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# PRESERVATION OF ELECTRON POLARIZATION IN THE MEIC COLLIDER RING*

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*Abstract*

A highly longitudinally-polarized (over 70%) electron beam is required by the nuclear physics programme of the Medium Energy Electron-Ion Collider (MEIC) at Jefferson Lab (JLab). To achieve this goal, a highly vertically-polarized electron beam is injected from the CEBAF. The polarization will be vertical in the arcs to avoid spin diffusion, and longitudinal at the collision points. The polarization rotation will be accomplished by using a total of four spin rotators, each of which consists of a set of solenoids and dipoles, placed at the ends of two arcs. The polarization configuration cancels the 1st order spin perturbation in the solenoids for the off-momentum particles and significantly reduces the synchrotron sideband resonances. In order to compensate the net Sokolov-Ternov depolarization effect, especially at higher energies, a continuous injection of a polarized electron beam from the CEBAF is being considered. We consider to perform a moderate spin matching in some key regions to extend the polarization lifetime so that the continuous injection can work more efficiently, while not imposing a burden on the optics design of the collider ring.

## INTRODUCTION

An essential aspect of the design strategy of JLab's MEIC electron ring is the need to meet the expectations of the nuclear physics programme, namely of preserving and manipulating a highly polarized electron beam [1]. At least 70% longitudinal electron polarization at collision points should be achieved with a reasonably long lifetime. Spin flipping is required to reduce the systemic uncertainties in the experiments.

To satisfy the requirements, various strategies from different perspectives have been carefully considered and investigated. In this paper, we will focus on realistic considerations of various related issues from the injection to the storage of polarized electron beam.

## POLARIZATION STRATEGIES

A highly vertically-polarized electron beam (>85%) is injected from the CEBAF into the MEIC electron collider ring at a full energy from 3 to 12 GeV. Such an injection with vertical, instead of longitudinal, polarization has three advantages. First, it avoids spin decoherence caused by the energy variation during the acceleration in the CEBAF. Second, it simplifies polarization transport between the CEBAF and MEIC collider ring. Third, electron beams with vertical polarization are injected to the MEIC electron collider ring in the arc section. By doing this, it can significantly reduce the background in the detector because dipole magnets in the arc sweep out incompletely injected electrons so that they have less chance to propagate through the chamber and hit the detectors.

The polarization in the MEIC electron collider ring is designed to be vertical in the arcs to minimize spin depolarization, and longitudinal at collision points for experiments, as shown in Figure 1, using four universal spin rotators [2] located at each end of two arcs. Such spin rotators, composed of interleaved solenoid and dipole fields, were designed to rotate electron polarization in the whole energy range from 3 to 12 GeV. The transverse orbital coupling induced by the longitudinal fields in the solenoids is neutralized by placing quadrupoles between half solenoids [3,4].

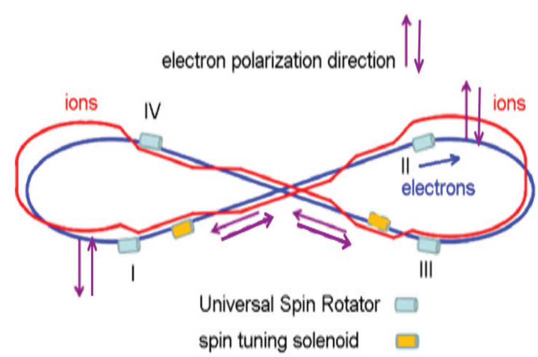


Figure 1: Polarization configuration in the MEIC electron collider ring.

The polarization configuration in the MEIC electron collider ring is determined by the solenoid field directions in the pair of spin rotators in the same long straight. These were chosen to have the opposite solenoid polarities [5], as shown in Figure 2. Then the polarization is anti-parallel to the vertical guiding field in one arc and parallel to the guiding field in the other one, regardless of the choice of two possible opposite longitudinal polarizations (black solid and dashed arrows in Figure 2) at the IPs. Therefore, the Sokolov-Ternov self-polarization [6] process has a net depolarization effect in the whole collider ring, and both polarization states from the polarized source will be equally affected.

In addition, with such opposite longitudinal solenoid fields in the pair of spin rotators in the same long straight, the net field integral is zero. As a result, the 1st order spin perturbation in the solenoids for off-momentum particles

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vanishes. This significantly extends the polarization lifetime and reduces the burden on the spin matching and ring-optics design. Though this polarization configuration has zero equilibrium polarization, with highly polarized injected beams, the polarization lifetime at low energies (< 9GeV) is large enough (~half an hour to a couple hours) for detectors to collect data.

