DEVELOPMENT STATUS OF A MAGNETIC MEASUREMENT SYSTEM FOR THE APS SUPERCONDUCTING UNDULATOR*

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Abstract

Short-period superconducting undulators (SCUs) are being developed as part of the Advanced Photon Source (APS) upgrade program. The first test device is in fabrication. Before installation into the storage ring, the magnetic performance of the undulators will be characterized. The magnetic measurement facility routinely used for measuring and tuning conventional undulators cannot be employed for superconducting devices, so a new measurement system is being designed and built. The system is mechanically mounted on the undulator cryostat and uses a heated tube in the cold undulator bore to guide a Hall probe or measuring coils. A specially designed three-Hall sensor assembly allows measurement of the vertical and horizontal components of the magnetic field and the determination of the field at the magnetic midplane. A set of measuring coils is mounted on carbon-fiber tubes that can be translated and rotated in the undulator bore to measure the field integrals and their multipole components. The design of the measurement system and its construction status is described in this paper.

PLANAR SUPERCONDUCTING UNDULATORS FOR THE APS

Superconducting technology offers the possibility of building storage ring insertion devices with enhanced performance. A planar superconducting test undulator SCU0 is currently being built at the APS. The description of the device is given in [1,2]. Three more devices, SCU1-SCU3, are planned as a part of the APS upgrade project.

The main parameters of the APS SCUs are listed in Table 1.

Table 1: APS Superconducting Undulators Specification

Electron beam energy	7 GeV
Photon energy at 1st harmonic	20-25 keV
Undulator period	16 mm
Magnetic gap	9.5 mm
Magnetic length	
SCU0	330 mm
SCU1	1140 mm
SCU2, SCU3	≈ 2300 mm
Cryostat length	
SCU0	2063 mm
SCU1	2063 mm
SCU2, SCU3	≈ 3000 mm

The superconducting undulator magnetic structure consists of a top and a bottom jaw with a beam chamber positioned in between. The magnet is surrounded by two radiation shields and is cooled with liquid helium supplied from the buffer tank located inside the cryostat, as shown in Fig. 1.

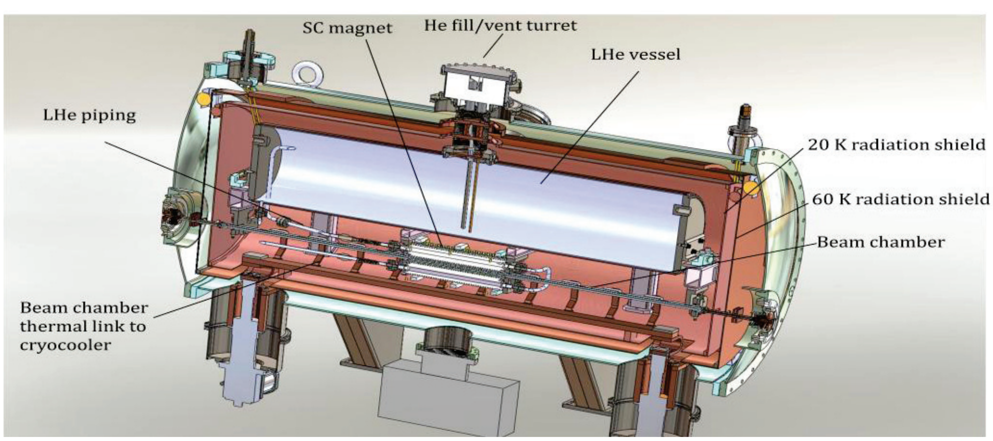

Figure 1: Superconducting undulator internal structure.

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MEASUREMENT SYSTEM REQUIREMENTS

The measurement strategy for the superconducting undulators includes characterization of the magnetic structure by itself in a vertical liquid helium bath cryostat. After the cryomodule is assembled, the undulator performance will be measured with a horizontal measurement system that is described below.

