

EUROTeV-Report-2006-045

STATUS OF THE HeLiCal CONTRIBUTION TO THE POLARISED POSITRON SOURCE FOR THE INTERNATIONAL LINEAR COLLIDER*

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Abstract

The baseline positron source for the International Linear Collider is a helical undulator based design which can generate unprecedented quantities of polarised positrons [1]. A major thrust of the global design in this area is led by the UK based HeLiCal collaboration [2]. The collaboration takes responsibility for the design and prototyping of the helical undulator itself, which is a highly demanding short period device with very small aperture, and also leads the start to end simulations of the polarised particles to ensure that the high polarisation levels generated are maintained from the source, right through the beam transport systems and up to the interaction point itself. This paper will provide an update on the work of the collaboration focussing on these two topic areas and will also discuss future plans.

INTRODUCTION

The International Linear Collider baseline configuration contains a helical undulator based positron source [1] since this is the lowest risk option of the available techniques and since it also offers a simple upgrade path to generating polarised positrons which are essential for fulfilling the full physics potential of the ILC [3]. The design produces positrons via an electromagnetic shower in a thin target due to incident synchrotron radiation produced by the undulator utilising the main ILC e- beam at 150 GeV. This concept has recently been

experimentally proven at the SLAC-based E166 experiment [4].

The HeLiCal collaboration is an integral part of the international effort which is focussed on producing a complete design for the positron source. HeLiCal is responsible for two major research efforts; the design and prototyping of the helical undulator itself and also the simulation of the depolarisation effects from start to end to ensure that the polarised beams are maintained until the interaction point.

HELICAL UNDULATOR R & D

The helical undulator is a highly demanding magnet that has a total length of ~100 m for the unpolarised source and ~200 m for the polarised source. It will have a very narrow circular aperture of 4 mm diameter (beam stay clear) and will generate first harmonic photons of energy 10 MeV by using the main electron linac as the drive beam at a fixed energy of 150 GeV.

An earlier iteration of the undulator design for the TESLA linear collider aimed at generating 20 MeV photons from a 250 GeV drive beam [5, 6]. This led to the development of two 14 mm period undulators with a peak field of 0.8 T; one using permanent magnets and one using superconducting technology. After building a prototype of each technology the decision was taken by the collaboration to focus on superconducting magnet technology for all future design work.

Magnet Modelling

Following the change in the photon energy specification and drive beam energy an extensive amount of magnetic modelling has been carried out to reoptimise the undulator parameters [7].

* Work supported 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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A key result from the earlier superconducting magnet modelling was that the inclusion of an iron former increased the on-axis field by ~ 0.5 T. However, it was also clear from the modelling that the field gradient at the iron-conductor interface was very steep and that this made it difficult to estimate the peak field in the superconductor – a vital parameter since this effectively limits the peak on-axis field of the magnet. To solve this problem very high mesh densities need to be used but this is not easy in a 3d model since there is effectively no symmetry in a helical magnet geometry.

A more effective way to examine the parameter space of the helical undulator is to do the initial analysis with analogous planar undulators which can be modelled in 2d, these can be used to examine the effect of changing the period, bore and winding size. However care must be taken in translating the 2d planar results into an equivalent value for a 3d helical undulator. Because of the azimuthal winding, the on-axis field of a helical undulator is always greater than that of a comparable planar undulator, for a given current density.

Following a detailed scan of the undulator parameter space, which included varying the winding bore, the period, the number of wires per ribbon, and the number of ribbon layers a fewer number of 3d models were investigated around the parameter region of interest [7]. The results are presented in figure 1.

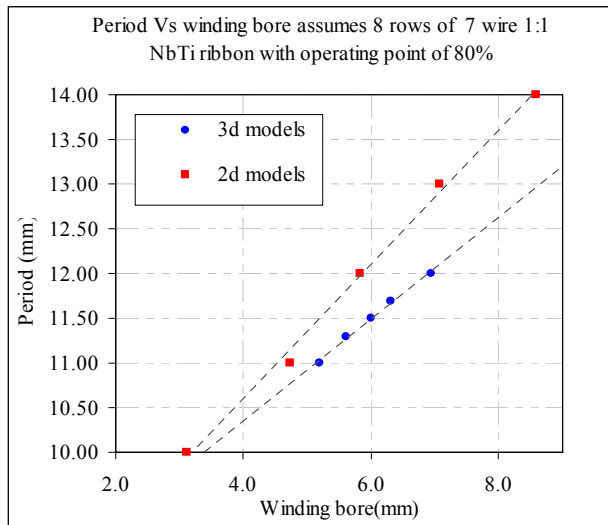


Figure 1. Comparison of 2d and 3d helical undulator models.

