STUDY OF ELECTRON POLARIZATION DYNAMICS IN THE JLEIC AT JLAB*

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Abstract

The design of an electron polarization scheme in the Jefferson Lab Electron-Ion Collider (JLEIC) aims to attain a high longitudinal electron polarization (over 70%) at collision points as required by the nuclear physics program. Comprehensive strategies for achieving this goal have been considered and developed including injection of highly polarized electrons from CEBAF, mechanisms for manipulation and preservation of the polarization in the JLEIC collider ring and measurement of the electron polarization. In particular, maintaining a sufficiently long polarization lifetime is crucial for accumulation of adequate experimental statistics. The chosen electron polarization configuration, based on the unique figure-8 geometry of the ring, removes the electron spin-tune energy dependence. This significantly simplifies the control of the electron polarization and suppresses the synchrotron sideband resonances. This paper reports recent studies and simulations of the electron polarization dynamics in the JLEIC electron collider ring.

INTRODUCTION

The Jefferson Lab Electron Ion Collider has been developed to deliver polarized electron and ion beams for collisions at the interaction points (IPs) [1]. The nuclear physics program requires high polarization, long polarization lifetime and capability of polarization control over a wide energy range. As the central part of this facility, we adopt a figure-8 shape collider ring design [2] to ensure the polarization in excess of 80% for both beams. The essence of a figure-8 ring is that an ideal lattice is transparent to the spin motion. Any spin orientation is periodic and the design-orbit spin tune is zero and energy independent. Since there is no preferred polarization orientation, the polarization can be easily stabilized and controlled using small magnetic fields [3].

The electron complex of the JLEIC consists of the existing CEBAF and the electron collider ring. CEBAF serves as a full energy injector providing a capability of continuous injection of a polarized electron beam, which is one of the key design strategies of electron polarization for maintaining a high equilibrium polarization. The electron collider ring is designed to have vertical polarizations in two arcs and longitudinal polarizations at the IPs. Spin rotation is realized by spin rotators [4] at each end of two arcs. As shown in Fig. 1, the polarization (solid or dashed purple arrow) is anti-parallel to the vertical guiding field (solid green arrow) in one arc and parallel to the guiding field in the other, regardless of the choice of two possible opposite longitudinal polarization states at the IPs. Hence, the Sokolov-Ternov self-polarization [5] process has a net depolarization effect in the whole collider ring. Two co-existing polarization states will be equally impacted over the whole ring and have the same polarization lifetimes. Detail of electron polarization design strategies are described in [1].

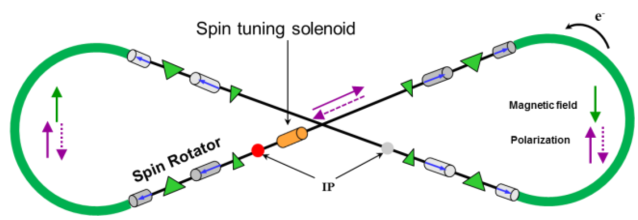

Figure 1: Polarization configuration in the JLEIC electron collider ring. Two polarization states (solid and dashed purple arrows) are co-existing in the collider.

TRACKING SIMULATION

With the figure-8 electron collider ring, the design-orbit spin tune is energy independent during the acceleration and storage. However, the zero design-orbit spin tune introduces the zero-integer spin resonance that needs to be compensated. To stabilize the spin motion, it is sufficient to use a weak magnet insertion to move the spin tune away from zero. In the electron polarization studies, a spin-tuning solenoid, shown in Fig. 1, is placed in the straight section. Since the polarization direction is longitudinal in the straight, the spin-tuning solenoid does not affect the polarization direction in the collider ring but generates additional spin precession, resulting in a change of the spin tune. Note that a full energy electron beam is injected from the CEBAF into the electron collider ring. Therefore, the spin-tuning solenoid does not need to ramp once an optimum spin tune is found.

Simulation of a spin tune scan has been performed in the electron collider ring to study how strongly the polarization lifetime depends on the spin tune. Various spin tunes can be obtained by adjusting the strength of the spin-tuning solenoid. With this, one can find an optimum spin tune that provides a long polarization lifetime. Figure 2 shows the tracking simulation results for an electron beam at 5 GeV using *SLICK/SLICKTRACK* [6]: the Sokolov-Ternov time is in red, the depolarization time in the linear approximation (SLICK) is in green and the depolarization time of 500 particles from a Monte-Carlo simulation (SLICKTRACK) is in blue.

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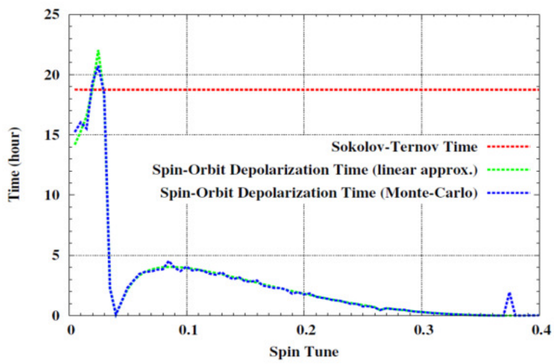

Figure 2: Spin tune scan for polarized electron beams at 5GeV in the electron collider ring.