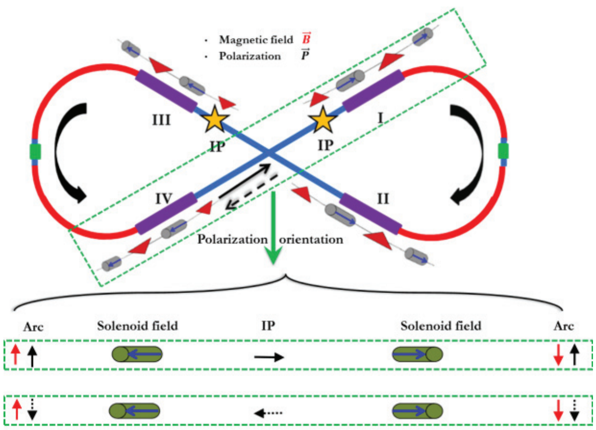


Figure 2: Polarization ($\vec{P}$, black arrow) directions remain same in the two arcs by having opposite longitudinal solenoid field directions in the same long straight. The blue arrow in the solenoid represents the field direction. The polarization orientation in one of the two long straights (shown in the green box) is exhibited under the half brace with two different polarization states at the IP.

The electron polarization configuration, combing with a figure-8 geometry of collider ring, produces a net zero spin precession. Hence the spin tune on the design orbit is zero and independent of beam energy. This significantly reduces the synchrotron sideband resonances. In addition, since there is no preferred direction of the polarization, the polarization can be easily controlled and stabilized by using relatively small magnetic fields, for example spin tuning solenoids in the straights where the polarization is longitudinal.

The desired spin flipping in the MEIC electron ring is likely to be implemented by alternating the helicity of the photo-injector drive laser at the source to provide oppositely polarized bunch trains. Here, two polarization states coexist in the collider ring and have similar polarization degradation in the aforementioned MEIC polarization configuration. Two long oppositely polarized bunch trains have been considered in the collider ring, as shown in Figure 3. This simplifies the Compton polarimeters for polarization measurements in the collider ring.

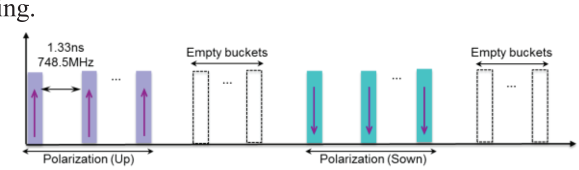


Figure 3: Bunch train and polarization pattern in the MEIC electron collider ring.

## POLARIZATION COMPENSATION

As mentioned above, the Sokolov-Ternov self-polarization has a net depolarization effect. This may be a challenge at higher energies where the polarization lifetime is mainly determined by the net Sokolov-Ternov depolarization effect and its lifetime is inversely proportional to the 5$^{th}$ power of the Lorenz factor. For the MEIC, we consider a scheme of continuous injection [7,8] of highly polarized electron beams from the CEBAF to compensate the polarization loss, especially at higher energies [5]. To make the continuous injection more efficient and to obtain a high average polarization over time, a moderate spin matching technique, to achieve spin transparency, will be applied to suppress spin diffusion in some key regions by tuning the optics elements around the ring.

### *Continuous Injection*

By mixing the partly depolarized stored beam with fresh highly polarized beam through continuous injection, the relative equilibrium polarization at a constant stored beam current is given as [5]

$$\frac{P_{equ}}{P_0} = \frac{\frac{I_{inj}}{I_{ring}} f_{rev}}{\frac{1}{\tau_{dk}} + \frac{I_{inj}}{I_{ring}} f_{rev}}, \qquad (1)$$

where $P_{equ}$ is the attained equilibrium polarization, $P_o$ is the injected polarization, $I_{inj}$ is the average injected beam current, $I_{ring}$ is the stored beam current, $f_{rev}$ is the revolution frequency, and $\tau_{dk}$ is the D-K polarization lifetime that can be estimated using the code SLICK [9]. The relative equilibrium polarization as a function of average injected current at various energies is shown in Figure 4 using the nominal MEIC designed parameters. At a reasonably low average beam current at the nA level, the relative equilibrium polarization above 85% in the MEIC electron collider ring can be easily achieved. If necessary, some extraction may be induced to avoid beam blow up.