Undulator Prototyping

In parallel with the magnet modelling a number of short undulator prototypes with a length of 300 mm have been built to develop the fabrication techniques required for the full scale undulator modules [8]. The parameters of the first two short prototypes built and tested, are listed in Table 1 and a photo of the first prototype is given in figure 2. Both of these prototypes have successfully demonstrated their full design field levels with no difficulty.

At least three more short prototypes will be built this year. 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 which will be a 4 m cryostat containing two ~ 2 m undulators. Following extensive magnetic testing the full scale prototype will be subject to electron beam transport tests.

Table 1. Parameters of the first two 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

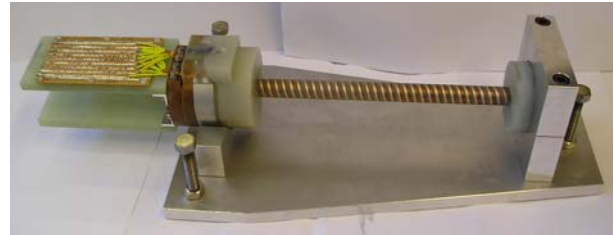


Figure 2. Photograph of the first superconducting prototype.

Wakefield Studies

Careful studies have 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 [9]. They have been calculated as a function of vessel radius for various materials and for the minimum, nominal and maximum 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 bunch length mode (150 μ m). For this reason we have rejected the idea of using a stainless steel vessel for the helical undulator. Fortunately several other options exist, such as aluminium, copper, or a copper or gold coated steel vessel. These options 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 [10]. A pessimistic model predicts that the energy spread increase will be below 10% if the vessel roughness is better than ~600 nm. Fortunately such smooth vessels are readily available in both steel (which would then have to be coated because of the resistive wall effect) and copper. The present assumption is that a copper vessel will be used for 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%.

Vacuum Studies

Achieving and maintaining a vacuum in the long, narrow, undulator vessel has also been studied. Fortunately the choice of superconducting technology, which will have a cold bore (4.2K), means that the system will act as a cryopump and will achieve a very low base pressure initially. This low pressure will be maintained so long as no synchrotron radiation from either the upstream dipoles or the undulator itself reach the vessel surface. Calculations of the undulator radiation at (relatively) large angles have been carried out to assess the number of photons that could impact on the vessel surface. It appears that, by installing simple photon collimators approximately every 10 to 20 m and also additional pumps with a similar spacing, a suitable vacuum level should be readily maintained. Further studies will now be performed to optimise the geometry and spacing of the photon collimators.

SPIN TRACKING

Polarized electrons with a polarization degree of at least 80% are foreseen for the baseline machine design. The undulator-based source can easily be upgraded to provide polarized positrons with high luminosity and a polarization degree of at least 60%. To fulfill the physics goals, it is important to ensure that no significant polarization is lost during the transport of the electron and positron beams from the source to the interaction region. Transport elements downstream of the sources which can contribute to a loss of polarization include the initial acceleration structures, transport lines to the damping rings, the damping rings, the spin rotators, the main linacs, and the high energy beam delivery systems.

We have studied the depolarization for two damping ring designs, the OCS ring and the 17 km TESLA ring [11]. Realistic misalignments (1/3 mm misalignments and 1/3 mrad roll for quadrupoles) and closed orbit corrections have been included. The transverse emittances of the injected beam were twice as large as those for the planned setup. Two energies have been studied, 4.8 GeV (close to a first order synchrotron resonance) and 5.066 GeV. The loss of polarization has been shown to be

negligible for the time the beam stays in the damping ring.

After acceleration up to 250 GeV for the first stage of the ILC, the beams must be brought into collision in the beam delivery system via bending and focusing magnets. For a 250 GeV electron undergoing the total of 11 mrad of bend, the spin precession is approximately 332° . Thus a study of spin-transport through the beam delivery system is required. Preliminary calculations with SLICKTRACK [12] running in a single pass mode indicate no significant loss of polarization.

Depolarizing effects in beam-beam interactions have also been evaluated for various ILC parameter sets. The expected depolarization is at most about 0.2%. At higher energy (1 TeV) the effect will increase by about a factor two.

There are still theoretical uncertainties in the simulations due to the use of the equivalent photon approximation for the incoherent processes; for strong fields the validation of the T-BMT equation in its current form has to be checked.

CONCLUSION

The HeLiCal collaboration is making an active contribution to the ILC undulator-based positron source design, particularly through the design and prototyping of the helical undulator itself and also the simulation of the depolarisation effects from start to end.

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