# STATUS OF THE UK SUPERCONDUCTING PLANAR UNDULATOR PROJECT

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*Abstract*

The UK is developing a short period, narrow aperture, planar superconducting undulator that is planned to be installed and tested in the 3 GeV Diamond Light Source. This paper will describe the main parameters of the undulator and the key design choices that have been made. First measurements will be presented of a 19 period test module and also the status of the 1.8 K cryogenic turret.

## INTRODUCTION

Superconducting undulators promise higher peak fields on axis than any other magnet technology but they are still not a mainstream solution for 3rd or 4th generation light sources. A team within the UK is collaborating on developing the design of a short period, narrow aperture, planar superconducting undulator that is planned to be installed and tested in the 3 GeV Diamond Light Source (DLS) [1]. This paper will describe the main parameters of the planar undulator and the key design choices that have been made. Recent progress is then described on the manufacture and testing of a single 19 period magnet array and the cryogenic system.

## PARAMETERS

The key parameters of the planar undulator have been developed in collaboration with DLS to ensure that the prototype will be compatible with installation into that facility with little disruption to the existing operational performance. In particular the magnet gap has been determined by ensuring that the new fixed gap aperture set by the undulator is equivalent to the existing lowest fixed gap aperture currently installed. The current limiting fixed gap vertical aperture is 8 mm over a 5 m long straight section. Scaling this down for a 2 m long magnet installed in the centre of a 5 m straight defines the vertical aperture to be 5.4 mm. This should ensure that the impact on the operation of DLS is negligible in terms of reduced aperture to the electron beam.

To select the undulator period and field strength a number of criteria were considered. These included:

- Maximising the flux and brightness at high photon energies (25 and 40 keV)
- Minimising the undulator harmonic number at these high photon energies
- The requirement to provide continuous tunability from the manganese K-edge at 6.49 keV and above.

The selected optimum undulator parameters are summarised in Table 1. It is estimated that if these parameters are achieved the beamline end station will receive an increase in flux of ~15 times and brightness of ~20 times at 40 keV when compared to their current in-vacuum undulator.

Table 1: Main Undulator Parameters

| | | |
|---|---|---|
| Magnet Length | 2.0 | m |
| Period | 15.5 | mm |
| Peak Field on Axis | 1.266 | T |
| Undulator K Parameter | 1.83 | |
| Required Phase Error | <3 | ° |
| Magnet Pole Gap | 7.4 | mm |
| Vertical Beam Aperture | 5.4 | mm |
| SC Wire Dimensions (measured) | 0.76 x 0.37 | mm |
| Current Density | 1530 | $A/mm^2$ |
| Operating Current | 430 | A |
| SC Material | NbTi | |
| Cu:SC Ratio (measured) | 0.87:1 | |
| Peak Field in the SC | 3.3 | T |
| Turns per Layer | 6 | |
| Number of Layers | 11 | |
| Magnet Operating Temperature | 1.8 | K |
| Beam Tube Temperature | 12 – 16 | K |

## DESIGN CHOICES

Despite the clear advantages of superconducting technology in the generation of very high magnetic fields, the generation of a relatively modest field (1.266 T) in a magnet with 15.5 mm period and magnet pole gap of 7.4 mm using this technology is extremely challenging. The SC material must be operated close to the quench limit to achieve these fields, leaving little safety margin. We have made a number of design choices in order to try




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to ensure that the undulator will achieve the design field whilst simultaneously maximising the safety margin.

The first design choice we have made is to provide an intermediate temperature (12 to 16 K) vacuum vessel for the electron beam. This vessel will be able to cope with the anticipated beam heating due to resistive wall wakefields and any uncollimated synchrotron radiation from the upstream dipole. This vessel will be thermally isolated from the undulator magnet with no direct points of contact allowed. A major consequence of this choice is that a full allowance of 2 mm is needed between the vertical beam aperture and the magnet pole gap to provide space for the vacuum vessel walls and thermally isolating vacuum gap.

The second design choice is that we aim to construct the magnet to within very challenging engineering tolerances in order to remove any requirement for magnet shimming. Numerous shimming proposals have been made for similar superconducting undulators but they all tend to have a negative impact in terms of reducing the peak field on axis or adding substantial complexity to the cryomodule. We have carefully assessed the engineering tolerances which are required in order to maintain the phase error to within ~3° and we have based our design on achieving these values.

The third design choice we have made is to operate the magnet itself at 1.8 K rather than the more usual 4.2 K. This reduction in temperature provides significant extra safety margin but simultaneously makes the cryogenic system more complex. The magnet will be stand-alone cryogenically, with all the cooling being provided by a number of dedicated cryocoolers. In order to demonstrate that 1.8 K can be achieved and maintained we have fabricated the cryogenic system of the undulator cryomodule offline already, with a dummy load to represent the undulator. Full cryogenic testing of this system has just started.

## MAGNET PROTOTYPE

Manufacturing a full 2 m solid magnet former to the tolerances required is at or beyond the limits of existing engineering capabilities and so, alternatively, shorter former sections will be machined from 1006 magnetic steel and separately wound and potted before being positioned and aligned onto a 2 m long structural I-beam, relative to an external datum, using an optical-style mounting system. Each magnet section is placed on height-adjustable screw jacks at 3 corners and, using a laser level, will be manipulated until parallel with the datum plane as required. The whole assembly will then be hung from the outer cryostat using adjustable rods; these create externally measureable reference points with which the position of the magnet can be determined and thus aligned to the beamline.

