Electron and positron polarisation at HERA: Past and Future [1]

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Abstract. Some aspects of radiative spin polarisation in the HERA electron/positron ring are presented.

INTRODUCTION

HERA is the $e^{\pm} - p$ collider at DESY in Hamburg. The e^+ or e^- beams run at about 27.5 GeV. Up to the end of 1997 the proton ring ran at 820 GeV. Since 1998 it has been running at 920 GeV. An integral part of the design of HERA was the provision of longitudinally spin polarised $e^{\pm}$ for the high energy physics experiments at the interaction points and the HERA $e^{\pm}$ ring is the first and only high energy $e^{\pm}$ storage ring at which longitudinal spin polarisation has been obtained.

Stored $e^{\pm}$ beams can become vertically polarised due to the emission of spin–flip synchrotron radiation — the Sokolov-Ternov (S–T) effect [1,2]. The maximum polarisation achievable is 92.4%, corresponding to a planar ring. To provide longitudinal polarisation at an interaction point (IP) the naturally occurring vertical polarisation in the arcs must be rotated into the longitudinal direction just before the IP and back to the vertical just after the IP using special magnet configurations called spin rotators.

Synchrotron radiation not only generates polarisation but can also cause depolarisation due to the stochastic excitation of the electron orbits by emission of synchrotron radiation photons [1–3]. The depolarisation can be strong in the presence of orbit distortions and is potentially very strong in the presence of spin rotators. Furthermore the ratio: (depolarisation rate/polarisation rate) increases strongly with energy. However, the depolarising effects associated with orbit distortion can be minimised by applying "harmonic closed orbit spin matching" [4,2] and the strong depolarisation associated with the rotators can, at least in principle,

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be combatted by optimising the optic using the technique of "strong synchrobeta spin matching" [5,2]. This has indeed proved to be the case: after a pair of dipole spin rotators was installed at the ends of the East interaction region in 1994 for the HERMES experiment, high longitudinal polarisation was obtained on the first attempt. Since then the HERMES experiment has been running regularly with longitudinal $e^{\pm}$ polarisation.

Since the details of the project and early performance including diagrams are available in [5,6] it is not necessary to repeat the details here. Instead, this article will review some special topics, provide an update on experience since 1994 and describe future plans. The reader is referred to [1–3] for extensive descriptions of the necessary basic theory.

OPTIMISATION AND TUNING

Depolarisation is particularly strong at the spin–orbit resonance condition: $\nu = k_0 + k_1 Q_1 + k_2 Q_2 + k_3 Q_3$ where the Q's are the tunes of the orbital modes, the k's are integers and ν is the amplitude dependent spin tune discussed in [7] in these Proceedings. At the typical energies of $e^{\pm}$ rings ν can be approximated by its value on the closed orbit, ν_0, [7] and this is usually approximately proportional to the machine energy.

So for high polarisation one should set ν_0 close to $1/2$ so that it is optimally away from the fractional betatron tunes. Indeed, 27.5 GeV corresponds to $\nu_0 \approx 62.5$. Then the optic should be strongly spin matched [2] while ensuring that it remains suitable for obtaining high luminosity. For example, the beam size at the interaction points must remain small and the tunes must remain acceptable — etc. This is done at the design stage and then for each new optic. The polarisation that can then be expected can be estimated using one of several computer codes [2]. Only the perfectly aligned ring should be considered! There is no point in trying to include the effects of misalignments — they are not only unknown but they would also totally confuse the matching procedure. A sketch illustrating the estimated polarisation before and after such spin matching can be found in [8]. It is recommended that the strong synchrobeta spin matching be done with the spin transfer matrix formalism since that involves mathematics closely related to that used in the various algorithms used to calculate the polarisation [2].

Once the machine is running, the orbit should be flattened as well as possible. Then, after the polarisation has reached equilibrium the energy should be scanned to see if more polarisation can be achieved. This ensures that one is not sitting at a synchrotron sideband of a parent betatron resonance.

The next step is to apply harmonic closed orbit spin matching by adjusting the specially provided orbit bumps [4,5,2]. This is done empirically by observing the polarisation as the orbit bumps are adjusted.

Once an acceptable level of polarisation has been obtained, a further energy scan can be tried as well as small adjustments of the orbital tunes.

BEAM–BEAM EFFECT

The $e^{\pm}$ polarisation at HERA can also be affected by the beam–beam (b–b) force occurring during collisions with the proton beam at the South and North interaction points (the H1 and ZEUS experiments) where, incidently, the polarisation is vertical. Since the b–b force is very nonlinear it is very difficult to make analytical calculations of its effect on $e^{\pm}$ beams. It is even more difficult to make analytical estimates of the effect on the polarisation. However, the naive expectation is that the b–b force reduces the polarisation. For example, even if the b–b force were linear, the spin matches could be disturbed. Normally is it assumed that it is a good idea to reduce the b-b tune shift but as usual, there is no substitute for measurement and in 1996 even during collisions with 50 mA of protons, positron polarisations of up to 70 % were observed with the rotators running. Earlier, in 1995, we maintained 70 % for a run lasting ten hours. So, at least under *those* conditions, b–b forces had little influence.

