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DEVELOPMENT AND PERFORMANCE OF 1.1-M LONG SUPERCONDUCTING UNDULATOR AT THE ADVANCED PHOTON SOURCE*

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Abstract

Development of superconducting undulators continues at the Advanced Photon Source (APS). The second superconducting undulator, SCU1, has been built and prepared for installation in the storage ring at the APS. This undulator has a 1.1-m long superconducting magnet and utilizes an improved version of the cryostat of the first superconducting undulator, SCU0. The results of the cold test of the SCU1 are presented in this paper.

INTRODUCTION

Superconducting undulators outperform other undulator technologies in terms of undulator peak field for a given period length and magnetic gap. The higher undulator field lead to higher photon fluxes, especially at higher photon energies. The advantage of superconducting undulator technology has been confirmed at the APS by operational performance of the SCU0. This undulator with a 0.3-m long magnet generates higher photon flux above 80 keV than a 2.4-m long hybrid undulator [1]. The next logical step was to increase the length of the SCU magnet. Such a milestone has been achieved with SCU1 – the second superconducting undulator developed at the APS. This paper gives a short description of the SCU1 and presents the cold test results of the undulator in detail.

SCU1 PARAMETERS

Parameters of SCU1 are listed in Table 1. The period length of 18 mm was chosen to have continuous photon energy coverage above 40 keV. The length of the magnet is 1.1 m – more than 3 times the length of the SCU0 magnet.

Table 1: Main Design Parameters of SCU1

Parameter	Value
Cryostat length, m	2.06
Magnetic length, m	1.1
Undulator period, mm	18
Magnetic gap, mm	9.5
Beam vacuum chamber vertical aperture, mm	7.2
Undulator peak field, T	0.97
Undulator parameter, K	1.63
Photon energy at fundamental, keV	11.7-25

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SCU1 DESIGN

Cryostat

The SCU1 uses a cryostat, which is an improved copy of the SCU0 cryostat [2]. Modifications include the addition of optical windows to the cryostat vacuum vessel that allow direct observation and measurement of the cold mass vertical position inside the cryostat. Also, several thermal links were added to improve cooling of the cold mass support frame. Kevlar strings that support the cold mass in the cryostat have been improved as well.

Magnet

The SCU1 magnet is continuously wound with a superconducting wire onto a low-carbon steel former, or a core (see Fig. 1). The winding scheme is different from the one used in the SCU0 magnet. Instead of first winding all odd grooves and then making a 180-degree turn and winding back all even grooves, the turn is now made after winding each groove. In the new core design, magnetic poles are left only on the face side of the core and the poles on the other sides are non-magnetic. Also, three liquid helium (LHe) channels in the SCU0 design are replaced with a larger diameter single channel in the SCU1 core. As a result of the design simplification, the cost of a 1.1-m SCU1 core is about the same as that of a 0.3-m long SCU0 core. It is worth highlighting that the SCU1 cores were fabricated to a very high level of precision. The measured groove dimensions were within 30 μm rms.

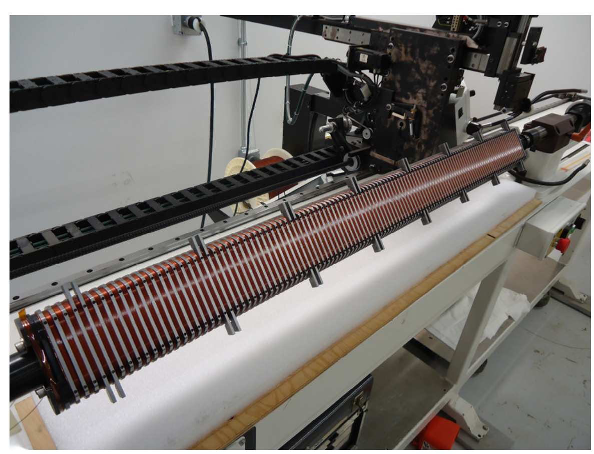

Figure 1: SCU1 magnet core on winding machine.

Similar to SCU0, a commercially available NbTi superconducting round wire is used in the SCU1 magnet, except a wire diameter of 0.6 mm is chosen instead of the 0.7 mm diameter used in the SCU0. The smaller wire size

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reduces the operating current of the magnet and therefore decreases the heat leak through the current leads.

SCU1 COLD TEST

Cryogenic Behaviour

The undulator was cooled down using four two-stage cryocoolers installed into the cryostat. Temperatures recorded during a typical 72-hour cool down are shown in Fig. 2. The undulator is then filled with about 50 litres of LHe.

