

STATUS OF R&D ON A SUPERCONDUCTING UNDULATOR FOR THE APS*

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Abstract

An extensive R&D program is underway at the Advanced Photon Source (APS) with the aim of developing a technology capable of building a 2.4-m-long superconducting planar undulator for APS users. The initial phase of the project concentrates on using a NbTi superconductor and includes magnetic modeling, development of manufacturing techniques for the undulator magnet, and design and test of short prototypes. The current status of the R&D phase of the project is described in this paper.

INTRODUCTION

The importance of developing superconducting short-period undulators has been highlighted in a white paper "Science and technology of future light sources" [1].

The APS Magnetic Devices Group is developing a planar superconducting undulator (SCU) for the APS users. Superconducting technology can open the way to shorter-period undulators; the present focus is on a period length of about 16 mm, half the period length of the APS 'conventional' undulator A [2]. Reduced undulator period length is an attractive option for APS users seeking high brilliance at higher photon energies (20-25 keV at first harmonic).

Despite the opportunities offered by the higher critical current density of a Nb₃Sn superconductor, we have chosen to pursue a NbTi-based undulator for now. During the past few years, undulator tests using Nb₃Sn at Berkeley [3], National High Magnetic Field Laboratory [4], and the APS [5] have shown that a Nb₃Sn-based undulator is viable in principle. However, the remaining technological challenges prompted our choice of NbTi for the first superconducting undulator at APS. We intend to return to a Nb₃Sn superconductor in the future.

APS SUPERCONDUCTING UNDULATOR PARAMETERS

Parameters of the APS superconducting undulator are summarized in Table 1. The magnetic length of standard APS undulators is 2400 mm; the first SCU may have a reduced length of 1200 mm.

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Table 1: APS Superconducting Undulator Specifications

Electron beam energy	7 GeV
Photon energy at 1 st harmonic	20-25 keV
Undulator period	16 mm
Magnetic length	1200 mm or 2400 mm
Maximum cryostat length	3500 mm
Beam stay-clear dimensions	7 mm vertical × 36 mm horizontal
Magnetic gap	9 mm

SUPERCONDUCTING UNDULATOR LAYOUT

The magnetic field in the SCU is created by a pair of superconducting magnets separated by a gap where a beam chamber is accommodated. Each magnet consists of two sets of racetrack-shaped coils connected in series with currents in opposite directions in adjacent coil windings. A layout of the SCU magnet is shown in Fig. 1.

The conceptual design of the SCU will be developed after completion of the R&D phase of the project and will include design of the cold mass, support structure, cooling circuit, power circuit, and vacuum tank, as well as control and protection systems, and a plan for installation into the APS ring.

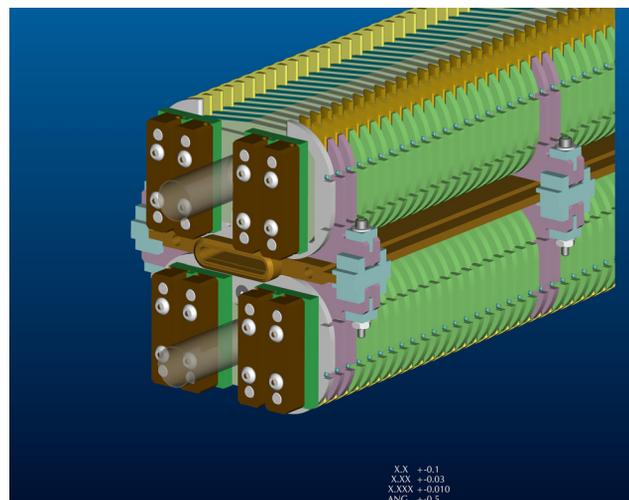


Figure 1: Magnetic structure layout of the APS superconducting undulator.

SUPERCONDUCTING UNDULATOR R&D

Goal of the R&D Phase

The R&D effort aimed at developing construction techniques for superconducting planar undulators up to 4 meters long intensified in 2008. This program involves magnetic modeling, developing manufacturing techniques, building and testing short prototype magnets, and thermal tests of possible cooling schemes.

Magnetic Modeling

Magnetic modeling is performed using Vector Fields' 2d and 3d OPERA software packages. The issues addressed are the field profile and the peak field value, design of the magnet ends including correction coils, and calculation of the load line of the superconductor. The results are discussed in detail in [6].

Manufacturing Techniques

The manufacture of superconducting undulators is a substantial challenge as it requires precise winding on precisely machined formers. Therefore the development of manufacturing techniques is an essential part of the R&D program. Magnet formers must be built to a precision of better than 50 μm over a length of 1.2 m and possibly 2.4 m. After careful winding, the coil must be impregnated with a high quality coil resin. A number of short prototypes were built in the course of developing these manufacturing techniques, starting with coils about 100 mm in length (10-pole prototypes) and then moving to lengths of about 330 mm (42-pole coils).

Thermal Tests

The cooling of superconducting coils can be done in various ways including bath cooling, passing a cryogen through a channel in the magnet core, or using a cryocooler either to recondense a cryogen vapor or in a cryogen-free scheme. We are performing thermal tests to investigate temperature distribution across a superconducting coil for various options of cooling. Thermal test results will be used to choose a cooling scheme for the superconducting coils and for a beam chamber, and to later design a cooling circuit for the SCU.