Quadrupoles are vertically misaligned according to a Gaussian distribution with an rms width of 0.2 mm and dipoles are rolled according to a Gaussian distribution with an rms width of 0.2 mrad. The rms vertical closed orbit excursion is corrected to within a few tens of micrometer level. As shown in Fig. 2, an optimum long polarization lifetime can be reached when the spin tune is moved away from zero by about 0.025. This requires a field integral of the spin-tuning solenoid of only about 3 T.m. The first order synchrotron resonance occurs when the spin tune equals the synchrotron tune of 0.038, due to the effect of the vertical closed-orbit distortion. A first order horizontal resonance occurs when the spin tune equals the fractional part of the horizontal betatron tune 0.33. Short polarization lifetimes with spin tunes between the first synchrotron and horizontal resonances are due to the lack of spin transparency of the spin rotator systems for the horizontal betatron motion.

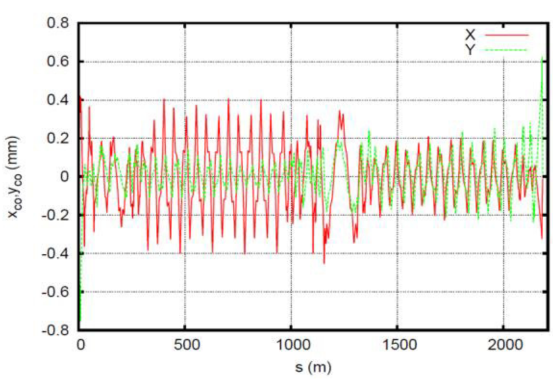

Figure 3: Horizontal (red) and vertical (green) closed orbit excursions with random quadrupole misalignments.

Preliminary tracking simulations are also carried out using *ZGOUBI* [7] to obtain two independent assessments of polarization. Note that more effort is needed to establish the same simulation conditions in the two codes so that one can make a fair comparison of simulation results. Therefore, the simulation performed in *ZGOUBI* has similar, though not exactly the same, conditions as the simulation in *SLICK/SLICKTRACK*. Quadrupoles in the electron ring are randomly misaligned in both horizontal and vertical planes so that the closed orbit excursions reach a few hundred micrometers, as shown in Fig. 3, that is considered to be a typical corrected orbit in an accelerator.

In order to restrict the computing time, spin tracking simulations are performed using 20 particles with the two characteristic spin tunes, 0.027 and 0.038. According to the simulation results from *SLICK/SLICKTRACK*, a spin tune of 0.027 produces a relatively long polarization lifetime and a spin tune of 0.038 gives zero polarization lifetime due to the first order synchrotron resonance. In order to balance the computing time consumption and time needed for electrons damped to the equilibrium condition caused by the synchrotron radiation, tracking simulations are performed for about 7 damping times (~ 80000 turns) when the electron emittance is very close to the equilibrium emittance of 9 nm-rad.

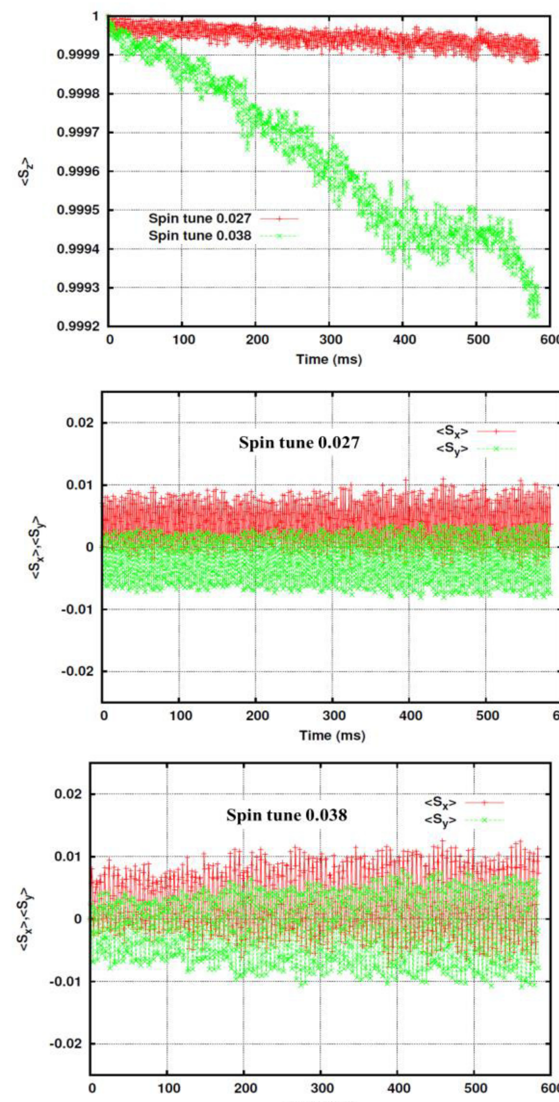

Figure 4: Average spin components ($<S_z>$-longitudinal, $<S_x>$-horizontal, $<S_y>$-vertical) as a function of time at two characteristic spin tunes of 0.027 and 0.038.

Figure 4 presents the simulation results of average spin components as a function of time for spin tunes at

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0.027 and 0.038. <S_z> is the longitudinal component, <S_x> and <S_y> are two transverse components. All particles are initially launched at the IP with the spin along the longitudinal direction, as required by the experiments. As shown in Fig. 4, the longitudinal polarization (top plot) decays with time and the transverse polarizations (bottom two plots) grow with time for both spin tunes. At the close-to-optimum spin tune of 0.027, the polarization decays much slower than the one at the spin tune of 0.038 where the first order synchrotron resonance occurs.

SUMMARY

This paper reports recent studies of the electron polarization dynamics in the JLEIC electron collider ring. Simulations are initiated and performed in two codes of *SLICK/SLICKTRACK* and *ZGOUBI* with the aim of comparing the results. Preliminary tracking simulation results are very encouraging. The future work will focus on running two codes under the same conditions for a fair comparison.

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