Status Of The HeLiCal Contribution To The Polarised Positron Source For The International Linear Collider

G.A. Moortgat-Pick[†,*], I.R. Bailey[†,**], D.P. Barber[†,‡], E. Baynham[§], A. Birch[¶], T. Bradshaw[§], A. Brummit[§], S. Carr[§], J.A. Clarke[†,¶], P. Cooke[**], J.B. Dainton[†,**], T. Greenshaw[**], L.J. Jenner[†,**], Y. Ivanyushenkov[§], A. Lintern[§], L.I. Malysheva[†,**], O.B. Malyshev[†,¶], J. Rochford[§], P. Schmid[‡] and D.J. Scott[†,¶]

[*]*Institute of Particle Physics Phenomenology, University of Durham, Durham DH1 3LE, UK*
[†]*Cockcroft Institute, Daresbury Laboratory, Daresbury, Warrington, Cheshire WA4 4AD, UK*
[**]*Department of Physics, University of Liverpool, Oxford St., Liverpool, L69 7ZE, UK*
[‡]*DESY-Hamburg, Notkestrasse 85, 22607 Hamburg, Germany*
[§]*CCLRC Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire OX11 0QX, UK*
[¶]*CCLRC ASTeC Daresbury Laboratory, Daresbury, Warrington, Cheshire WA4 4AD, UK*

Abstract. The baseline design of the positron source for the International Linear Collider (ILC) incorporates a helical undulator and pair-production target in order to generate the unprecedented quantities of positrons required to sustain the intended ILC physics programme. This configuration is challenging but readily achievable by using novel adaptations of existing technologies to avoid problems inherent in conventional positron sources in which the stresses in the target(s) and activation of the target station are both serious problems. In addition, a highly polarized positron beam, essential for realizing the full potential of the ILC, can be produced by a simple upgrade to the baseline design.

A major contribution to the international design effort is being led by the UK-based HeLiCal collaboration. The collaboration is responsible for the design and prototyping of the helical undulator itself, which is a short period device with a small aperture, and also leads development of the start to end simulations of the polarised particles to ensure that high levels of polarization are maintained from the sources, through the beam transport systems and up to the interaction point(s). Members of the collaboration are also involved in the EUROTeV-funded research programme to produce a design for a pair-production target which can operate reliably in the high photon flux of the undulator. This paper will provide an update on the work of the collaboration, focusing on the design, construction and testing of components of the polarized positron source, and will also discuss future plans.

Keywords: Positron source, ILC, undulator, polarized beams
PACS: 29.27.Hj, 29.25.Pj, 29.25.-t, 41.60.-m

INTRODUCTION

An undulator-based source has been chosen for the baseline design of the ILC [1] as it is believed to offer the most certainty of meeting the machine's luminosity requirements. In addition, this source offers a simple upgrade path for generating polarised positrons which are essential for fulfilling the full physics potential of the machine [2]. It is intended to site the source in a chicane commencing at the 150 GeV point of the ILC main e^- linac, where it will produce positrons by perturbing the e^- beam and using the resulting synchrotron radiation to instigate electromagnetic showers in a thin target. This concept has recently been demonstrated successfully at lower energies using the SLAC-based E166 experiment [3].

The HeLiCal collaboration [4] is an integral part of the international effort to develop a complete design for the positron source. Results from our depolarisation simulations are featured elsewhere in these proceedings [5] and progress on the target design has recently been reported elsewhere [6]. This report discusses the design of the helical undulator itself; details of additional undulator studies by the collaboration can be found in reference [7].

The helical undulator is a highly demanding magnet whose total length is likely to be between 100 m and 200 m depending on the maximum degree of positron polarisation required. It will be composed of modules approximately 4 m in length with a very narrow circular aperture 5.85 mm in diameter, and will generate first harmonic photons of energy 10 MeV, corresponding to a ‘deflection parameter’ close to unity. Computational and analytical studies of the expected cryopumping effects and photodesorption rates in the device show that by installing simple photon collimators approximately every 10 m to 20 m and also additional pumps with a similar spacing, a suitable vacuum level (nominally 10^{-8} Torr) should be readily maintained.

HeLiCal has previously developed two short prototype 14 mm period undulators with a peak field of 0.8 T: one using permanent magnets and one using superconducting technology [8, 9]. After evaluating the field qualities of the devices and the relative costs and properties of the technologies, the decision was taken by the collaboration to focus on superconducting magnet technology as described below.

