advanced Photon Source, Argonne National Laboratory, Lemont, USA

Abstract

Magnetic measurements of existing superconducting undulators (SCUs) are performed under normal operating conditions after final assembly into the cryostat and before installation on the Advanced Photon Source (APS) storage ring. The SCU cryostat for the APS upgrade has been scaled in length from the current cryostat and will contain two SCUs. While some aspects of the current measurement system, such as a room temperature measurement bore, are desirable to retain, scaling the current measurement techniques and system to the length required for the APS upgrade cryostat is not feasible. To address these challenges, a unique system has been developed at the APS to allow measurements of the two SCU magnets in the long cryostat. The measurement system developed allows the magnets to be operated under normal operating conditions while maintaining the measurement equipment at room temperature and atmospheric pressure.

INTRODUCTION

An upgrade of the superconducting undulator (SCU) magnetic measurement system at the Advanced Photon Source (APS) is in progress. The system will be used to verify the magnetic field quality and installation readiness of the superconducting undulators (SCUs) for the APS upgrade (APSU) [1].

Certain aspects of the existing SCU magnetic measurement system [2, 3], which was adapted from the Budker Institute in Novosibirsk, Russia for measuring superconducting wigglers [4], are desirable to retain. A convenient feature of the previous system is that of having an ambient temperature and pressure aperture through the magnetic gap of the SCU while the SCU is under normal operating conditions, i.e., vacuum and cryogenic temperatures in the production cryostat. This removes the requirement for a separate measurement cryostat and eliminates the need to disassemble and reassemble the magnetic structure before installation on the storage ring. Switching between Hall sensor based and wire based measurements is also easily accommodated.

This upgrade provides an opportunity to improve or alter features of the existing system. Some methods currently used to measure a single SCU in the 2-meter long APS cryostat are difficult to scale to the length of the 4.8-meter long APSU cryostat that will house two SCUs; in particular, the current method of mounting a Hall sensor at the end of a 2-meter long carbon fiber tube and driving it into the guide tube in a telescoping fashion. Also, the existing system uses a titanium guide tube under tension, which is heated by an applied current. Maintaining straightness and uniform temperature of the guide tube have proven to be difficult to achieve.

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† kasa@anl.gov

GUIDE TUBE CONCEPT

Retaining the previously mentioned features requires the magnetic measurements of the SCU to be made within the aperture of the electron beam vacuum chamber. The minimum aperture is 6 mm by 16 mm in the vertical and horizontal directions, respectively; therefore, the guide tube must fit within this region. Since the chamber is cooled to cryogenic temperatures, the guide tube must be thermally isolated and maintained at room temperature.

To address these issues it was decided to manufacture the guide tube out of aluminum through the process of extrusion and machining. Through the extrusion process, a precise racetrack aperture measuring 4 mm vertically and 16 mm horizontally can be formed then machined to the final outside dimensions. Features for mechanical support and temperature control are also incorporated into the final machining process.

A cross section of the guide tube installed inside the beam vacuum chamber is shown in Fig. 1. The region of interest for magnetic measurements is the blue-shaded area encompassing the beam centerline and defining the guide tube aperture. Placement of the guide tube inside the asymmetric beam chamber aperture is accomplished using low heat-leak Torlon® standoffs. This minimizes thermal communication between the beam chamber at 20 K and the guide tube maintained at 300 K. The space outside the guide tube but inside the beam chamber is kept at vacuum pressure, and the guide tube aperture is open to atmosphere. A channel for heater wires is machined along the length of the guide tube.

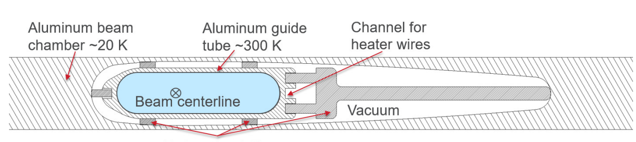

Figure 1: Cross section of the guide tube placement inside the beam vacuum chamber.

