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MEASUREMENT RESULTS OF THE FIRST SCAPE PROTOTYPE*

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Abstract

The SCAPE (SuperConducting Arbitrarily Polarizing Emitter) undulator is under development at the Advanced Photon Source (APS) as a part of the APS upgrade. SCAPE is comprised of four superconducting magnets which are arranged to create an on-axis undulator field that can be planar, elliptical, or circular. As a first step towards developing a full length device, a 0.5-meter long prototype was manufactured and assembled for testing in a liquid helium bath cryostat. A description of the mechanical assembly and subsequent measurement results of the first prototype will be presented in this paper.

INTRODUCTION

Diffraction limited storage rings allow for the use of round beam chambers in straight sections where insertion devices are installed. The round beam chambers with a small aperture provide an opportunity for implementing magnet arrays to form a unique and flexible type of undulator, SCAPE (SuperConducting Arbitrarily Polarizing Emitter).

SCAPE [1] consists of four superconducting magnets which are arranged such that they form a vertical planar and horizontal planar undulator, see Fig. 1. A small round beam chamber allows the magnetic gap of the vertical pair of magnets to be the same as the horizontal pair. If one pair is shifted longitudinally by 1/4 period relative to the other then various types of undulator fields can be generated easily by changing the current in each pair, i.e. planar, elliptical, and circular.

As a first step towards demonstrating the capabilities of a SCAPE style undulator, a short prototype was manufactured and tested in a liquid Helium (LHe) bath cryostat.

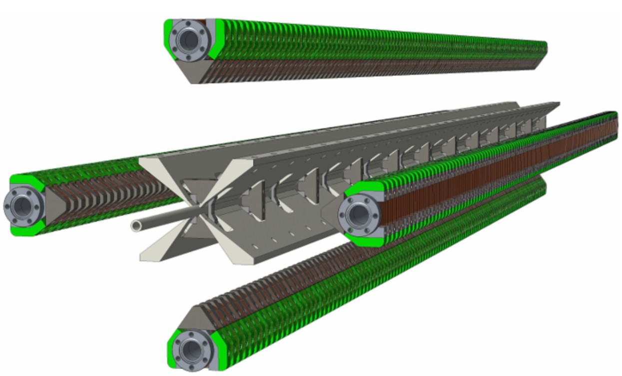

Figure 1: Exploded view of the SCAPE magnet with the beam vacuum chamber [1].

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CORE DESIGN AND COIL WINDING

The main body of the core is extruded from aluminum in a triangular shape with a round bore through the center to provide a LHe cooling channel in the operational cryostat. Grooves for winding the NbTi superconducting coils are defined by steel poles that are bolted to the core and G10 blocks that are pinned to the core sides. On the side opposite the steel pole tips are standoffs which are integral to the aluminum core and provide a means to bolt the core to a strong-back in the four-core assembly. The strong-back also serves as one side of the epoxy impregnation mold after the completion of winding.

During winding, brass pins are used to transition the conductor from one groove to the next while changing the winding direction. There are 9 layers of conductor in a coil pack with 10 turns in the odd numbered layers and 9 turns in the even numbered layers for a total of 86 turns in a full coil pack. A reduced number of turns are wound in the last two grooves, 29 turns in the last groove and 56 turns in the 2nd to last groove, to gradually reduce the magnetic field. Figure 2 shows one of the cores on the winding machine during the winding process. Many of the features implemented in this design were adapted from planar superconducting undulators developed at the Advanced Photon Source [2].

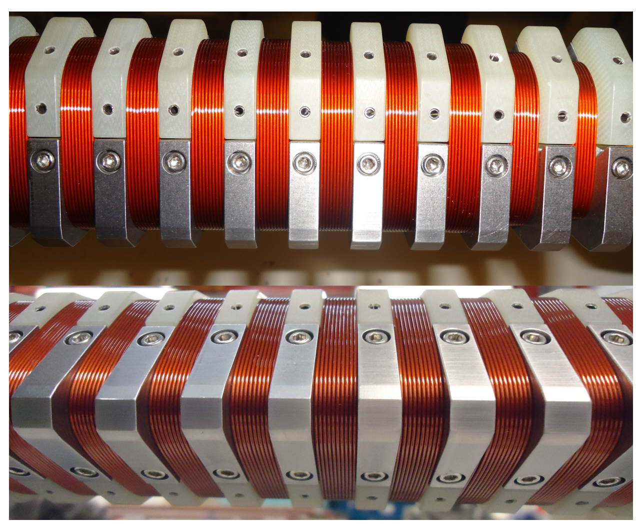

Figure 2: Core features and coil winding of the SCAPE prototype. The top photo is the side of the core showing the G10 side spacers and the reduced number of turns in the last two coil packs. The bottom photo is the pole side of the core.

Four cores were manufactured, wound, and impregnated at the APS. They were assembled into the SCAPE configuration and prepared for testing. Details of the undulator and coil are shown in Table 1.

