

# CONSTRUCTION OF A FULL SCALE SUPERCONDUCTING UNDULATOR MODULE FOR THE INTERNATIONAL LINEAR COLLIDER POSITRON SOURCE\*

J.A. Clarke<sup>1,2,3</sup>, I.R. Bailey<sup>2,3</sup>, E. Baynham<sup>4</sup>, T.W. Bradshaw<sup>4</sup>, A. Brummitt<sup>4</sup>, A. Bungau<sup>2,5</sup>, F.S. Carr<sup>4</sup>, N.A. Collomb<sup>1</sup>, J. Dainton<sup>2,3</sup>, A.F. Hartin<sup>6</sup>, S. Hesselbach<sup>7</sup>, K.M. Hock<sup>2,3</sup>, Y. Ivanyushenkov<sup>8</sup>, L.J. Jenner<sup>2,3</sup>, A. Lintern<sup>4</sup>, O.B. Malyshev<sup>1,2</sup>, L.I. Malysheva<sup>2,3</sup>, G.A. Moortgat-Pick<sup>2,7</sup>, J. Rochford<sup>4</sup>, N.C. Ryder<sup>1,2,9</sup>, D.J. Scott<sup>1,2</sup>, B.J.A. Shepherd<sup>1,2</sup>, L. Zang<sup>2,3</sup>.

<sup>1</sup> STFC Daresbury Laboratory, Warrington, UK

<sup>2</sup> Cockcroft Institute, Daresbury Science and Innovation Campus, Warrington, UK

<sup>3</sup> Department of Physics, University of Liverpool, Liverpool, UK

<sup>4</sup> STFC Rutherford Appleton Laboratory, Didcot, Oxfordshire, UK

<sup>5</sup> University of Manchester, Manchester, UK

<sup>6</sup> John Adams Institute, Oxford University Physics, Oxford, UK

<sup>7</sup> Institute of Particle Physics Phenomenology, University of Durham, Durham, UK

<sup>8</sup> Argonne National Laboratory, Argonne, IL, USA

<sup>9</sup> Department of Physics, University of Bristol, Bristol, UK.

## Abstract

The positron source for the International Linear Collider (ILC) is dependent upon a ~200 m long helical undulator to generate a high flux of multi-MeV photons. The undulator system is broken down into a series of 4 m cryomodules, which each contain two superconducting helical undulators. Following a dedicated R&D phase and the construction and measurement of a number of short prototypes a full scale cryomodule has now been manufactured for the first time. This paper reports on the design, manufacture, and test results of this cryomodule.

## INTRODUCTION

The positron source is a highly challenging subsystem of the ILC. The intense luminosity requirements imply positron numbers per macropulse approximately three orders of magnitude beyond that so far delivered. Another requirement of the ILC is that the source can be upgraded to provide polarised positrons (up to 60%) and this imposes restrictions on the possible solutions available. The solution adopted uses a helical undulator to generate high energy, circularly-polarised, photons that strike a target and generate electron-positron pairs. The latest design of the positron source is described in [1]. A recent proof of principle experiment at SLAC has demonstrated the feasibility of this technique by generating 6 MeV positrons with >80% polarisation [2].

In order to generate the ~10 MeV photons required using an undulator necessitates the use of a very high energy electron beam in combination with a high field, short period, undulator. The high energy electron beam is, of course, also required by the ILC itself. The number of photons required dictates the need for >10 000 undulator periods and so efforts have been made to minimise the

period as far as possible in order to minimise the overall length required. Nevertheless it is clear that the complete undulator must be made of a large number of modules (each of several metres in length) that are installed together to form the full device.

Initial studies compared alternative magnet designs and technologies. The superconducting bifilar helix design was found to be the optimum solution for our application [3]. This particular design was subject to a period of intense R&D which resulted in a number of short superconducting prototypes being manufactured and tested. Following this phase it was decided that a full scale cryomodule should be constructed to confirm the overall design and to prove that the undulator magnet could be successfully scaled up from centimetres to metres. This paper reports on the design, manufacture and magnet testing of this first ever ILC undulator cryomodule.

## SHORT PROTOTYPES

The main purpose of the manufacture and testing of the short (300 and 500 mm long) prototypes was to establish suitable fabrication techniques that could be scaled up to longer magnets and also to establish the optimum parameters for the magnet. Details of this R&D phase are given in [4].

A summary of the peak fields achieved by the prototypes as a function of undulator period is plotted in Figure 1. This shows that as the project progressed the period was able to be reduced whilst at the same time enhancing the field strength so as to maintain the required parameters that would still generate 10 MeV photons with the 150 GeV electron beam. This increase in field (despite the reduction in period) was possible through the inclusion of iron poles and yoke and also by changing to a more advanced wire with a higher ratio of superconductor to copper.

\*Work supported in part by the EC under the FP6 "Research Infrastructure Action - Structuring the European Research Area" EUROTeV DS Project Contract no.011899 RIDS.

