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DEVELOPMENT OF A SUPERCONDUCTING HELICAL UNDULATOR FOR THE ILC POSITRON SOURCE

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Abstract

An undulator positron source has been selected by the International Linear Collider (ILC) community as a baseline. For the ILC a helical undulator capable of producing 10 MeV photons and with a period as close as possible to 10 mm is required. The HeLiCal collaboration in the UK is looking at the merits of both permanent magnet and superconducting technologies for the design of a helical undulator. For the superconducting option, several prototypes have been built and tested. This paper details the design, construction and test results of the first superconducting prototypes.

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INTRODUCTION

The work of the HeLiCal collaboration is focused on R&D aimed at the construction of an undulator which meets the specifications for operation in the ILC (500 GeV e^+e^- interactions in the first stage).

Options for undulator insertion devices in electron accelerators include permanent magnet and superconducting magnet technologies. The collaboration has built and tested short undulator prototypes based on both technologies and eventually decided in 2005 to select superconducting technology for the ILC undulator.

The design, construction and test results of the first superconducting prototypes are presented in this paper.

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ILC UNDULATOR PARAMETERS

The requirements for the ILC undulator were discussed at the Second ILC Accelerator Workshop at Snowmass [1] and agreed by the Global Design Effort Meeting in Frascati [2]. They are listed in the following table.

Table 1: ILC Undulator Parameters

Electron energy	150 GeV
First harmonic photon energy	10 MeV
Period	10 mm (desirable)
Beam stay clear	4 mm
Total length (for unpolarised positron source)	100 m

SUPERCONDUCTING UNDULATOR R&D

Aim of R&D Phase

The HeLiCal collaboration has launched an extensive R&D programme with the goal of developing construction techniques applicable for building up to 2 m-long superconducting helical undulator sections which can be used to build a full-scale undulator module for the ILC positron source. This phase of the project will lead to the design and manufacture of the first 4-m long undulator module followed by measuring its performance in an electron beam.

Magnetic Modelling

Intensive magnetic modelling is being carried out, as a part of the R&D programme, in order to select the winding geometry of the undulator. Software packages OPERA 2d and 3d from Vector Fields Ltd [3] are used for the modelling studies.

The results of magnetic modelling indicate that:

- A winding with a flat shape (with the minimal radial height to width ratio) creates maximal field on axis for a given current density. However, taking into consideration the peak field in the conductor, a square shape was found to be optimal.
- The peak field in the conductor is about twice the field on the undulator axis. According to the modelling, the highest field in the conductor is usually in the internal layers of the winding.
- The inclusion of magnetic material outside the winding increases the field on axis. The largest field enhancement is achieved when, in addition to the outer yoke, the former poles are also made of magnetic material.

More results of the magnetic modelling are given in [4].

Fabrication R&D

An extensive R&D programme has been launched to develop fabrication techniques suitable for producing 2-m long sections of short-period helical undulators. The issues of machining undulator formers with a precision of 50 μm or better, incorporating a beam pipe into the former, developing winding and vacuum impregnation techniques are being addressed.

SHORT UNDULATOR PROTOTYPES

In order to test the techniques developed during the manufacture R&D, a number of short undulator prototypes with a length of 300 mm have been built. Parameters of the first two short prototypes built and tested, are listed in Table 2.

Table 2: Parameters of Short Prototypes.

Parameter	Prototype 1	Prototype 2
Design field on axis	0.8 T	≥ 0.8 T
Former material	Al	Al
Winding period	14 mm	14 mm
Winding bore	6 mm	6 mm
Magnet bore	4 mm	4 mm
Winding	8-wire ribbon, 8 layers	9-wire ribbon, 8 layers
Prototype goal	Check winding technique	Check effect of mechanical tolerances

At least three more short prototypes will be built. Prototypes 3 and 4 will have a shorter period (12 mm) and will differ only in the former material (Al in one and soft iron in the other), these will be used to compare with the magnetic modelling results. Prototype 5 will be a short version of the final geometry selected for the full scale prototype and it will be used to check manufacturing technique and winding geometry before building longer undulator sections of the first full-scale undulator module.

Prototype I

The very first 300 mm–long superconducting helical undulator prototype has been built and successfully tested. Its description and the results of preliminary tests can be found in [5]. A view of this prototype before installation into the cold test rig is shown in Fig.1.

The field measurement facility for short undulator prototypes has been recently improved. It now allows a precise control over the movement of Hall probe in the undulator bore. This new facility was used to re-measure the performance of prototype 1 and will be employed to test all the following prototypes.