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Table 1: SCAPE Prototype Parameters

Parameter	Unit	Value
Period	mm	30
Periods	N	16.5
Magnetic gap	mm	10
Cond. diameter	mm	0.7
Full coil turns	N	86
Max current	A	675
Operating current	A	540

TEST SETUP AND MEASUREMENT RESULTS

Assembly of the four cores is accomplished by bolting the strong-backs together to form the two orthogonal pairs of planar undulators. The strong-backs have machined features that allow the cores to be precisely located to define the magnetic gap and shift one pair by 1/4 period. The photo on the left in Fig. 3 shows the four cores assembled with the vertical and horizontal pairs highlighted.

Once the assembly is complete it is integrated into a fixture for testing in the LHe bath cryostat. The coils are instrumented for voltage measurements during coil training and inductance measurements. A guide tube is installed in the magnetic gap to allow for field mapping using a Hall sensor. Coils 1 and 2 were wired in series and coils 3 and 4 were wired in series inside the cryostat. The vertical test assembly is shown in Fig. 3.

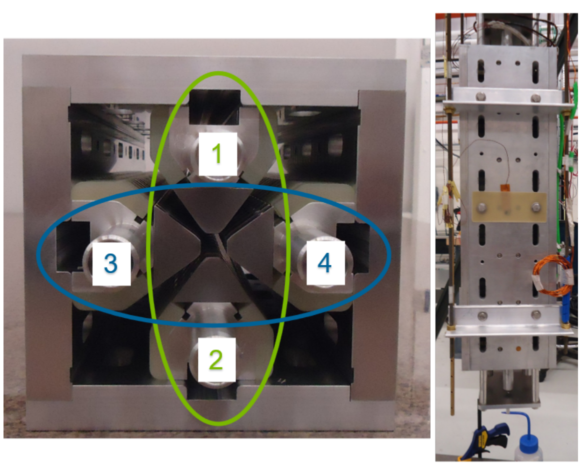

Figure 3: Left: SCAPE assembly of four cores. Right: Assembly being prepared for installation in the LHe bath cryostat.

Measurement Results

Testing began with coil training of each pair. This consisted of ramping the current until one of the coils in the pair transitions and is no longer superconducting or quenches. This is repeated until the training plateaus. Coil pair 1 and 2 were trained up to the maximum current of approximately 675 A which was attained around the 20th training quench. Their training profiles, shown in Fig. 4, were very similar and the operating current of 540 A was reached after the 5th quench. Training of coil pair 3 and 4 was attempted next and it was found that the pair was limited to 403 A after the first quench. The reason for the current limit was due to coil 4 being exposed to excessive heat during an oven malfunction during the cure cycle of the epoxy impregnation process.

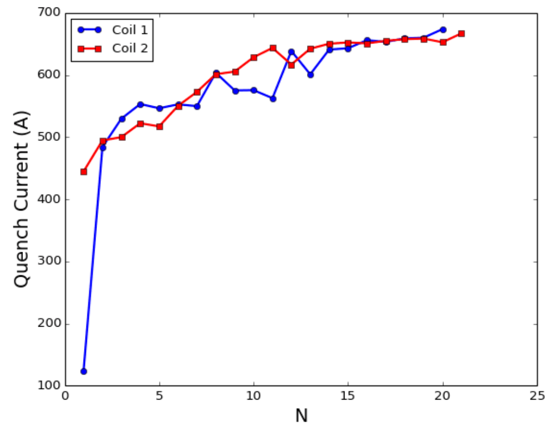

Figure 4: Coil training of coil pair 1 and 2 of the SCAPE prototype.

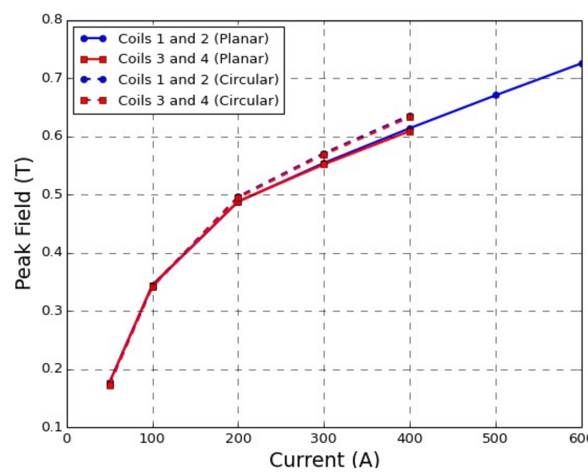

Figure 5: Excitation curves of the SCAPE prototype in planar mode and circular mode. Coil pair 3 and 4 was current limited.