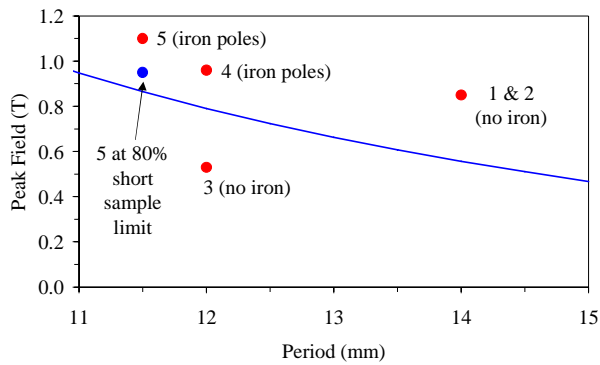


Figure 1: Summary of the performance of the 5 short prototypes. The final prototype (5) has an operating point (blue circle) well above the required parameters needed to achieve 10MeV photons (blue line).

## MODULE DESIGN AND MANUFACTURE

The helical undulator module consists of a conventional vacuum cryostat and two superconducting undulator magnets. The basic dimensions of the cryostat vacuum vessel are 0.4 m diameter by 4 m long with a services turret 0.95 m high. The main parameters of the cryomodule are summarised in Table 1 and a sketch showing the main features of the module is given in Figure 2.

Table 1: Parameters for the ILC Undulator Cryomodule

Undulator type	Superconducting, Helical
Undulator period	11.5 mm
Undulator field strength	0.86 T
K value	0.92
Nominal current	216 A
Photon Energy	10 MeV (1 <sup>st</sup> harmonic)
Undulator length	1.74 m
Vacuum bore (diameter)	5.23 mm for prototype, 5.85 mm in ILC
Module cryostat length	4 m
Number of undulators per cryomodule	2 (independently powered)
Vacuum chamber material	Copper
Vacuum chamber operating temperature	4.2 K

The two magnets are supported by a stiff U beam and the complete assembly is cooled to 4.2 K by immersion in a liquid helium bath. The helium bath is supported from the cryostat vacuum vessel by four carbon fibre rods. The radiation heat load on the helium bath is absorbed by a shield cooled to 50 K. Cooling is done with a two stage cryogenic cooler. The first stage runs at 50 K and is attached to the radiation shield, the second stage runs at 4.2 K and is attached to a helium condensing chamber which provides the liquid helium for the bath.

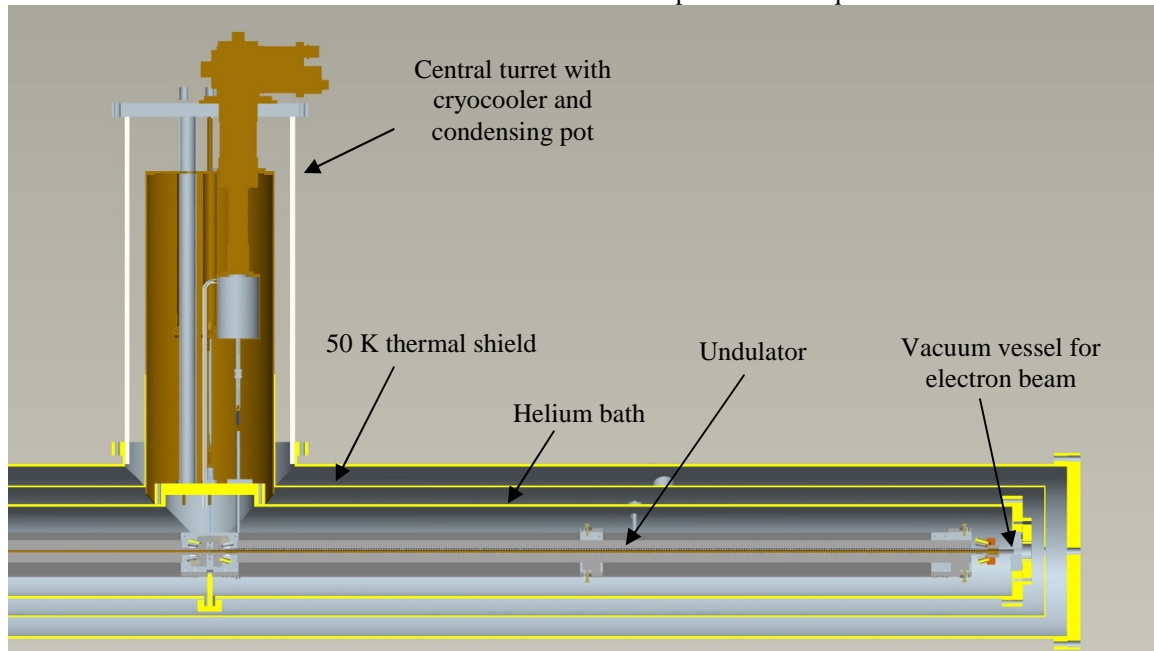


Figure 2: Model of one half of the 4 m long module, showing the central turret region and one full undulator.