Thermal analysis determined the amount of applied heat required to maintain the guide tube at room temperature is 5.4 W/m. Applying 0.8 A to a 9.6 m length of 32 AWG phosphor bronze wire will generate the necessary heat. A deformation and stress analysis predicts that the deformation

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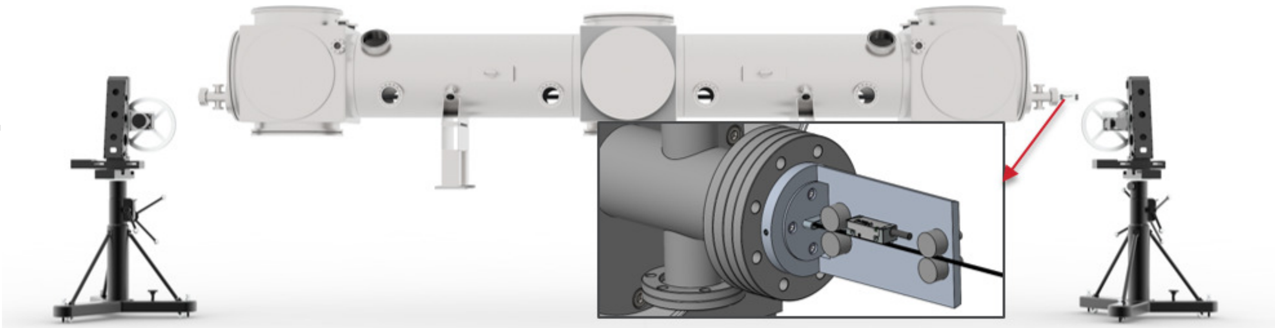

Figure 2: Measurement system installed at the ends of the SCU production cryostat. The inset is a close view of the encoder linear scale and stationary read head assembly.

of the guide tube will be 22 µm, and the maximum stress of 53 MPa is well below the yield strength of aluminum.

Positioning of the guide tube inside the magnetic gap is dependent upon the alignment of the beam chamber. It is expected that the guide tube aperture can be located vertically within ±100 µm of the center of the magnetic gap.

HALL SENSOR DRIVE SYSTEM

On-axis and off-axis field scans using a Hall sensor are performed to determine various characteristics of an undulator. By scanning a Hall sensor through the magnetic gap, the periodicity, phase errors, beam trajectory, peak field, and other characteristics of the undulator can be determined. For reliable measurements to be performed, the position of the Hall sensor within the gap needs to be determined. In systems developed for SCU magnetic measurements, the longitudinal position of the sensor is typically measured with a resolution of approximately 1 µm. Previous measurement systems accomplished this using a fixed linear encoder scale or a laser interferometer [2, 5].

An alternative method was devised during the design phase of the project using a reel/de-reel type system incorporating a flexible linear encoder scale. The main benefit of this approach is the elimination of a long linear stage, which in this case would be on the order of 5 m long if we were to scan from one end of the cryostat. Now, the system will occupy a small footprint at the ends of the cryostat with the drive components mounted to survey stands, making the measurement system compact and portable.

A computer model of the measurement system installed at the ends of the 4.8-meter long SCU production cryostat is shown in Fig. 2. The spools on the stands are mechanically linked and operate in unison to maintain tension on a linear scale, which gets coiled on one of the spools. The free end of the scale attaches to a carriage that slides inside the guide tube and transports the Hall sensor, see Fig. 3. The horizontal and vertical positions of the Hall sensor are determined by its placement on the carriage and the guide tube position relative to the magnetic gap. Currently, the plan is to use at least one 3-axis Hall sensor from Senis [6], mounted on the carriage near the beam centerline.

Attached to the other side of the carriage is a wire or thread that is coiled up on the spool at the other measurement stand. As the linear scale passes the stationary read head, shown in the inset of Fig. 2, the position of the Hall sensor can be determined.