A ~300 mm long prototype magnet former has been machined and measured to confirm that the tight engineering tolerances have been achieved. This former has subsequently been wound and potted and is now undergoing a series of magnet tests in a vertical cryostat at 4.2 K to verify its performance (Figures 1 and 2). The current in the magnet so far has been increased from 0 to 260 A with a longitudinal magnetic field profile being recorded by a Hall probe at several intermediate currents. The current will continue to be increased until the quench limit is attained.

Two pre-production arrays will be manufactured, wound, potted, and magnetically tested next. Lessons learnt from the first prototype, particularly concerning the insulation and potting process, will be incorporated into these magnets. If they perform to specification they will be used in the final magnet assembly.

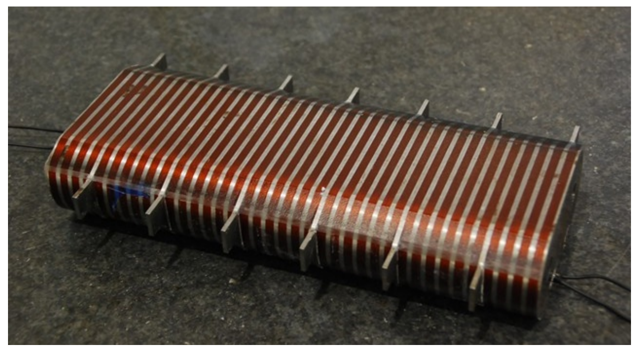

Figure 1: Fully wound and potted magnet array awaiting magnet tests.

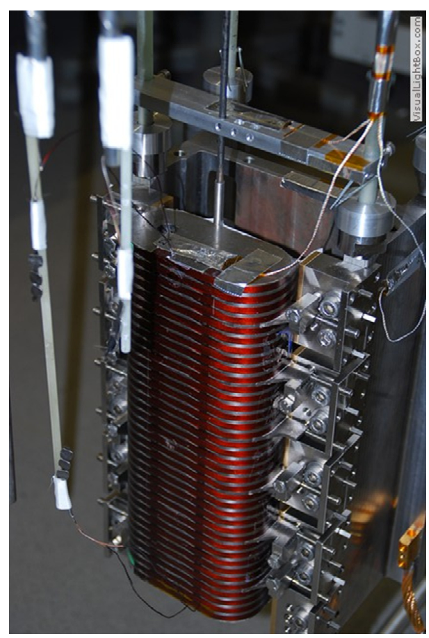

Figure 2: Magnet array mounted vertically for 4.2 K magnet tests.

## CRYOGENIC SYSTEM

The cryogenic design for the superconducting undulator is based on the use of closed cycle refrigerators. In order to achieve the required critical current from the superconductor the magnet temperature needs to be 1.8 K. This is achieved by using a continuous flow cryostat in the central turret. A series of heat exchangers, linked to the refrigeration stages, returns the circulating helium to the bath where it is expanded through a JT valve. For the temperature specification 16 mbar will be required on the effluent side of the helium expansion. In order to meet the heat loads a minimum helium flow of 10 mg/s is required – this corresponds to a STP flow of about 3.4 litres/min. This circulation will be provided by a Leybold SC30D scroll pump. Cooling pipes through the undulator deliver the liquid helium to the cold mass of the magnet. The main two stage refrigerator also provides intermediate cooling for the High Temperature Superconducting (HTS) current leads. The design allows for the turret and 1.8 K continuous flow cryostat system to be tested off the main undulator cryostat prior to final integration.

The beam tube will be operated at 12 to 16 K – at this temperature the maximum residual resistance ratio for the material is achieved and there is little benefit in cooling to lower temperatures. The load on the beam tube is dominated by the wakefield heating from the beam and this was originally estimated to be up to 40 W. However, initial results from the COLDDIAG experiment on DLS suggest this may be an underestimate [1]. Cooling of the beam tube is currently achieved by the use of two closed cycle refrigerators (Sumitomo SRD415) one at each end of the undulator. The first stage of these refrigerators also cools the ends of the 55 K radiation shields. The beam tube also partly acts as a thermal radiation shield for the magnet system. Should the wakefield heating estimate need to be revised upwards it is possible to install a third closed cycle refrigerator.

The current leads will be composed of copper from room temperature to 55 K and then HTS from 55 K to 4 K. From there NbTi will be used into the main coil. The heat load on the two-stage cryocooler in the turret is dominated by the heat leak down the current leads – this will be approximately 34 W.

The complete cryogenic turret assembly and dummy heat load have been manufactured and assembled in parallel to the magnet prototype and commissioning of this system has just commenced (Figure 3). This will enable the challenging cryogenic system to be fully commissioned offline to confirm its performance prior to the complete assembly of the final undulator magnet, significantly reducing the project risks in this area.

Figure 3: Cryogenic turret assembly prior to testing.

## SUMMARY

A collaboration in the UK between STFC and DLS is working on the design of a very challenging superconducting undulator. The magnet parameters have been selected to maximise the performance of the undulator in terms of flux and brightness from below 6.5 keV to 40 keV.

A first complete winding of one ~300 mm section has been successfully fabricated and this is now undergoing magnet tests. In parallel, the 1.8 K cryogenic system has been assembled and offline tests have commenced.

Two pre-production magnets will be manufactured shortly to confirm the final design solution. If these both perform to specification they will be incorporated into the final magnet, which requires fourteen such magnets to complete the 2 m undulator.

## REFERENCES

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