The magnets are helically wound directly on to the beam pipe with a superconducting ribbon and each one is 1.8 m long. A single magnet of ~3.6 m long was considered but based on previous work 1.8 m was considered a more practical length.

The helium bath support system rods are allowed to pivot to prevent any temperature stresses due to

differential thermal contractions and are designed to have zero contraction in the vertical direction. Variations in axial length of up to 12 mm between the vacuum vessel and the helium bath are absorbed by bellows.

The closed cycle helium system was chosen because it eliminates the need for transfer lines or dewars and allows

for continuous operation without the need for any topping up of the cryogenics.

A central services turret is used to contain the cryogenic cooler, the helium condensing chamber, current leads, instrumentation, and a nitrogen precool system. A central turret was chosen because it eliminates most of the thermal contraction problems between the magnets and their associated turret connections. It also allows the current leads to be connected directly to the magnets without the need for flying leads running the length of the magnet.

The magnet formers were fabricated by scaling up the processes which were developed during the production of the five prototype formers. The key steps involved in the production were:

- drilling a ~6 mm hole to suit the beam tube in a ~2 m long iron former.
- machining a two start groove of 11.5 mm pitch in the iron former using a 4 axis milling machine and soldering the copper vacuum tube into the former.
- winding eight layers of superconducting ribbon on to the former and vacuum potting the complete assembly in a special jig.

### MEASUREMENTS

The radial component of the magnetic field on the axis of the undulator was measured by Hall probe at helium temperatures. This was achieved by immersing each undulator magnet section vertically in a liquid helium bath and passing two small Hall probes mounted in a close tolerance, push fit, insert. The probes were mounted orthogonally to each other so that both transverse planes of the field could be measured simultaneously. The insert was fixed to a graphite rod which allowed the Hall probes to be moved along the bore. The movement of the probes was controlled using a stepper motor and screw assembly, the resolution of the probe position was  $\pm 0.02$  mm along the axis. The Hall probe voltages were logged using a 16-bit ADC at each point along the bore, the typical voltage resolution of the system was  $\pm 0.05$  mV, note that the Hall probe signal at nominal field was ~300 mV. In addition to the axial movement the azimuthal position of the probe could be rotated manually to a number of fixed positions which were separated by  $45^\circ \pm 1^\circ$ . The movement and data logging were synchronised using a LabVIEW data acquisition programme.

The tests show that both magnets can operate at the nominal design current of 216 A. The maximum observed quench current was 301 A and 306 A for magnets 1 and 2 respectively (see Figure 3). Magnet 1 exhibited little quench training but magnet 2 needed extensive quench training, the reason for the difference between these two identical undulators is not yet understood. A summary of the test results for the two undulators is given in Table 2.

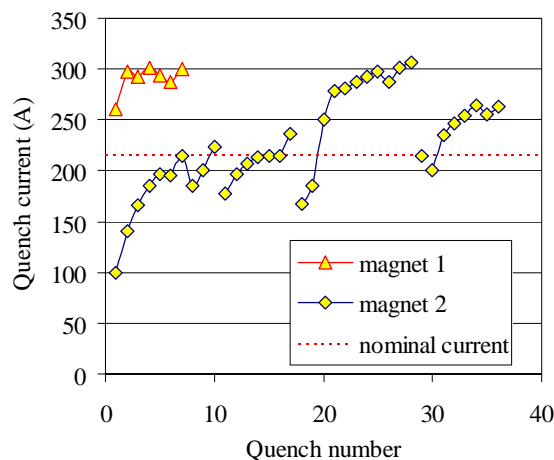


Figure 3: Magnet quench behaviour for the two identical undulators.

Table 2: Summary of the Magnet Measurement Results for the Two Undulators

Parameter	Magnet 1	Magnet 2
Field at 215 A (T)	0.88	0.89
RMS of Peak Field (T)	0.014	0.013
Period (mm)	11.48	11.46
RMS of Period (mm)	0.018	0.027
Maximum Field Achieved (T)	1.13	1.13
Maximum Current Achieved (A)	301	306

### CONCLUSION

Following a sustained period of R&D, which established the optimum undulator parameters and manufacturing techniques, a full scale ILC positron source undulator cryomodule has been designed. All of the major components for the module have now been manufactured and assembly is well underway.

The two undulators which are housed in the cryomodule have been magnetically tested prior to assembly into the module and this has proven that both magnets can operate at the required field level with a significant safety margin.

Once the module is completed it will be tested to confirm that the undulators can operate at the required current level and also to measure the cryogenic performance of the full device. It would be very valuable to carry out further magnet measurements in the fully assembled state and also to transport an electron beam through the device to confirm its performance but at present there are no plans for these additional tests.

### REFERENCES

- [1] J.A. Clarke et al, "The design of the positron source for the ILC" these proceedings.
- [2] G. Alexander et al, PRL 100, 210801 (2008).
- [3] D.J. Scott et al, PR-STAB, 10, 032401 (2007).
- [4] Y. Ivanyushenkov et al, PAC 07, p 2865.