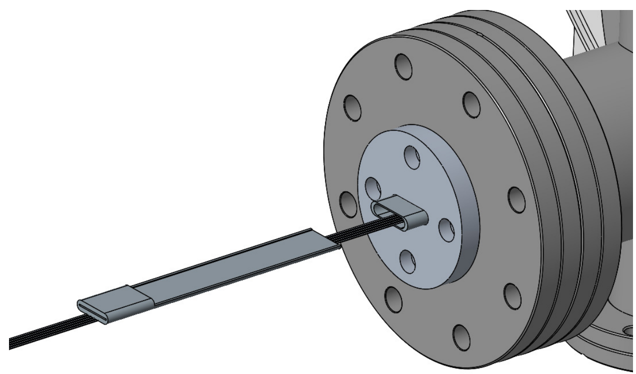

Figure 3: Concept of the Hall sensor carriage that slides within the guide tube.

A non-magnetic scale, made using Inconel 625, combined with a Veratus series read head from Celera Motion [7] is capable of achieving resolutions on the order of 1 µm with a specified accuracy of ±3 µm. The scale is available in lengths up to 30 m and is 6 mm wide with a thickness of 0.2 mm, making it very flexible and capable of being coiled on the spools.

On the end with the encoder read head is a servo motor that uses the linear encoder as position feedback. On the opposite end is a torque motor that maintains a constant torque depending on the voltage applied. As the servo motor releases or draws in the flexible encoder scale, the torque motor automatically follows along while keeping tension relatively constant.

WIRE-BASED MEASUREMENTS

Switching from the Hall sensor-based measurements to wire-based measurements, such as a rotating coil or pulsed wire to determine the field integrals, requires replacing the

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servo and torque motor assemblies with rotary stages, shown in Fig. 4. The rotary stages are mounted to a 3-axis stage assembly to allow for positioning of the wire in the guide tube aperture and horizontal scanning. This 3-axis assembly is also installed during Hall sensor measurements, but not necessary.

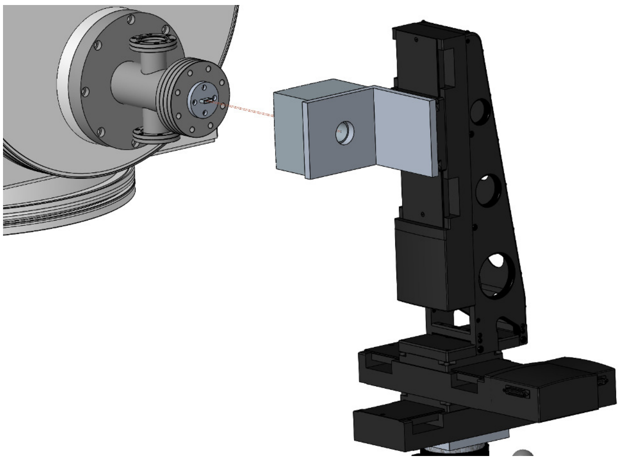

Figure 4: Rotary stage installed on the 3-axis stage assembly for wire-based measurements.

The rotary and linear stages are identical to the current SCU measurement system [2]. A single turn of 100 µm to 150 µm copper beryllium wire will be used to form the coil that is supported by a coil mounting system developed and currently in use at the permanent magnet undulator measurement facility at the APS [8]. Easy adjustment of the coil width, expected to be in the range of 2 mm to 3 mm, is achievable. Also, switching between various coil geometries,such as rectangular, figure-8, and triangular, is straight forward.

CONCLUSION

A new magnetic measurement system for the APSU SCU program is under development that will allow measurements to be made in the production cryostat and under normal operating conditions. Common undulator magnetic measurement techniques, such as Hall sensor field scans and wire-based methods, are capable of being performed. The system is compact, versatile, and-due to the elimination of the need for a long linear stage-portable. Assembly, shown in Fig. 5, and commissioning activities of the system are in progress. Measurement of a fully characterized permanent magnet undulator is planned in order to benchmark the new system before measuring a double SCU in the long cryostat.

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Figure 5: Measurement assemblies including the alignment stands, 3-axis stage assembly, spools, and motors for the Hall sensor. Also pictured is the control rack.

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