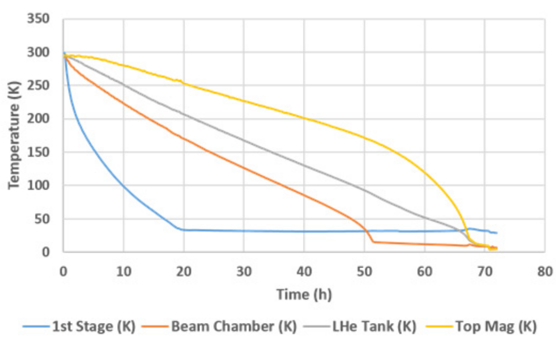

Figure 2: The SCU1 temperatures during cool down.

Electron beam heating was simulated by applying heat to the cold part of the beam chamber using heaters installed on the beam chamber. As expected, the temperature of the beam chamber did increase but the magnet temperature was stable as listed in Table 2. This test demonstrates a good thermal isolation of the superconducting magnet from the beam chamber.

Table 2: Heat Simulation Test

Magnet Current (A)	Beam Chamber Heat (W)	LHe Tank Pressure (Torr)	Magnet Tempe-rature (K)	Beam Chamber Tempe-rature (K)
0	0	760	4.22	7.26
450	0	760	4.22	7.26
450	20	760	4.22	14

As in the SCU0, the cooling power provided by the cryocoolers in the SCU1 exceeds the heat load on the 4-K circuit, thus providing excess cooling power at this thermal stage. To stabilize the pressure in the LHe circuit in this situation, heat is periodically applied to the LHe tank by using a heater mounted on the tank surface. From measuring the duty cycle of this heater and knowing its power, one can calculate the excess cooling capacity at 4 K. The excess cooling capacity is about 400 mW for a static condition when the magnet is not powered, and is about 360 mW with the magnet powered to the designed operating current of 450 A. When heat of 20 W is applied to the beam chamber, the excess cooling capacity reduces to about 280 mW. It should be noted that in the SCU0, which has a similar beam chamber, the measured electron beam heat load on the beam chamber is about 15 W [1].

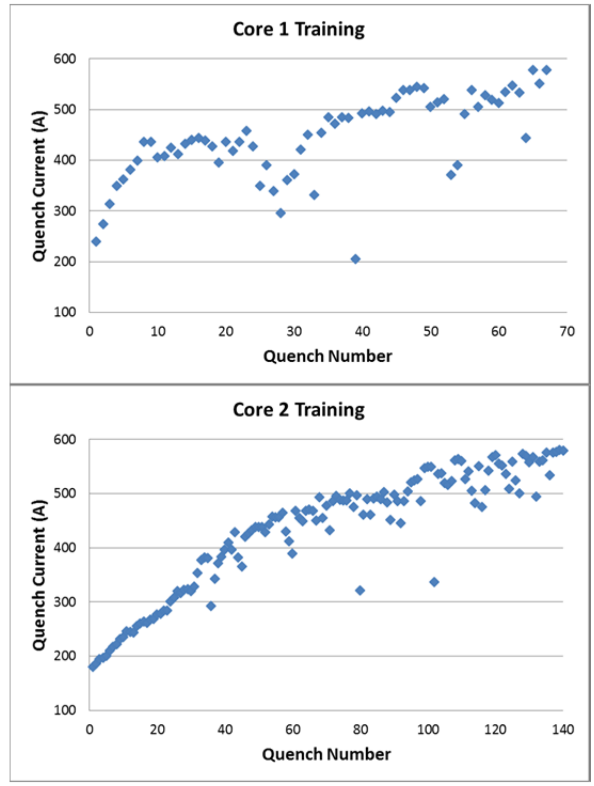

Figure 3: Training history of SCU1 magnet cores.

Magnetic Performance

Before installation into the cryostat, the SCU1 magnet was assembled and tested in a vertical LHe bath cryostat. The goal of this test was to train the magnet and to make preliminary measurements of the magnetic field profile with a Hall probe. The quench currents during training are shown in Fig. 3. It is evident from the data that it required about 70 quenches to train one core and about 140 quenches for training the other core. It should be noted that after installation into the horizontal cryostat, the magnet reached the operation current after only several quenches.

Preliminary magnetic measurements with a Hall probe in the LHe bath cryostat indicated that an unexpected vertical dipole component at a level of a few Gauss existed in the undulator field. To compensate for this undesirable field, a pair of dipole correction coils was added to the magnetic structure. The results of the magnetic measurements shown below were taken with this corrector switched on.

