

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

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Abstract

The positron source for the International Linear Collider (ILC) is a helical undulator-based design, which can generate unprecedented quantities of polarised positrons. The HeLiCal collaboration [1] takes responsibility for the design and prototyping of the superconducting helical undulator, which is a highly demanding short period device with very small aperture, and also leads the start to end simulations of the polarised electrons and positrons to ensure that the high polarisation levels generated survive from the source up to the collision point. This paper will provide an update on the work of the collaboration, focusing on these two topic areas, and will also discuss future plans.

INTRODUCTION

The ILC Reference Design Report (RDR) contains a helical undulator based positron source [2] since this is the most promising 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 been experimentally proven by the E166 experiment at SLAC[4].

The HeLiCal collaboration is an integral part of the international effort which is focussed on producing a complete design for the positron source [5]. 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

Undulator Parameters

A parameter study for the helical undulator carried out by a group at Argonne National Laboratory is summarised in Table 1 [6] using the ILC Baseline Configuration Document (BCD) undulator parameters and 4 other possibilities. The positron yield calculated by simulating the photon production in the undulator, positron production in the target and then capture and acceleration to the damping ring. A 100 m undulator was considered in all cases and the conversion target was 1.45 cm of titanium. The yield is the number of positrons that are injected into the damping ring per electron that passes through the undulator.

Table 1. Positron production and capture study.

| Parameter Set | BCD | 1 | 2 | 3 | 4 |
|------------------|------|------|------|------|------|
| λ_u (mm) | 10 | 11.5 | 10.5 | 10 | 12 |
| K | 1 | 0.92 | 0.64 | 0.42 | 0.72 |
| Aperture (mm) | - | 5.85 | 5.85 | 8 | 8 |
| Yield | 2.13 | 1.37 | 0.86 | 0.39 | 0.75 |
| Yield (60% Pol.) | 1.1 | 0.7 | 0.53 | 0.32 | 0.49 |

In general, to reduce costs, as short an undulator as possible is required. Undulators with a larger aperture would make alignment of individual modules easier, but, according to this study, their lower on-axis field strength would mean more modules are required. For the ILC Reference Design Report [2] an undulator with a period (λ_u) of 11.5 mm, K = 0.92, aperture = 5.85 mm and length of 147 m was chosen as this gives the highest yield with realistic undulator parameters.

* 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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Undulator Prototyping

Following selection of superconducting technology for the ILC undulator [7], an R&D programme to develop the short-period superconducting helical undulator has been completed [8]. Several short prototypes with lengths 300 mm to 500 mm were built and successfully tested. Figure 1 shows the measured field on-axis as a function of λ_u for the different prototypes at a current of 200 A.

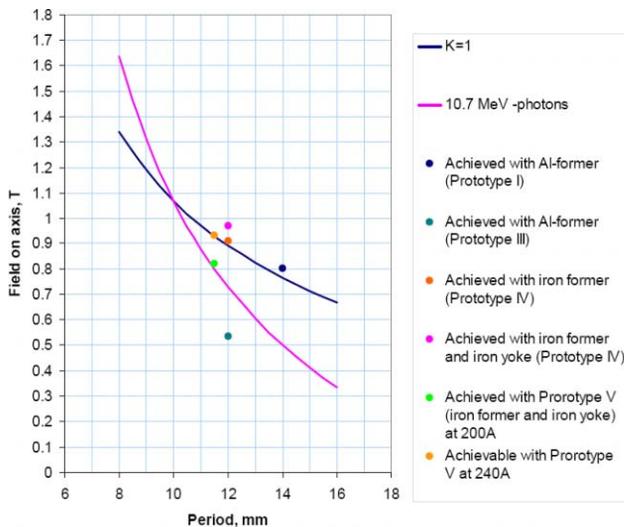


Figure 1: peak on-axis field at 200 A for the various different undulator prototypes.

4 m Module

Based on the short prototype models 4 m long module with parameters similar to parameter set 1 in Table 1 is now being constructed [9]. In the cryostat there will be two individually powered 1.74 m undulators. Magnetic field measurements of the undulators will be performed prior to their assembly in the cryo-stat. The module is expected to be completed in late 2007. it is then planned that the module will be tested in an electron beam. With a beam energy of ~70MeV the radiation output would be in the visible regime allowing for easy characterisation of it's polarisation.

To allow for the contraction of the parts during cool-down bellows need to be used. Designs with shielded bellows and unshielded bellows were considered. The shielded bellows design resulted in trapped air volumes that would require holes in the shielding for pumping. The wakefield effects of such holes is not known for the ILC beam parameters. The unshielded bellows design would have exposed bellows that would also have wakefield effects. However, it was found that the wakefield effects of the unshielded design were negligible and so unshielded bellows design was adopted [10].

