Depolarisation in the damping rings of the ILC

L.I. Malysheva[1] and D.P. Barber[2]*

1- Department of Physics - The University of Liverpool
Liverpool, L69 7ZE - UK

2- Deutsches Elektronen–Synchrotron - DESY
22603 Hamburg - GERMANY

Spin polarisation will play an important role in the physics programme of the International Linear Collider (ILC). A well designed and aligned damping ring should not produce any significant depolarisation. This is confirmed by simulations using the code SLICKTRACK. However, it should be recognised that there is no full decoherence of the horizontal components of spins.

1 Overview

If highly spin–polarised electron and positron beams are to be available at the interaction point(s) of the ILC, it is essential that the damping rings cause no significant depolarisation. However, enhancement of synchrotron radiation by the wigglers in damping rings has the potential to cause spin depolarisation via the spin-orbit coupling embodied in the Thomas-BMT (T-BMT) equation [1]. Thus a special study of depolarisation in the ILC damping rings has been made [2]. In principle there are three effects which can either reduce the value of the polarisation at the interactions point(s) or add uncertainty to the direction of the polarisation at the interaction point(s). These are respectively the effect of synchrotron radiation just mentioned, and two effects related to a possible mismatch of the incoming spin distribution with the "ideal" spin distribution of particles with non-zero orbital amplitudes.

2 The effect of synchrotron radiation

Spins precess in the magnetic fields according to the T-BMT equation. But the stochastic nature of the emission of synchrotron radiation puts some random motion (noise) into the particle orbits. In the (non-uniform) quadrupole fields, the noise is transmitted to the spin motion and initially mutually parallel spins can start to spread out so that the beam becomes depolarised. In principle, synchrotron radiation can also lead to a build up of polarisation via the Sokolov-Ternov (ST) effect [1] but in damping rings this can be neglected since the alternating fields in the wigglers ensure that the asymptotic ST polarisation is very low. Also, the ST build-up rate is very low.

As a part of a study to determine the optimal damping ring configuration for the ILC, the depolarisation for a few damping ring designs (e.g., the OCS and TESLA lattices) has been estimated [2]. Since the beam is not at equilibrium, a Monte-Carlo simulation of the effect of stochastic photon emission was carried out using the code SLICKTRACK [3]. Even with typical misalignments (1/3 mm misalignments and 1/3 mrad roll for quadrupoles) the loss of polarisation is negligible both for the design energy of 5.006 GeV and close to a first

*Also Visiting Staff Member at the Cockcroft Institute, Daresbury Science and Innovation Campus, and at the University of Liverpool, UK.

order spin-orbit resonance at 4.8 GeV. See for example fig. 1 in [4]. A similar conclusion emerges from simulations with SLICKTRACK for the (newer) OCS6 lattice at 5.0GeV. The simulations were performed both for a small energy spread ($\pm$45KeV) expected for injected electron bunches and for the large initial transverse emittances and initial energy spread of $\pm$25MeV, expected for the positrons from the positron source of the ILC baseline-design.

3 The invariant spin field and the associated effects

Whereas radiative depolarisation is irreversible, the other two effects are mainly associated with radiationless, i.e., reversible, equations of spin motion. Both can be understood in terms of the so-called "invariant spin field" $\hat{n}$ [5, 6] which describes the direction of the equilibrium polarisation at each point in phase space. The natural "reference direction" for describing spin motion in a storage or damping ring is the unit vector $\hat{n}_0$, the periodic solution (of unit length) of the T-BMT equation on the closed orbit [1]. In a properly aligned damping ring $\hat{n}_0$ will be just a few milliradians from the vertical. In $e^{\pm}$ storage rings $\hat{n}_0$ gives the direction of the equilibrium polarisation of the whole beam. If the beam is in equilibrium with non-zero emittances and spins are set initially parallel to $\hat{n}_0$, instead of $\hat{n}$, the polarisation will fluctuate. See, for example, fig. 9 in [6]. Nevertheless, at the low energies of the damping rings, the effects of such fluctuations are negligible away from spin-orbit resonances. Note that earlier work with MERLIN for 1.98 GeV in the NLC damping rings [7, 8] which confirmed the positions of spin-orbit resonances, did not include synchrotron radiation and was therefore concerned with just these kinds of fluctuations.

