DEVELOPMENT OF A SUPERCONDUCTING HELICAL UNDULATOR FOR A POLARISED POSITRON SOURCE

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Abstract

A method of producing a polarised positron beam from e^+e^- pair production in a target by circularly polarised γ-radiation is being investigated. Polarised photons are to be generated by the passage of a high energy electron beam (250 GeV as anticipated in the International Linear Collider - ILC) through a helical undulator. For production of 20 MeV photons, an undulator with a period of 14 mm, a bore of approximately 4 mm and magnetic field on axis of 0.8 T is required. First prototypes have been constructed using both superconducting and permanent magnet technologies which are capable of producing the necessary magnetic field configuration in the undulator. This paper details the design, construction techniques and field measurement results of the first superconducting prototype and compares the results with simulation.

INTRODUCTION

The International Linear Collider brings new challenges for particle and accelerator physicists and engineers. An example is the need for a positron beam of adequate intensity, with if possible substantial polarisation [1,2].

Polarised positrons (and electrons) are produced when circularly polarised γ-radiation is incident on a thin target producing Bethe-Heitler e^+e^- pairs. Polarised γ-radiation is produced by the passage of a high energy electron beam through a helical undulator [3].

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). It follows the "proof-of-principle" work of the E166 experiment at SLAC, where such an undulator optimised for polarised photon production of energy 10 MeV from a 50 GeV electron beam [4].

Options for undulator insertion devices in electron accelerators include permanent magnet and superconducting magnet technologies. The collaboration aims to make a technology choice in 2005, following the evaluation of short prototypes, and then to develop the construction techniques with a full scale module, and, if possible, evaluate its performance.

The present status of work on the superconducting undulator prototype is described in this paper.

UNDULATOR PARAMETERS

For production of 20 MeV photons, an undulator with a period of 14 mm, a bore of approximately 4 mm and magnetic field on axis of 0.8 T is required [5]. These parameters were chosen for a superconducting undulator prototype of 20-period length, Table 1.

Table 1: Undulator Prototype Specifications

Design field	0.8 T
Period	14 mm
Magnet bore	4 mm
Winding bore	6 mm
Winding section	4×4 mm^2
Overall current density	1000 A/mm^2
Peak field	1.8 T

MAGNETIC MODELLING

Intensive magnetic modelling was undertaken in order to choose the winding geometry of the undulator. Software packages OPERA 2d and 3d from Vector Fields Ltd [6] were used for the modelling studies. In the most sophisticated model the undulator structure is simulated as a set of independent helical wires as shown in Fig. 1.
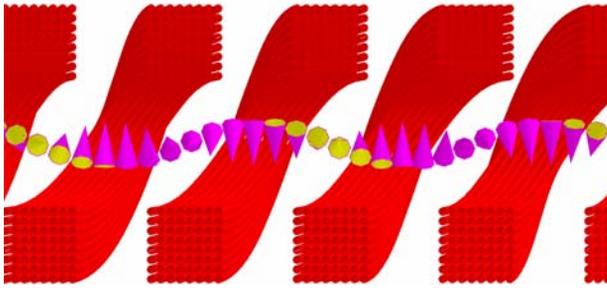
Figure 1: 3d OPERA multiwire model of the undulator. Cones represent the magnetic field vector.

A simplified model where undulator winding is simulated as a double-helical conductor with rectangular cross-section is also used.

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. A current density of 1000 A/mm^2 is required to create a 0.8 T field on axis for a winding with a 4×4 mm^2 cross-section , an internal winding diameter of 6 mm and a pitch of 14 mm.
- the peak field in the conductor with the above geometry is about 1.8 T.
- the winding radius variation of 0.1 mm leads to 4% change in the on axis field value.
- 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.

According to the modelling, the highest field in the conductor is usually in the internal layers of the winding (Fig.2). The conductor peak field is about twice the field on the undulator axis.

Undulator conductor load lines (Fig.3) were calculated for a winding geometry of 8 layers with 8 wires in a layer and for 8 layers with 9 wires in a layer. The prototype
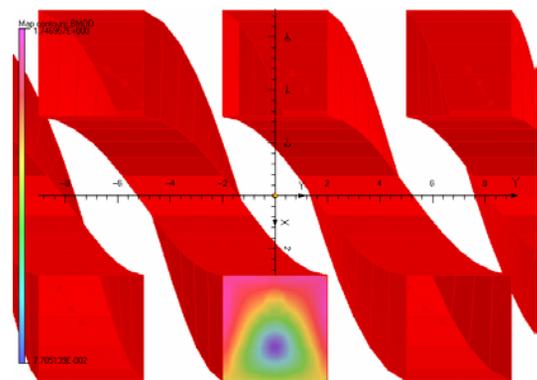

Figure 2: Region with highest peak field (pink coloured) in the undulator winding.

described below uses an 8×8 winding geometry (an 8×9 winding geometry will be tried next). According to the calculations, the superconductor in the current prototype reaches about 94% of short sample at the operating current of 226 A, while in the second prototype this value will be reduced to about 86%.
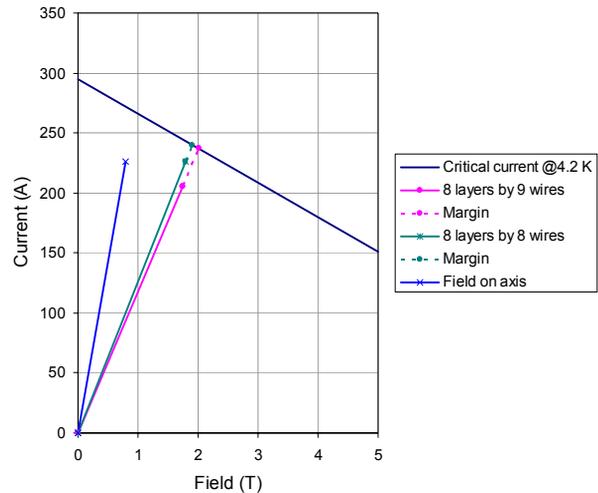

Figure 3: Undulator conductor load lines.

