Summary on Electron/positron polarization in rings

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1 Self polarization.

Electrons in storage rings can become spin polarized due to emission of synchrotron radiation. This is the so called Sokolov–Ternov effect. In flat rings without uncompensated solenoids the polarization is perpendicular to the machine plane and has a maximum value of $P_{st} = 92.4\%$. However real rings have misalignments, inhomogeneous fields, vertical bends etc and synchrotron radiation excites orbit motion. This leads to depolarization. So synchrotron radiation not only creates polarization but also causes loss of polarization. Then equilibrium polarization that can be attained is the result of a balance between the two effects. To obtain the longitudinal polarization preferred by experimenters the polarization vector which is vertical in the arcs must be rotated into the longitudinal direction before an interaction point and back to the vertical afterwards using magnet systems called spin rotators. But depolarization can be very strong if the polarization vector is horizontal in parts of the ring or if vertical dispersion generates vertical emittance. The depolarization in particularly strong at spin–orbit resonances: $\nu_{\rm spin} = k + k_I\nu_I + k_{II}\nu_{II} + k_{III}\nu_{III}$. So with rotators the depolarization can be very dangerous. However this source of depolarization can in principle be combatted by a special choice/adjustment of the optic called strong synchro–beta spin matching. It is also necessary to adjust orbit distortions to keep the polarization vector very close to vertical in the arcs using a method called harmonic closed orbit spin matching. In spite of these difficulties, up to 70% longitudinal polarization *has* been achieved at high energy, namely at 27.5 GeV in the electron–proton collider HERA. Spin matching works. Up to 57% vertical polarization has been achieved at 46 GeV in LEP. In 1999 7% vertical polarizaton was achieved in LEP at 60 GeV.

This experience is the basis of preparations for attaining high polarization in new machines. Note that the techniques for the suppression of depolarization are also applicable to rings for which the beam is already polarized at injection.

2 New rings under consideration

Some new $e^\pm - p$ or $e^\pm -$ nucleus storage rings are now being considered. They require high luminosity (10^{33}cm^{-2}sec^{-1} or more) and longitudinally polarized $e^\pm$ and protons. The EPIC machine would have 3.5 – 7 GeV $e^\pm$ and 16 – 32 GeV protons. The eRHIC concept would involve installing a 10 GeV ring in the RHIC tunnel to complement the 250 GeV polarized protons with polarized electrons. The possibilities of installing a 185 GeV electron ring in the VLHC tunnel as well as attaining polarization at 45 GeV in the $e^{\pm}$ booster ring are also being studied. These concepts present new challenges even with the experience gathered at HERA and LEP.

With the system of spin rotators (effectively each pair represents a Siberian Snake) suggested for eRHIC the Sokolov–Ternov effect would vanish so that a pre–polarized beam would have to be injected either from a linear accelerator or from a polarizing injector. The latter has the advantage that polarized positrons could be provided. However, it is conceivable that the polarization lifetime could then be several hours with some attention to spin matching. For EPIC, the polarization rate at the central energy of 5.25 GeV would be hours unless polarizing wigglers were installed. Up to about 90 % polarization might then be attained. The Sokolov–Ternov polarizing time at the VLHC would be about 2 hours but the spread, due to the energy spread, of the rate of spin precession would be so great that the beam would be very strongly depolarized by synchrotron sideband resonances. This depolarization could be suppressed by installing a pair of snakes but the Sokolov–Ternov effect would then vanish unless the radiation rates in the two segments of the ring could be made unequal with the aid of wigglers or dipoles of unequal strength. The 45 GeV VLHC injector ring could probably be designed to have polarization characteristics somewhat similar to those of LEP but with a Sokolov–Ternov time of less than an hour. In any case *careful calculations of the rates of depolarization in such rings are essential.* It is inadmissible to rely solely on calculations of the pure Sokolov–Ternov characteristics of a ring given the software and experience now available for estimating depolarizing effects.

Another class of ring, namely those for which a pre-polarized beam is injected at low energy, accelerated very quickly in just a few turns and then extracted such as in the 15–25 GeV ELFE at CERN design, should present no problem provided that the polarization in the arcs of the race track is vertical. The success of polarized operation of the CEBAF ring has already lent support to the efficacy of the race track concept. However, injection at low energy followed by slow acceleration to high energy will very likely lead to a loss of polarization as resonances are crossed in the presence of the "depolarization enhancing" effect of synchrotron radiation. There is already evidence of this at ELSA in Bonn at 1.76 GeV.

Low energy $e^{\pm}$ rings are also important, namely for our understanding of subtle spin–orbit dynamical effects. For example, among other things, the MIT–Bates ring will provide a very useful check of the existence and magnitude of the "kinetic polarization" mechanism which is distinct from the Sokolov–Ternov effect.

3 Recommendations for obtaining high self polarization or large lifetime for stored injected polarization.

- Include polarization in the design (lattice, rotators, optic, spin matching) from the start — it should not be an "add on".
- Pay particular attention to:
  - alignment control and beam position monitoring and provide facilities for beam–

based monitor calibration so that the depolarizing effects of misalignment can be minimized and harmonic C.O. spin matching can be facilitated

  - careful solenoid compensation — provide local anti–solenoids if possible.

- Use the spin transfer matrix formalism for spin matching in exotic machines and understand the physics of the spin–orbit coupling of each section of the ring. Ensure that spin matching is not hindered by a lack of independent quadrupole circuits.

- Pay close attention to polarimetry. Fast precise polarimeters are essential for facilitating fast adjustment of the orbit or tunes. Build the machine around the polarimeter(s) so that bremsstrahlung and synchrotron radiation backgrounds are avoided.

- There is plenty of software available for detailed numerical calculations. The theory of depolarization for linear orbit motion is well established.

- Very interesting depolarization effects due to beam–beam forces have been seen at HERA and LEP. For future high luminosity ring–ring colliders it will be very important to have a good understanding of these effects and to be able to carry out reliable simulations with tracking codes. This could become a high priority for running in the presence of intense proton beams.

4 Question

How is the polarization of an intense proton beam of the kind needed for EPIC and eRHIC affected by combined intrabeam scattering and electron cooling with IBS times of about 20 minutes?