The horizontal measurement system will include:

- A Hall sensor to measure both vertical (B_y) and horizontal (B_x) components of the field along the Z (beam) axis.
- A stretched-wire coil to measure the integrated vertical and the integrated horizontal field. The coil must be able to be scanned ±5 mm in the horizontal X direction, orthogonal to the longitudinal axis, in order to determine the integrated multipole moments.
- A figure-8 coil to measure the second field integral.

In addition, the system must fit inside the SCU beam chamber bore that has a vertical opening of 7.2 mm and a horizontal opening of 53 mm.

WARM GUIDING TUBE APPROACH

During operation of the SCU, the beam chamber is at cryogenic temperatures with a vacuum inside it. Placing the Hall sensors and coils directly in this environment leads to design challenges such as the need to place mechanical drive components inside the vacuum and to provide a means of determining the actual location of the magnetic sensors despite position variation due to thermal contraction of the system components in the cold environment. The change in the sensitivity of the Hall probe with temperature would also be an issue.

An alternative approach has been developed by a team at Budker Institute, Novosibirsk, Russia for measuring superconducting wigglers [3]. In their scheme a Hall sensor is guided through a thin-walled warm tube that is stretched inside the cold bore. The bore of the guiding tube is open at the ends thus giving easy access for the magnetic sensors and measurement coils.

A warm-tube scheme is being adopted for the APS SCU measurement system. Hall sensors and stretched coils are mounted on carbon fiber tubes that are moved inside the guiding tube by an external drive. The titanium guiding tube is heated to room temperature by electrical current and is thermally insulated from the cold beam chamber by vacuum. The dimensions of the beam chamber and a warm guiding tube are shown in Fig. 2.

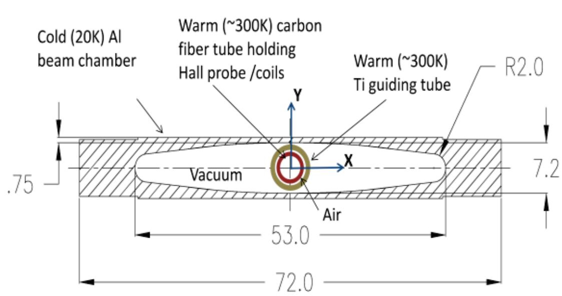

Figure 2: Beam chamber with warm guiding tube.

A possible drawback of this scheme is that the heat load on the superconducting coils might be increased. However, thermal analysis of the setup found that the expected heat transfer by radiation is on the order of 0.9 W. In the SCU, the beam chamber is cooled by two cryocoolers with a total cooling power of 40 W, so the additional heat load from the warm guide tube is relatively small; smaller, in fact, than the few-watt anticipated beam heat load.

HALL SENSORS

Three Hall sensors are packaged into a sensor assembly as shown in Fig. 3. Two horizontal sensors are used for the measurement of the vertical field component. The sensors are separated by a known gap and allow measurement of the field at two points on the vertical axis. One can then determine the value of the field at the magnetic midplane of the undulator provided the vertical field profile is known. This new technique is described in [4,5]. The third, vertical, sensor is used for the measurement of the horizontal component of the field.

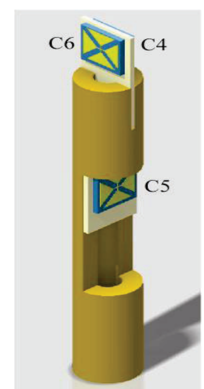

Figure 3: Hall probe assembly.

The Hall probe package is attached to the tip of a carbon fiber tube-holder that can be both moved longitudinally and rotated.

Behavior of Hall sensors at various temperatures has been studied at the APS and is described in [6].

STRETCHED COILS

Measurement coils could also be mounted on a carbon fiber tube and moved or rotated by an external drive. Possible geometries include both the rectangular and the figure-8 coils as illustrated in Fig. 4.

