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SUPERCONDUCTING UNDULATORS FOR THE ADVANCED PHOTON SOURCE UPGRADE*

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Abstract

The magnetic devices group at the Advanced Photon Source (APS) is in the process of designing and developing superconducting undulators (SCUs) for the APS upgrade. While similar in some aspects to previous SCU systems currently in operation at the existing APS, the new SCU systems will include two undulators installed in one cryostat which occupies an entire straight section of the storage ring. Straight sections containing planar undulators will either be configured as "in-line", where the two undulators behave as one source, or canted, where the two undulators are operated independently. Also under development is a superconducting arbitrary polarizing emitter (SCAPE) that can produce planar, elliptical, and helical undulator fields.

INTRODUCTION

The Advanced Photon Source (APS) is in the midst of preparing to upgrade (APSU) the storage ring to reduce electron beam emittance utilizing a multi-bend achromat lattice while doubling the stored beam current. Combining the upgrade of the storage ring lattice with the selection of high performance undulators, the generated x-rays of the APSU are expected to be two to three orders of magnitude brighter than the APS.

Due to the ability of superconducting undulators (SCUs) to generate higher on-axis magnetic fields than other undulator technologies at a given magnetic gap and period length, the APSU has decided to incorporate SCUs into the project. SCUs have been selected for sectors that need x-rays at higher energies where they are expected to outperform their permanent magnet counterparts [1], see Fig. 1.

Four sectors are being prepared to operate two planar SCU magnets housed in one 4.8-meter long cryostat. One sector will reuse an existing planar SCU in a 2-meter long cryostat. Another sector is planning to operate two superconducting arbitrary polarizing emitters (SCAPE) into one 4.8-meter long cryostat.

Previous experience in designing, fabricating, and operating SCUs at the APS is being leveraged during the preparations for the APSU installations. The design of the planar magnet structure, which serves as the winding mandrel, is being modified to simplify the manufacturing process and the cryostat design is based on the second-generation cryostat developed during the helical SCU project at the APS [2, 3]. Design of the SCAPE magnets is in the early stages and a 0.5-meter long prototype has been constructed and tested.

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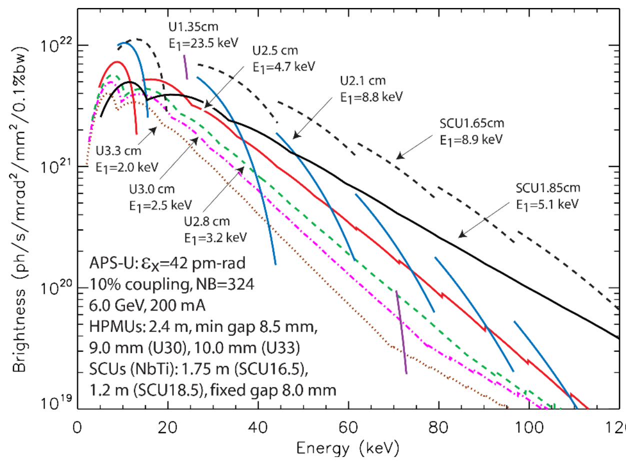

Figure 1: Calculated brightness tuning curves of odd harmonics of most hybrid permanent magnet undulators and SCUs for APS-U.

CRYOSTAT

A cryostat for the SCU magnets is in fabrication and consists of a 4.8-meter long stainless steel vacuum vessel shown in Fig. 2, one thermal radiation shield, and a liquid helium (LHe) tank. The LHe tank is supported through a low-heat-leak suspension system comprised of invar rods and low-thermal-conductivity plastic spacers. The magnets and electron beam vacuum chamber are supported from the underside of the LHe tank and the aluminum electron beam chamber is thermally isolated from the magnets through low-heat-leak stand-offs and a vacuum gap. The aperture of the beam chamber is asymmetric with respect to the magnet center, Fig. 3. This prevents the synchrotron radiation originating from the upstream bending magnet from being absorbed by the cold SCU beam chamber, thereby reducing the heat load on the cryostat.

There are three cooling circuits within the vacuum vessel and the cooling power is provided by up to seven Sumitomo [4] cryocoolers. Five cryocoolers are available, if necessary, to maintain the magnet cooling circuit at 4.2 K and up to two cryocoolers can be used to provide cooling for the aluminum electron beam chamber to maintain the chamber below 20 K and minimize beam-stimulated desorption of gases accumulated on the chamber cold surface. The first stages of all the cryocoolers are connected to the thermal radiation shield and the warm end of the high-temperature superconducting leads. A preliminary thermal analysis has been completed and excess capacity at 4.2 K is expected, which will allow the SCU cryostat to operate without losing LHe inventory.