Once the assembly of the SCU1 was completed, the magnetic performance of the undulator was measured with the existing magnetic measurement system that had been previously developed and used for the measurements of the SCU0 [3].

The magnet excitation curve is shown in Fig. 4. At the design current of 450 A the undulator delivers the field of 0.976 T. The max quench current is about 520 A, thus giving a comfortable margin for the device operation.

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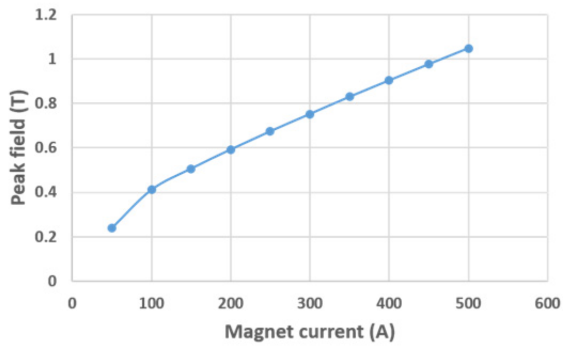

Figure 4: SCU1 magnet excitation curve.

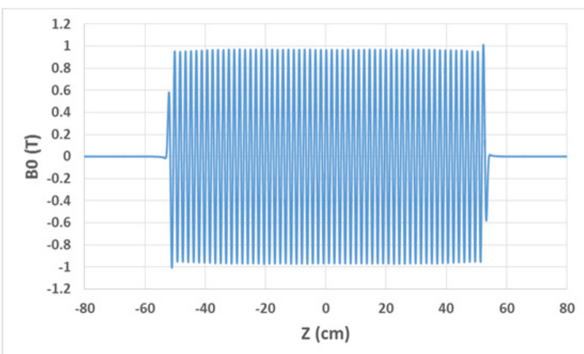

Figure 5: Measured field profile at design current of 450A.

The undulator's vertical magnetic field was measured with a moving Hall probe. A typical field profile is shown in Fig. 5. The Hall probe data was used to calculate the phase errors shown in Fig. 6. At the design current of 450 A, the measured phase error is about 5.3 deg. rms.

The first and second field integrals were measured with stretched wire coils. The first field integrals varied between -25 G-cm and -40 G-cm for the magnet current in the range of 50-500 A, while the second field integrals varied between 12000 G-cm^2 and 42000 G-cm^2. The measured field integrals are well within the specifications.

Dynamic behaviour of the field integrals was measured during quenches triggered by heaters mounted on the magnet cores. The first vertical field integral during such a quench is shown in Fig. 7 together with the main coil and corrector currents.

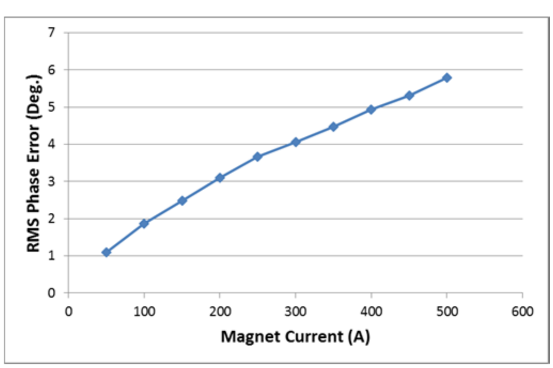

Figure 6: Measured phase errors.

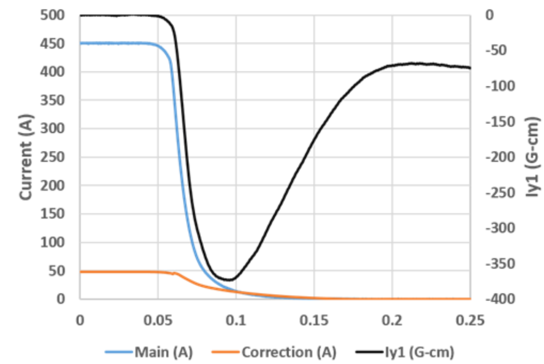

Figure 7: Change of the SCU1 magnet currents and the first vertical field integral during magnet quench.

CONCLUSION

A second superconducting undulator, SCU1, was built at the APS. This device contains a 1.1-m long superconducting undulator magnet in a SCU0-type 2-m long cryostat. The undulator has successfully passed a stand-alone cold test and is ready for installation into the APS storage ring.

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