Undulator Prototyping

Following computer simulations of the magnet geometry [10], a number of short undulator prototypes with a length of 300 mm have been built to develop the fabrication techniques required for full scale undulators [11]. Each undulator is produced by winding superconducting (NbTi) ribbon into grooves on a metal former. The parameters of the first four short prototypes built and tested, are listed in Table 1.

All of these prototypes have successfully demonstrated their full design field levels with no difficulty. Prototypes III and IV have a shorter period (12 mm) than the first two devices and differ from each other only in the former material (aluminium and soft iron respectively). The measured on-axis peak field of prototype III is ~ 0.53 T and the measured on-axis peak field of prototype IV with a magnetic yoke is ~ 0.97 T with measured peak to peak variations of less than 1%. These figures are in good agreement with the computer simulations which predict values of 0.52 T and 0.96 T.

Prototype V will be a 500 mm long device with an iron former and a copper beam pipe with a vacuum bore of ~ 5.2mm. A design has also been developed for a full scale module prototype consisting of a 4 m cryostat containing two ~ 2 m undulators with the same vacuum bore and materials as prototype V.

TABLE 1. Parameters for the first four short superconducting undulator prototypes.

	Prototype I	Prototype II	Prototype III	Prototype IV
Former material	Al	Al	Al	Fe
Period (mm)	14	14	12	12
Groove shape	rectangular	trapezoidal	trapezoidal	trapezoidal
Winding bore (mm)	6	6	6.35	6.35
Vacuum bore (mm)	4	4	4	4.5 *
Wires / layer	8	9	7	7

* Stainless steel tube

Electron Trajectory And Wakefield Studies

Preliminary studies have been carried out on the impact of magnetic field imperfections on the trajectories of electrons travelling through the undulator. Computer simulations have been carried out for helical fields with random perturbations a factor of five greater than those obtained from the measurements of the devices described in the previous section. The simulations show that by introducing simple dipole steering magnets at the mid-point and at the end of a 4 m module, deviations in the electron trajectories can be kept below a few microns. Trajectory deviations due to systematic misalignments of the modules have also been simulated, but no significant effects have yet been found.

Extensive studies have also been made of the impact of the long, narrow aperture, vacuum vessel on the drive electron beam to ensure that the electron beam properties are not degraded by either resistive wall impedance or surface roughness. The DC, AC and anomalous skin effect longitudinal resistive wall wakefields have been computed for the undulator vessel [12] as a function of vessel radius for various materials and for a large range of possible ILC parameters.

The most significant impact of the vessel resistance is on the energy spread of the electron beam. Although it is difficult to obtain accurate data on the material properties of stainless steel at cryogenic temperatures, it seems likely that a stainless steel vacuum chamber would increase the energy spread of the electron beam by the order of 10% when the ILC is operated in the shortest envisaged bunch length mode (150 μm). For this reason we have rejected the idea of using a stainless steel vessel for the helical undulator. Other options such as aluminium, copper, or a copper or gold coated steel all produce an increase on the energy spread of the order of 1% at cryogenic temperatures, which is perfectly acceptable.

We have also studied the impact of surface roughness on the electron beam energy spread [13]. A pessimistic model predicts that the energy spread increase will be below 10% if the vessel roughness is better than 600 nm. Copper vessels with an appropriate smoothness are readily available and it is envisaged they will be used in the undulator. Measurements of a sample copper vessel gave a smoothness of < 100 nm which, according to the pessimistic model, would lead to an energy spread increase of $< 2\%$.

OUTLOOK AND CONCLUSION

The HeLiCal collaboration has demonstrated the feasibility of constructing NbTi superconducting helical undulators with field qualities and apertures suitable for operation in the ILC baseline positron source. Construction of a first 4 m long device consisting of two superconducting undulators with iron formers in a single cryostat should be complete in the Summer of 2007. Further studies into geometric Wakefield effects, beam-jitter effects and other phenomena are ongoing along with the collaboration's other projects developing spin transport simulations and designing an appropriate pair-production target.

ACKNOWLEDGMENTS

This work was supported in part by the Commission of the European Communities under the 6th Framework Programme "Structuring the European Research Area", contract number RIDS-011899.

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