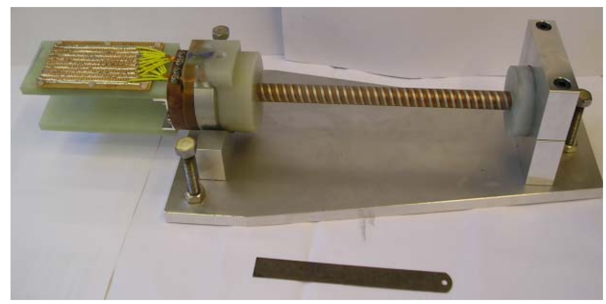

Figure 1: Undulator prototype 1 completed.

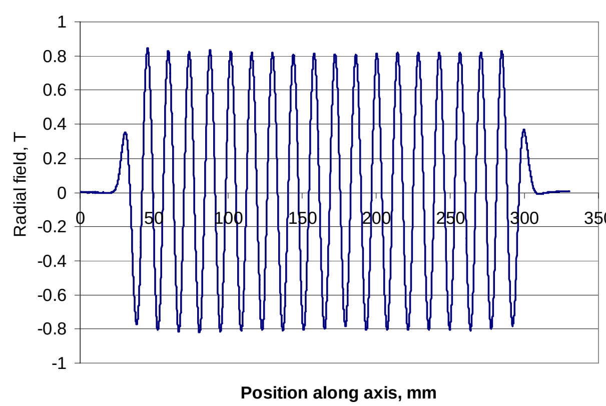

Figure 2: Profile of the axial component of the magnetic field on the undulator axis for prototype 1.

The prototype 1 field profile measured at the current of 220 A, is shown in Fig.2. The radial field reaches its nominal value of 0.8 T on the undulator axis. Note that this prototype has never quenched at any field level although it operated very close (estimated 95 %) to the conductor short sample limit.

Prototype 2

The goal for this prototype was to machine a former with a helical groove capable of accommodating a winding with a 9-wire ribbon and to check the effect of mechanical tolerances on the field quality. The former for this prototype was milled on a 4-axis machine unlike the prototype 1 former which was turned on a lathe. After completion of the field profile measurements, the winding was sectioned in order to measure the actual geometry of the winding. It was found that the winding bore (inner winding diameter) of this undulator was about 100 μm smaller in the middle part as compared to the nominal winding bore of 6 mm while the end parts have significantly larger winding bore. This leads to the increase of the radial field on axis (peak value) in the middle part of the undulator by about 0.017 T or by 2%.

Variation of the average radial field (peak value) on axis with the inner winding diameter measured for prototype 2 is shown in Fig.3. One can conclude that to keep the field variation better than 1%, the geometrical precision of the magnetic bore should be at the level of 50 μm. This precision is now set as the target for machining of the formers for all subsequent prototypes.

A section of the prototype 2 winding is shown in Fig.4, the trapezoidal geometry of the groove can be easily seen. This shape of the groove was required to accommodate a 9-wire ribbon with the minimal gaps between the ribbon layers and the groove.

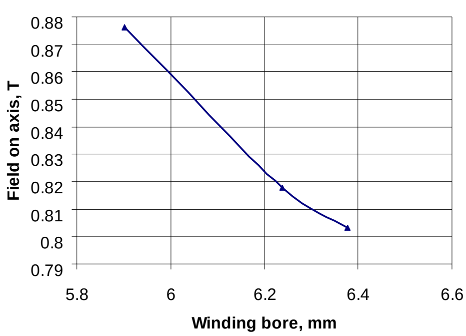

Figure 3: Dependence of average radial field on axis (peak value) versus average winding bore as measured for prototype 2.

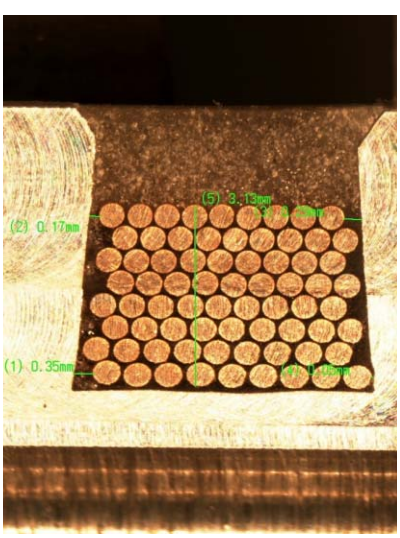

Figure 4: Undulator prototype 2 winding cut.

CONCLUSION

The HeLiCal group is running an R&D programme aiming to develop a full-scale undulator module which meets the specifications for operation in the ILC positron source.

This programme includes both the magnetic modelling and the technological R&D with the aim being to manufacture 2-m long sections of superconducting helical undulator.

Several short prototypes are being built, two of them have already been tested. Both prototypes reached the design field on axis of 0.8 T.

At least three more short prototype will be built to validate manufacturing techniques, to study the effect of iron poles in the former on the field value and to compare the results of magnetic modelling with measurements.

Successful completion of the R&D phase will enable techniques to develop first full-scale undulator module.

ACKNOWLEDGMENT

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