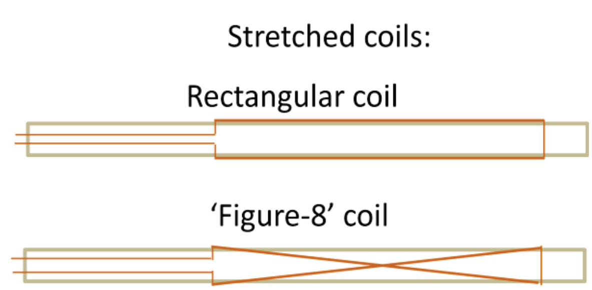

Figure 4: Configurations of the measurement coils.

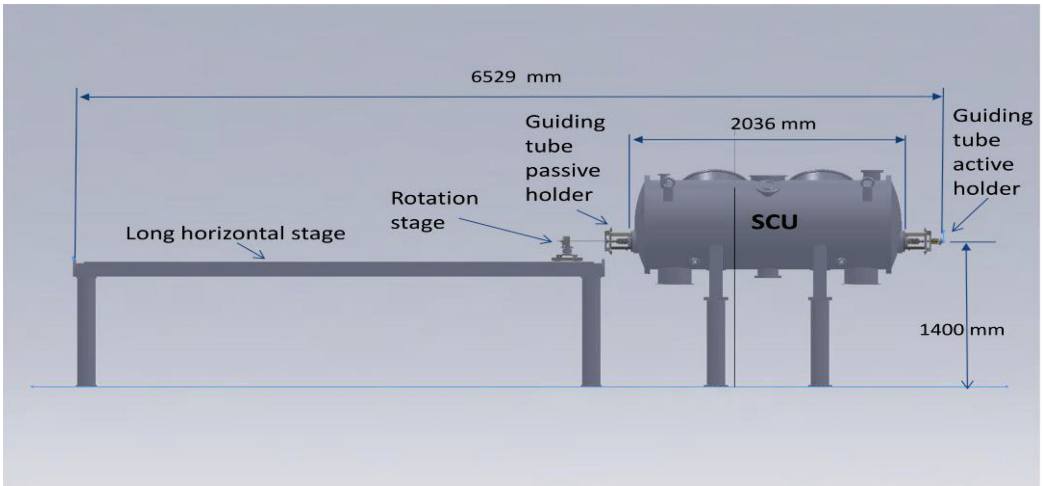

Figure 5: Measurement system layout.

CONCEPTUAL DESIGN

The measurement system conceptual design is the result of a joint effort between teams from the APS and the Budker Institute. It is based on the Budker experience in fabricating similar measurement systems for superconducting wigglers, but incorporates the measurement capabilities required for APS undulators.

The measurement system is designed as an extension to the SCU cryostat with the guiding-tube holders, active and passive, directly attached to the beam chamber flanges as shown in Fig. 5.

The active holder is equipped with a tensioning system that stretches the guiding tube to keep it straight and to help avoid significant contact with the cold beam chamber. In addition, both the active and the passive guiding-tube holders are equipped with horizontal stages that allow lateral (X) displacement of the guiding tube.

The guiding tube is open at both ends. This makes it easy to change the sensor holders so that the holder for the Hall probe assembly can be swapped for a coil holder as measurements move from one technique to another.

Longitudinal movement of the Hall probe holder or the stretched coil holders is provided by a long horizontal stage. A carriage on this stage holds a rotating stage that provides the rotational motion for the Hall probe or stretched-wire coil holder attached to it.

The horizontal stage is equipped with a precise measurement scale that defines the longitudinal position of the magnetic sensors in the cryostat. Since the sensors are moving through the warm guiding tube, any effect of thermal contraction is eliminated.

PROJECT STATUS

The conceptual design of the measurement system is completed and work on the detailed design has been started. We are also working to characterize the Hall sensors and to gain experience in the fabrication of compact stretched coils. The measurement system is scheduled to be ready by early next year.

CONCLUSIONS

A planar superconducting test undulator is currently being built at the APS. It requires a dedicated horizontal measurement system that will use the warm-tube approach developed by the team at the Budker Institute, Russia, for the measurement of superconducting wigglers. The measurement system is currently being designed to satisfy the more demanding measurement requirements for APS undulators. The detailed design is now underway and fabrication is expected to be largely completed this year.

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