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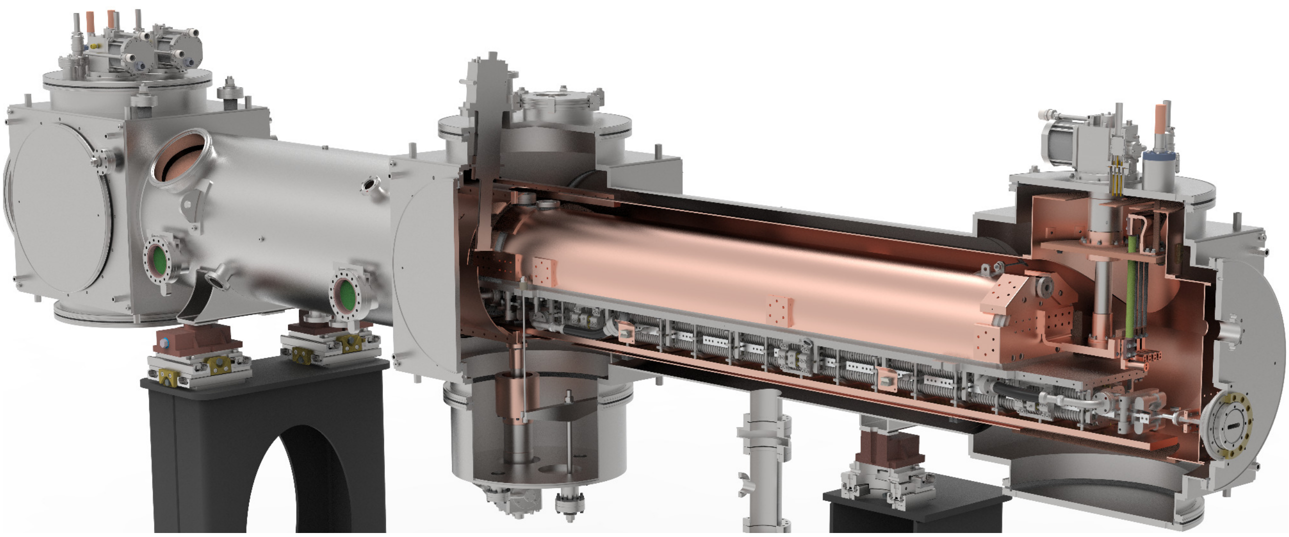

Figure 2: Rendering of the 4.8-meter long SCU cryostat with a portion of the vacuum vessel and thermal shield cut away to expose the cold mass.

It is desirable to have the ability to measure the magnetic field and monitor the alignment of the magnets within the production cryostat and when the system is under normal operating conditions, i.e. under vacuum and at cryogenic temperatures. To achieve this, a new magnetic measurement system is being developed [5] and eight optical windows have been incorporated into the cryostat to perform survey and alignment measurements at any time during operation. Horizontal and vertical displacements of the magnets can be measured through the optical windows using a precision 2D laser scanning tool developed at the APS [6].

MAGNETS

Inside the 4.8-meter long cryostat it is possible to operate two SCU magnets. The maximum length of a single SCU is 1.9-meters. The topology of the SCU magnets for APSU will be either planar or the four-core SCAPE. Of the four sectors scheduled to have two SCU magnets, two will be configured to operate in tandem and two will be operated in a canted configuration with a maximum canting angle of 1 mrad. The magnetic period of the planar structures will either be 16.5 mm or 18.5 mm with a magnetic gap of 8 mm. In the case where the magnets are in a canted configuration, the magnetic length of a single SCU will be shorter than 1.9 m due to the requirement of a canting magnet at the center of the straight section inside the cryostat. The maximum length of the SCAPE magnets has not yet been determined, but the planned periodicity of the magnetic structure is 30 mm.

In all cases, there are plans to include horizontal and vertical field integral correction magnets inside the cryostat, upstream and downstream of each SCU magnet pair. Similar correction magnets have been incorporated into the existing SCUs in operation at the APS. The corrector magnets can be either superconducting or copper-wound magnets.

Planar

The design of the planar magnetic structure is functionally similar to current SCUs in operation at the APS [7], but some modifications have been made to simplify the manufacturing process. Previous SCU designs consisted of a central machined core with slots to install the magnetic poles on the electron beam side and side spacers to create the winding groove. The APSU design consists of a monolithic rectangular core with directly machined winding grooves. Half-round sections are attached to the sides to complete the racetrack winding groove. As with current SCUs, the structure also serves as the winding mandrel and channels are bored through the length of the core to provide a path for LHe to cool the superconducting coils. Stainless piping is used to connect the magnets to the LHe tank and clamps will be used to maintain the uniformity of the magnetic gap to provide a high-quality undulator field [8]. With the exception of the LHe piping, these features and the beam vacuum chamber are shown in Fig. 3.