UNDULATOR FABRICATION

The undulator was wound with superconducting wire VACRYFLUX 5001 type F54 [7] onto an Al former. Preliminary R&D on the winding indicated that winding the undulator with a wire ribbon could significantly reduce technical difficulties encountered at the ends of the multiwire winding. A similar approach is implemented at CERN for the winding of LHC corrector magnets. Nine 0.44 mm wires were bonded in a flat ribbon with a width of approximately 4 mm and a thickness of 0.5 mm. The ribbon was then wound into a spiral groove in the former (Fig.4). To achieve a continuous winding of two helices in one operation, two sets of pegs are used at the ends of the undulator for the return of the ribbon into the adjacent helical groove.

After winding, the undulator coil was vacuum impregnated with epoxy resin and the wires in the ribbon were interconnected at the terminal block to form the series winding. As a result, the undulator winding forms a multilayer, continuous, double-helical, winding with two leads for connection to a power supply. The final view of the undulator before installation into the cold test rig is shown in Fig.5.

TEST RESULTS

Measurements at Room Temperature

The radial component of the magnetic field on the axis of the undulator was measured with a Hall probe at room temperature with the undulator current set to 0.7 A. A stepping motor was used to drive a specially fabricated, small, Hall probe through the undulator bore at a constant speed while the Hall probe signal was

continuously read into a PC. The shape of the field was found to be in agreement with the simulation.

Measurements at Liquid Helium Temperature

The undulator was mounted in a liquid helium bath. The level of liquid helium in the cryostat was monitored with discrete level sensors to ensure that liquid helium covered both the undulator coil and the superconducting current leads. The temperature of the undulator was monitored during cool-down and operation.

Voltage taps were used to measure the resistive voltage across the undulator coil with a nano-voltmeter when the undulator was powered. In the cold test the undulator reached the maximum current of the power supply at 225 A without quenching. The voltage across the complete undulator coil was at the level of 10^{-6} V. This indicates that all joints have a resistance $< 10^{-8}$ Ohm.

The undulator field profile measured at the current of 220 A, is shown in Fig.6. The radial field reaches its nominal value of 0.8 T on the undulator axis.
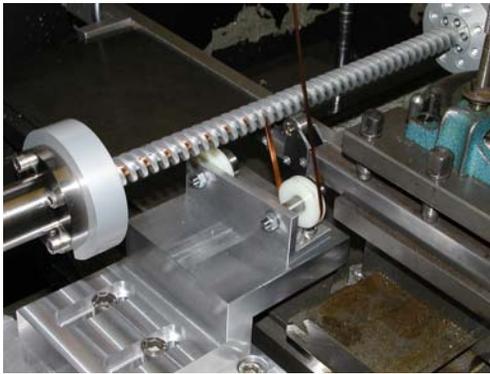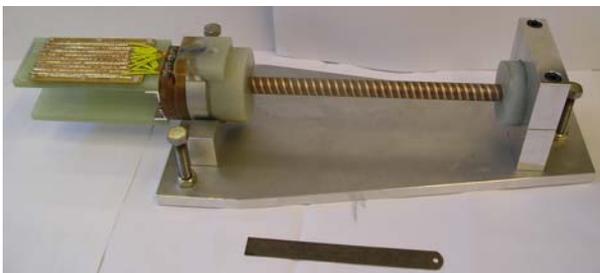

Figure 4: Undulator winding on a lathe.

Figure 5: Undulator prototype completed.

CONCLUSION

The feasibility of using superconducting magnet technology for the construction of a helical undulator for a polarised positron source for the International Linear Collider is underway.

A 20-period prototype undulator has been built, excited and the field map measured. The undulator reaches its nominal working field on axis of 0.8 T at the current of about 220 A without quenching.
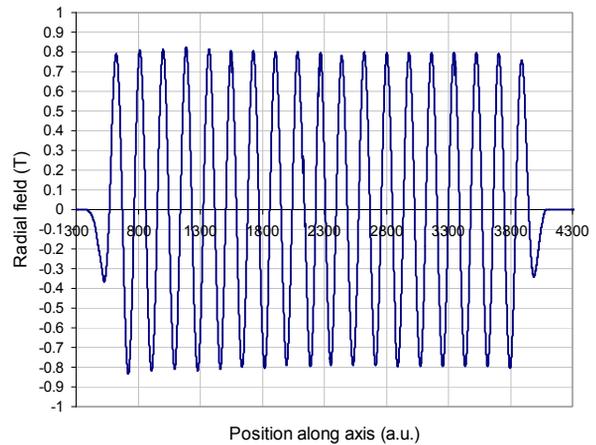

Figure 6: Profile of the axial component of the magnetic field on the undulator axis.

The undulator field profile measured at liquid helium temperature, agrees with the one simulated with the OPERA 3d software package.

The next step in the R&D programme includes the fabrication of a second prototype with improved winding geometry and an outer magnet yoke.

ACKNOWLEDGMENT

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