Magnetic measurement data from field scans were still able to be collected even though coil 4 limited energizing the pair to 400 A. Coils 1 and 2 were energized and field scans were performed up to a current of 600 A in planar mode. Coils 3 and 4 were energized separately up to 400 A. After collecting data in planar mode all four coils were powered in series to measure the field in circular mode. It should be noted that left and right circular mode are possible by simply switching the polarity of one of the coil pairs. Also, elliptical mode is achieved by operating the coil pairs with different currents. The excitation curve of planar and circular modes is shown in Fig. 5.

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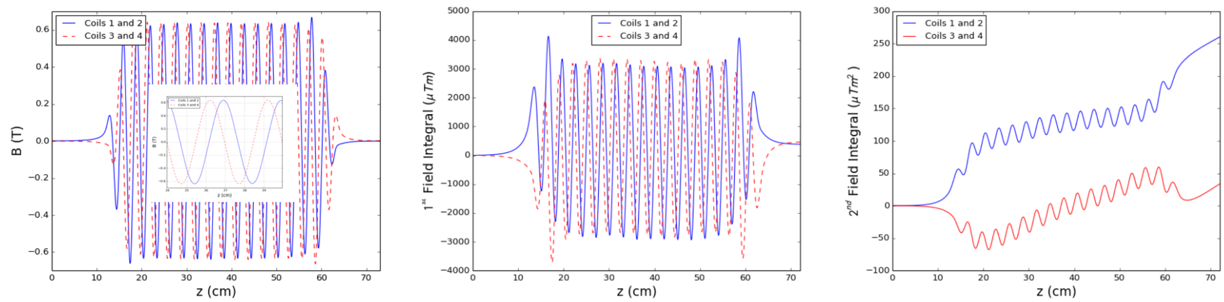

Figure 6: Orthogonal field scan data with SCAPE powered in circular mode at 400 A.

It can be observed that the magnitude of the field is slightly greater when SCAPE is operated in circular mode. One likely explanation is that in planar mode, where only one coil pair is energized, the poles which are not energized redistribute the flux in a manner that slightly reduces the on-axis field.

Figure 6 shows the magnetic field data from two orthogonal scans along with the 1st and 2nd field integrals. The inset shows the phase difference between the two scans and analysis suggests that the two magnets are shifted by roughly 1/4 period. Comparing the locations of the field peaks reveals that there is an error of about 200 µm in the shift.

Magnetic Simulations

Magnetic simulations of the SCAPE coil geometry were performed using Radia [3]. The geometry as-built was simulated along with a model that added two layers to a full coil pack, increasing the number of turns from 86 to 105. The as-built model and measured data are compared in Fig. 7. Increasing the number of turns yields an increase in on-axis field of about 20 %, according to the model. Comparison of the 105 turn model to the measured data is shown in Fig. 8.

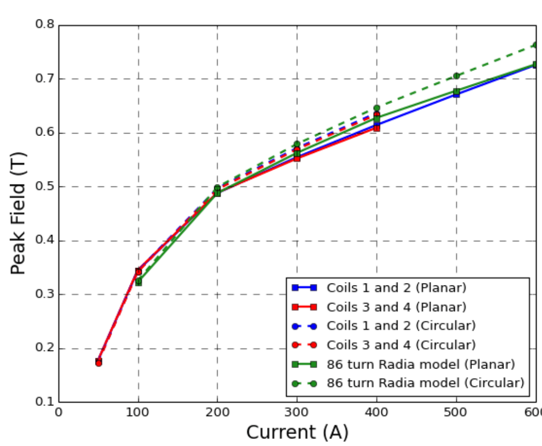

Figure 7: Plots of the 86 turn Radia model excitation curves along with the measured data.

CONCLUSION

A short prototype SCAPE device was manufactured, assembled, and tested in a LHe bath cryostat. Different modes of undulator operation were successfully demonstrated and the results were in agreement with magnetic modelling. Future SCAPE geometries will allow for an increase in the number of turns resulting in an increase of the on-axis magnetic field.

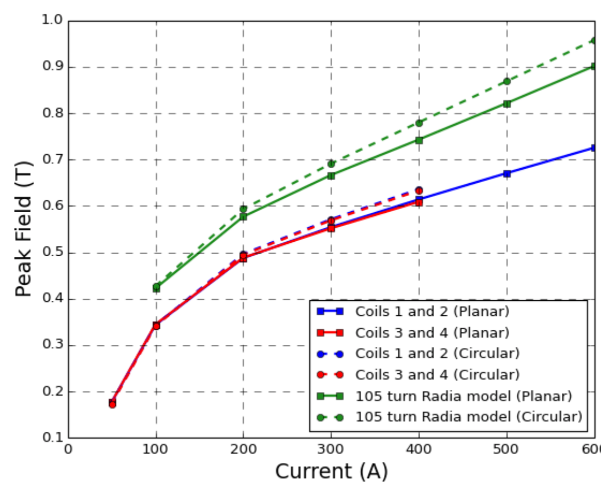

Figure 8: Plots of the 105 turn Radia model excitation curves along with the measured data.

ACKNOWLEDGEMENTS

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