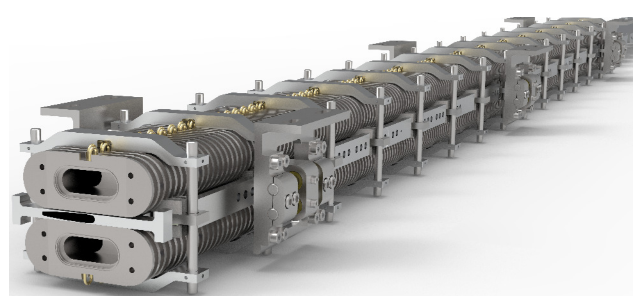

Figure 3: Model of the planar SCU magnetic assembly and beam vacuum chamber.

The magnets will be continuously wound with 0.6 mm diameter Niobium Titanium (NbTi) superconductor from Supercon, Inc. [9] Transitioning the superconductor from one groove to the next will take place on the side opposite

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the poles and will be accomplished by a 180° turn around a brass pin. A full coil pack will consist of 53 turns and the two coil packs at either end will have a reduced number of turns with NbTi trajectory correction coils wound on top of the main coil.

SCAPE

SCAPE consists of four aluminum cores with low carbon steel poles [10]. The four cores are arranged so there are two orthogonal SCUs, vertical and horizontal, situated around a circular beam chamber, see Fig. 4. One SCU, say the horizontal, is shifted by 1/4 period relative to the vertical SCU. This orthogonal and shifted arrangement allows an on-axis field to be generated in an arbitrarily polarizing fashion, e.g. horizontal and vertical SCUs with equal field provide circular polarization.

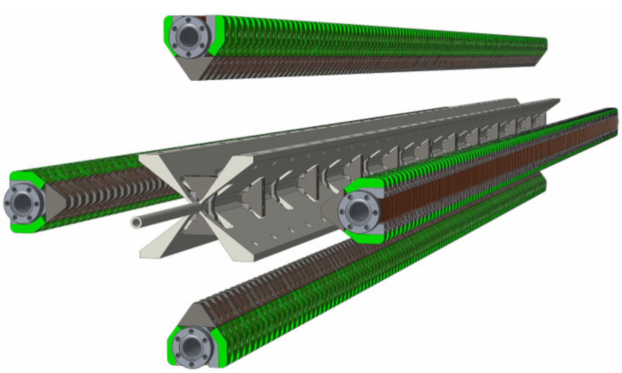

Figure 4: Exploded view of the SCAPE magnet with the beam vacuum chamber [10].

Rather than the racetrack design of the planar SCU, the SCAPE magnet has a winding mandrel, triangular in shape, that allows the magnetic gap to be as small as possible and fit around a circular beam chamber. As with the planar SCUs, the superconducting coils are cooled through cooling channels in the aluminum core, and the main coil consists of a single NbTi conductor. The same turn-around scheme is used to transition from one groove to the next during coil winding. A 0.5-meter long prototype has been constructed and tested in a LHe bath cryostat. Figure 5 is a Hall probe field scan of the prototype in circular mode.

CONCLUSION

Developments of SCUs are progressing at the APS in preparation for the APSU. A 4.8-meter long cryostat is currently in production and expected to be completed during the summer of 2019. Manufacturing of the planar magnetic structures is expected to be complete towards the end of 2019 and progress on the SCAPE design is on-going. Subsystems are also being developed to support magnetic measurements and alignment measurements under normal operating conditions in the production cryostat.

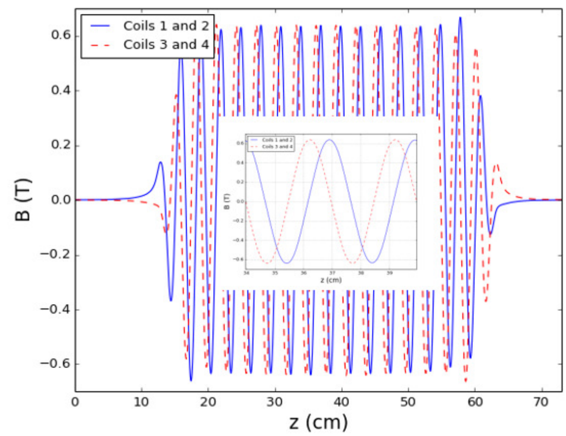

Figure 5: Magnetic measurement of the 0.5-meter long SCAPE prototype in circular mode. Inset is a two period close-up of the data showing the 1/4 period shift between the orthogonal magnets.

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