Wakefield Studies

Previous work has calculated the longitudinal wakefields for the different bunch distributions, ILC parameters, vessel materials and DC, AC and anomalous skin effect impedances [11]. From these longitudinal wakes the transverse wakes can be simply be calculated

via integration. The peak transverse kick is found to be 0.27 eV $\mu\text{m}^{-1} \text{m}^{-1}$ for a 5.85 mm diameter copper vessel at 77 K. This has been used along with particle tracking in MAD and a simple SVD based correction algorithm to estimate an emittance dilation of the electron beam caused by the undulator line. It was found that the emittance increase is mainly due to the optics of the line, with the resistive wall wakefields being a negligible effect [12]. None of this modelling included the synchrotron radiation (SR) produced in the undulator section. Independent studies, without wakefields, have modelled this and shown that the effects of SR from the undulator and QUAD-BPM misalignments on the emittance growth can be tolerated [13, 14].

In a separate study the effects of geometric wakefields on the beam emittance have been considered [10]. In the current design of the undulator line there are two main elements that have tapers, the photon collimators and the transitions between the room temperature vessels and the cold bore of the undulator module. These tapered sections induce wakefields which can kick an off-axis beam transversely.

The undulator tapers have been designed with an exposed bellows at a radius of 18 mm. This is to mitigate vacuum pumping issues that were a concern for a shielded bellows design.

All the tapered sections considered are axially symmetric and for these simple systems there is good agreement between theory, simulation and experiment [15]. The bellows were modelled using analytic expressions [15] and the 2D code ECHO[16].

Currently there is no engineering design for the photon collimators, but an assessment of the effects of likely parameters can be made. Their design is assumed to be an axially symmetric taper down to a minimum aperture and then a similar taper back up to the nominal vessel radius of 18 mm. For a 2 mm radius aperture and taper angle of 0.01 rad the kick factor is 0.15 V $\text{pC}^{-1} \text{mm}^{-1}$ and for a 2 mm radius aperture and a taper angle of 0.1 rad the kick factor is 6.7 V $\text{pC}^{-1} \text{mm}^{-1}$. The kick factor of the undulator module was found to be 0.96 V $\text{pC}^{-1} \text{mm}^{-1}$.

Based on these kick factors an emittance increase due to misalignments of the elements can be simulated. The mean emittance increase of 10 000 separate error-sets for an rms displacement of 100 microns (truncated at 300 microns) was found to be ~1% in the vertical plane and negligible in the horizontal plane.

Future work should combine all these effects in one simulation.

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. A more detailed discussion of the spin tracking results are presented elsewhere [17].

Source Polarisation

Gaps between the undulator modules will produce interference effects between the radiation from the separate modules, affecting the polarisation and intensity of the photons. It is well known that radiation from two linear crossed undulators can be circular polarised if there is an upstream dispersive element such as a monochromator [18]. Although it is thought that the target wheel does not act as a dispersive element [19], it may be possible to perform an experiment using the two individually powered undulators in the 4 m prototype module to confirm this.

Studies of the impact of the photon collimator aperture on the photon and positron polarisation, along with thermal and mechanical studies of the collimator design are also underway and will be presented at a later date.

Polarisation Tracking

The Monet-Carlo tracking code SLICKTRACK [20] has been extended to simulate spin motion through the BDS and linac. Simulations in the BDS show very small amounts of depolarisation. The results obtained are in excellent agreement with BMAD simulation [21]. Simulations for the linac show negligible depolarisation, confirming earlier work [21].

The loss of vertical polarisation in the damping rings of the ILC was estimated using and found to be negligible. Additional simulations support our earlier results [22, 23] which showed that the horizontal components of the spin vectors of the electrons and positrons injected into the damping rings do not fully decohere and that the distribution of the spin projections on the horizontal plane reach an equilibrium in the frame rotating at the spin precession frequency. It is therefore very important that the spins be properly aligned along the vertical prior to injection.

Further theoretical work has been carried out to analyse depolarisation processes during ILC beam-beam interactions, including depolarisation through spin precession. In addition the polarisation dependence of coherent and incoherent pair production has been studied, and these effects are being incorporated into the CAIN software package. This work is ongoing, but initial results from CAIN indicate a substantial decrease in low energy incoherent pair production when polarisation effects are included.

SLICKTRACK is being further extended to include non-linear orbital motion, which will allow a detailed

study of spin motion in non-linear elements such as the helical undulator.

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, assessing its impact on the main electron beam and also the simulation of the depolarisation effects from start to end.

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