Since a few proton bunches, which would normally be in collision with electrons (positrons), are by intent missing, not all electron (positron) bunches come to collision with protons. Towards the end of 1996 a second Compton polarimeter, built by HERMES, came into operation [9]. At about the same time we began to run with up to 100 mA of protons and then noticed that at the high currents it was difficult to attain more than about 60 %. Whereas the first Compton polarimeter measures vertical polarisation in the West area, the new polarimeter measures longitudinal polarisation directly close to HERMES and collects data much more quickly. Note that the *value* of the polarisation is the same all around the ring. This is confirmed by the two polarimeters. With the faster polarimeter it became possible to study the polarisation with sufficient precision on a bunch–to–bunch basis. Then contrary to intuition, it was seen that the colliding bunches sometimes have *more* polarisation than the non-colliding bunches [10,9]. We interpret this unexpected result as being due to the b–b tune shift: the colliding bunches and non–colliding bunches have different betatron tunes. So it is possible that the non–colliding bunches are close to a depolarising spin–orbit resonance (probably a synchrotron sideband resonance of a parent resonance [2]) and likely that the colliding bunches are not on such a resonance. Moreover, in the presence of the (non-linear) b–b effect the resonance structure can be very rich. This interpretation is supported by the fact that with slightly different machine tunes, there is either little difference between the colliding and non–colliding polarisations or the colliding bunches indeed have less polarisation than the non–colliding bunches.

One also sometimes observes that in the presence of b–b effect the rise time for the polarisation after injection is larger than that expected from standard radiative polarisation theory and that the polarisation level is sometimes relatively insensitive to the settings of the closed orbit harmonics of the harmonic closed orbit correction scheme. Clearly, it makes little sense to calibrate a polarimeter, by measuring the rise time [4], while the beam is in collision with protons.

The electron (positron) bunches in HERA come in three groups of sixty bunches with gaps between the groups. This causes dynamic beam loading of the rf cavity system so that the synchrotron tune can vary along a group with the result that electrons (positrons) at the beginning of a group can be closer to a depolarising resonance than those at the end (or vice versa). Thus we sometimes see a variation of the polarisation of the colliding bunches across a group.

In 2000 under normal running conditions with typically 90 mA or more of protons we had about 50 % to 60 % of equilibrium polarisation, averaged over the bunches. Figure 1 shows measurements with the vertical and longitudinal polarimeters of the polarisation in July 2000 with about 100 mA of protons. We hope to get more insight into the effect of b–b forces on polarisation from numerical tracking simulations.

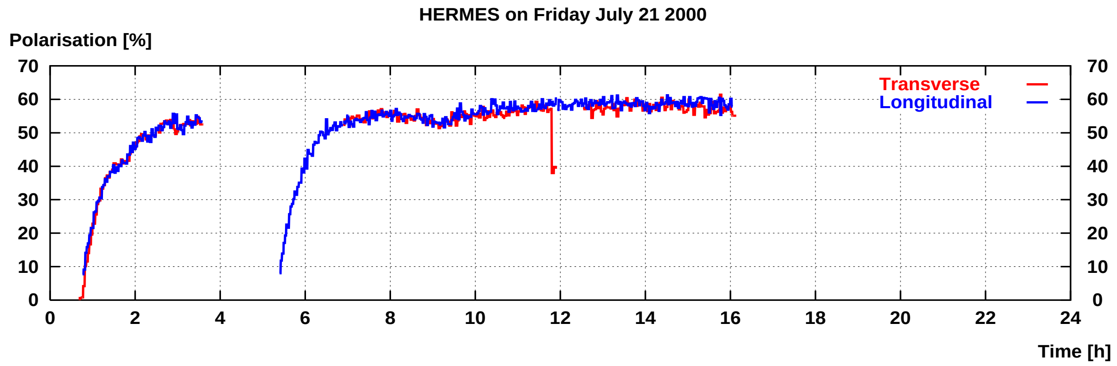

FIGURE 1. Longitudinal and vertical polarisation vs. time (hours) with positrons in collision with 100 mA of protons in North and South. The dip at 9.00 was due to adjustments to the closed orbit.

THE HERA LUMINOSITY UPGRADE

At the time of writing HERA is undergoing a major upgrade to increase the luminosity by a factor of about 4.7 [11]. This will be achieved by going to smaller beta functions at the interaction points and smaller horizontal $e^{\pm}$ emittance (by using an optic with 72 degree instead of 60 degree phase advances in the arcs and by shifting the rf frequency). The smaller beta functions require that the mini–beta combined function magnets are moved closer to the interaction points and that, in turn, entails removal of the "antisolenoids" used to counteract the effect of the H1 and ZEUS solenoids on the beam and the spin. The design orbit is then curved in the solenoids and coupling must be compensated with skew quadrupoles. Moreover, the b–b tune shifts will increase sharply [11]. H1 and ZEUS will also be equipped with spin rotators so that those experiments can run with longitudinal polarisation too. These modifications have major implications for $e^{\pm}$ polarisation and present nontrivial spin matching problems.

STRATEGY FOR ATTAINING HIGH RADIATIVE POLARISATION

In order to ensure attaining high longitudinal $e^{\pm}$ polarisation via the S–T effect at high energy (a few tens of GeV) in a storage ring, the lattice, the rotators, the optic etc, should be appropriately designed from the beginning. It is difficult to add polarisation as an after thought. Particular attention should be paid to good alignment control and beam position monitoring. For example, beam based calibration of monitor positions should be possible. The detector solenoids should be compensated locally with anti–solenoids. Very careful attention should be paid to polarimeter design so that synchrotron radiation and gas bremsstrahlung backgrounds are avoided. The feasibility of satisfactory strong synchrobeta spin matching should be demonstrated at the design stage and the resulting required number of independent quadrupole circuits should be provided.

At a few GeV the depolarisation effects tend to be much weaker than at (say) HERA energies but even for low energy rings calculations show that one should not be complacent.

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