SHORT UNDULATOR PROTOTYPES

10-pole Prototypes

A number of short prototypes that have ten magnetic poles have been manufactured and some of them tested. The first five 10-pole prototypes built are shown in Fig. 2.

Both soft steel and aluminum were used to manufacture test coils. A 0.75-mm superconducting round wire by Supercon was chosen for the SCU. The number of turns in



Figure 2: The first five 10-pole test coils.

a single winding is 39 with reduced numbers of turns at the ends. Two coils, one made of iron and another with Al core and poles, were tested in liquid helium. The field profile, measured with a Hall probe at a distance of 3.4 mm from the surface of the poles, is shown in Fig. 3 for both coils. The effect of iron in enhancing the peak field is clearly seen. The training curve for the iron-core coil is shown in Fig. 4.

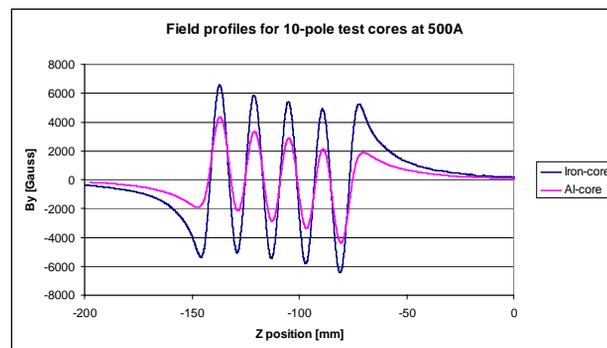


Figure 3: Field profiles for 10-pole iron-core and Al-core test coils taken at a distance of 3.4 mm from the pole surface.

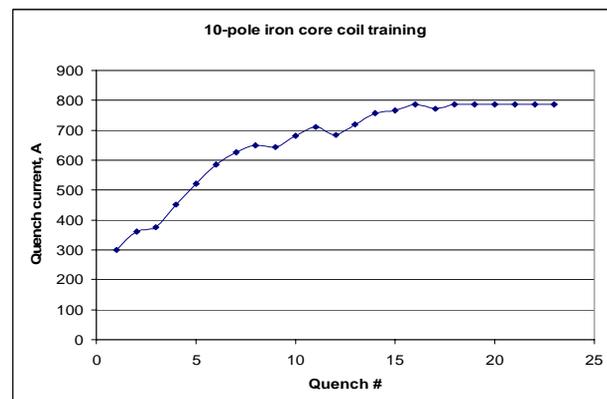


Figure 4: Training curve for 10-pole iron-core test coil.

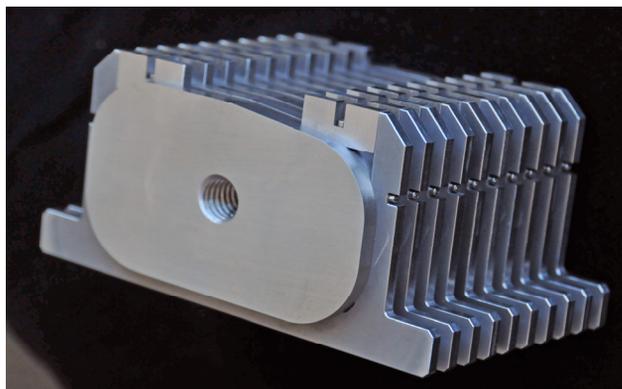


Figure 5: A 10-pole prototype manufactured using an Al core and the assembled technique.

Another three short coils made of Al were used for epoxy-impregnation tests and for developing the resin impregnation technique.

42-pole Prototypes

After successful testing of the 10-pole coils, we designed and built a pair of 42-pole prototype magnets, each equipped with correction coils at the ends. While the 10-pole prototypes were machined out of a single block of material, the longer coils were assembled. Individual pole elements were positioned in grooves cut into a continuous central core. This technique was proven first on a 10-pole piece, shown in Fig. 5. This method can open a way of combining different materials in a magnet former, such as combining an Al core piece with inserted soft iron poles. Another possibility is to combine magnetic and non-magnetic poles so as to lead to a quasi-periodic superconducting undulator as discussed in [7].

A pair of 42-pole coils with an iron core and iron poles was built in this way. After assembly the geometry of the formers was measured; a precision in the groove width of 9 μm rms and in the groove depth of 7 μm rms was achieved. The coil winding onto these formers was performed on a specially built winding machine, and one of the wound coils is shown in Fig. 6. These magnets will be tested soon in liquid helium in a vertical test cryostat. Another pair of magnets with an Al core and iron poles is being built.

CONCLUSION

An extensive R&D program is underway at the Advanced Photon Source to develop the technology for producing superconducting planar undulators. A number of 10-pole and 42-pole prototypes were built and successfully tested. The R&D phase of the project will be followed by a conceptual design of the first full-scale device, which will be built in the next two years.



Figure 6: A 42-pole test coil wound on an assembled iron-core with iron poles.

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