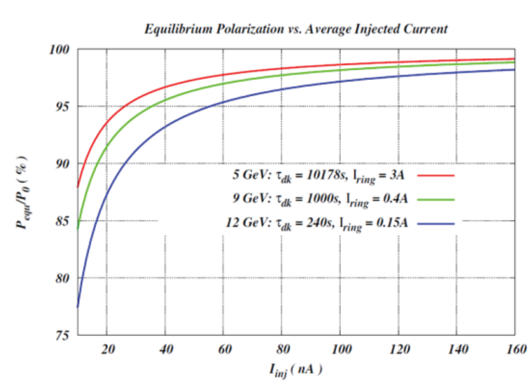


Figure 4: Relative equilibrium polarization as a function of average injected current at various energies.

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In addition, continuous injection compensates particle losses due to any inter-beam scattering effects so that a constant beam current can be achieved. Continuous injection also reduces the burden of expanding the momentum acceptance because a standard momentum acceptance can facilitate particle extraction. [5]

### *Spin Matching*

As expected from Eq.(1) and demonstrated in Fig.4, a reasonably large D-K polarization lifetime in the MEIC electron collider ring guarantees that the continuous injection scheme can work with lower average injected current. A longer D-K polarization lifetime can further reduce the average injected current required to maintain a high polarization. The lower the continuously injected beam current is, the lower the induced background in the detectors. Therefore, a moderate spin matching in some key regions to extend the polarization lifetime can help the continuous injection scheme to work more efficiently. In practice, depolarization due to closed orbit distortion resulting from magnet misalignments will also need attention.

Achieving spin transparency requires a large amount of work on the optics. However, the first impression can be easily obtained through diagnostic facilities provided in the code SLICK [9]. Dominant contributions to the polarization lifetime can be discovered by switching on or off spin-orbit coupling matrices in chosen sections. Such experience has been applied for HERA polarization studies and guided the spin matching strategy.

Recently, the code SLICK has been modified to allow spin tune scans at fixed energy, as a way to investigate depolarization resonances without the usual widely used actual energy scans and the accompanying necessary retuning of the rotators. As an example, Figure 5 shows the polarization lifetimes for a perfectly aligned ring in a range of spin tune from 0 to 0.45 at 5 GeV. The Sokolov-Ternov polarization lifetime (red line in Figure 5) is determined by the accelerator design and independent of the spin tune. The polarization lifetimes with spin-orbit coupling matrices on (green line in Figure 5) and off (blue line in Figure 5) degrade when the spin tune approaches the horizontal betatron tune at 0.32 and synchrotron tune at 0.051. However, away from the 1st order horizontal and longitudinal resonances, the polarization lifetime is about 3 times larger with spin-orbit coupling matrices off for the quadrupoles in the spin rotators, than when they are on. This test illustrates the way, mentioned above, to look for dominant sources of depolarization due to spin-orbit coupling and as expected it shows that spin matching to make this region spin transparent would be helpful.

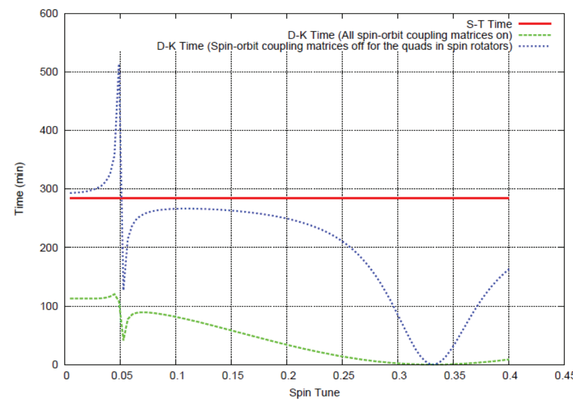


Figure 5: Example of spin tune scan at 5GeV MEIC electron collider ring.

## CONCLUSION

The strategies for achieving highly polarized electron beams in the MEIC collider ring have been described in detail. These include the injection of polarized electron beams from the CEBAF, the polarization configuration in the electron collider ring, and polarization preservation with the help of continuous injection and moderate spin matching. The code SLICK has been modified to partially simulate the effect of varying the spin tune and this will play an important role in the polarization studies in the future.

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