A second and much more important effect which is of basically the same nature is illustrated in fig. 1 for electrons in the OCS6 lattice when the initial relative energy spread is $\pm$45 KeV. Here, all spins are initially tilted by 100 mrad from $\hat{n}_0$, along the same direction. The first (top) curve shows the mean square angle of tilt. It is so large that it is not significantly influenced by synchro-betatron motion and synchrotron radiation. The other two curves show the mean squared projections of the spins on the radial and longitudinal directions. They oscillate almost sinusoidally as the polarisation vector basically just precesses around $\hat{n}_0$. However, the peak-to-peak range is slightly less than 10000 mrad^2, indicating that there is some decoherence, due to synchrotron radiation, of the projections of spins on the plane perpendicular to $\hat{n}_0$. In fact the distribution of the projections comes to equilibrium with respect to the rotating mean direction, with an r.m.s. spread of about 14 degrees and this is consistent with a simple model [9]. Thus, contrary to common expectation, there is no complete decoherence of the spin projections. The same is true for large initial energy spreads. So, if the injected polarisation is tilted sufficiently from $\hat{n}_0$, the direction of the polarisation vector at ejection and, in turn, that of the polarisation vector at the interaction point(s) will depend on the time at which the ejection kickers are fired. The injected polarisation should therefore be set sufficiently parallel to $\hat{n}_0$, or for these damping rings, to the vertical.

4 Conclusions

New SLICKTRACK simulations for the ILC damping ring lattice support our earlier conclusion that the depolarisation is negligible and that the horizontal projections of the spins of the electron bunches injected into damping ring need not rapidly decohere. It is therefore important that the polarisation vector be properly aligned prior to injection. More details

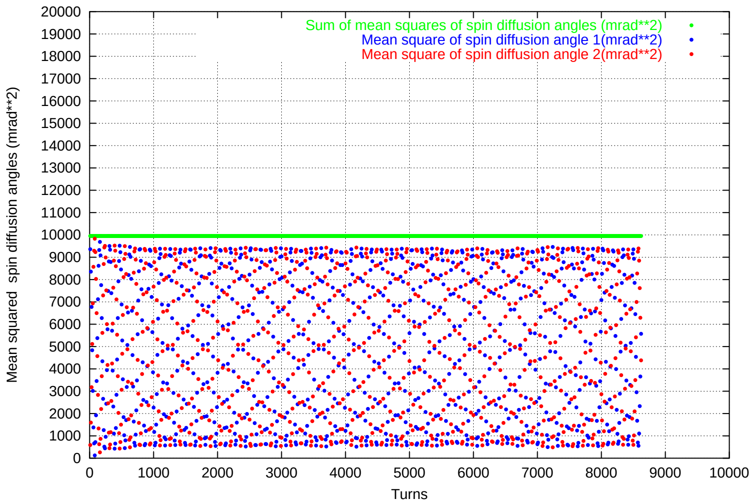

Figure 1: OCS6: mean squared spin angles at 5 GeV for a synchrotron tune of 0.0638, sampled every 10 turns for about 7 transverse damping times.

and results of simulations for positrons with their large initial energy spread will be provided in an extended version of this paper, published as a Cockcroft report. See [10] too.

References

[1] D.P. Barber and G. Ripken, Handbook of Accelerator Physics and Engineering, Eds. A.W. Chao and M. Tigner, World Scientific, 3rd edition (2006).

[2] A. Wolski *et al.*, Configuration studies and recommendations for the ILC Damping Rings, LBNL-59449, Cockcroft-06-04 (2006).

[3] D.P Barber *et al.*, Polarisation in the eRHIC electron(positron)ring, Cockcroft-04-01 (2004).

[4] L.I. Malysheva *et al.*, *Depolarization effects at the ILC*, 17th International Spin Physics Symposium (SPIN2006), Kyoto, Japan (2006).

[5] D.P.Barber, J.A. Ellison and K. Heinemann, Phys. Rev. ST Accel. Beams **7**(12), 124002 (2004).

[6] K. Heinemann and G.H. Hoffstaetter, Phys.Rev. **E 54**(4) 4240 (1996).

[7] A. Wolski and D. Bates, LCC-0155, CBP Tech Note-326 (2004).

[8] N.J. Walker, "MERLIN", http://www.desy.de/~merlin

[9] K. Heinemann, DESY Report 97–166 (1997) and arXiv physics/9709025.

[10] `http://ilcagenda.linearcollider.org/contributionDisplay.py?contribId=252&sessionId=92&confId=1296`