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SPIN DYNAMICS IN THE JLEIC ION INJECTOR LINAC*

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Abstract

One of the requirements for the future Electron Ion Collider (EIC) is to collide polarized electrons and light ions with at least 70% polarization for each beam. For light ions, polarized ion sources are used for injection to a linac, which is usually the first accelerator in the collider chain. The Jefferson Lab EIC (JLEIC) ion injector linac consists of a low-energy room-temperature section with quadrupole focusing followed by a superconducting linac with solenoid focusing inside long cryomodules. These two sections have different effects on the spin. Spin dynamics simulation studies are carried out for the JLEIC injector linac in order to preserve and maintain a high degree of polarization for light ion beams for delivery to the booster. The different options to maintain and restore the spin in the different sections of the linac for hydrogen, deuterium and helium ions are presented and discussed. Results from both the Zgoubi and COSY-Infinity codes are presented and compared for every section of the ion linac but the radio-frequency quadrupole (RFQ). Currently, a method to simulate the RFQ using Zgoubi is being investigated.

INTRODUCTION

The Jefferson Lab Electron Ion Collider (JLEIC) is based on a ring-ring collider design [1]. It consists of two intersecting accelerators, one producing an intense beam of electrons, the other a beam of protons, light or heavier atomic nuclei, which are steered into head-on collisions.

One of the accelerator challenges is to produce and maintain a high degree of polarization to be able to get insight into the nucleon spin. Around ~70% polarization is needed for both beams, the electron and the light ion beams [2].

A high energy option for JLEIC's ion complex was recently presented [3], consisting of a 150 MeV ion linac, an 8-GeV figure-8 low-energy booster, a 12-GeV figure-8 high-energy booster and a 200 GeV collider ring. See Fig. 1 for a schematic layout of the current JLEIC ion complex design.

The more compact 150 MeV ion linac [4] was adopted from the alternative design approach [5], and consists of a low-energy room-temperature section with quadrupole focusing followed by a superconducting linac with solenoid focusing inside long cryomodules. See Fig. 2 for a schematic layout of JLEIC ion injector linac.

A spin dynamics study was carried out in the ion linac to ensure a high degree of polarization of the beam. Two different codes, Zgoubi [6] and COSY-Infinity [7], were used for this study. Code-code benchmarking was one of the recommendations of the Community Review Report [8], which is especially important where beam measurement data is not available.

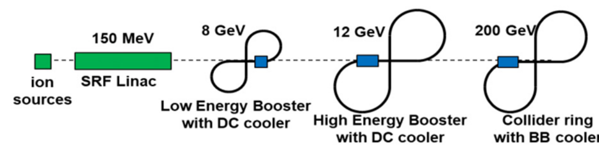

Figure 1: A schematic layout of JLEIC ion complex [3].

SPIN DYNAMICS IN SRF LINAC

The two different sections of the ion linac are analysed separately. The room-temperature section and the superconducting section have different effects on the spin because of the different focusing and beam energy in each section.

Room-temperature Section

The room-temperature section consists of a Low Energy Beam Transport line (LEBT), a radio-frequency quadrupoles (RFQ) and a drift tube linac (DTL). The LEBT section is from the source to the RFQ. The DTL section connects the RFQ to the superconducting radio-frequency (SRF) section.

Spin tracking simulations for both proton and deuteron beams have been performed using both the Zgoubi and COSY-Infinity codes. Unfortunately, none of the codes have a special element for the RFQ, therefore the simulations have been done only for the LEBT and the DTL. Currently, a method to simulate the RFQ using Zgoubi is being investigated.

Figure 3 shows the evolution of different spin components along the LEBT for both proton and deuteron beams. The simulation was performed for a beam of 100 particles starting with vertical spin in both Zgoubi and COSY-Infinity. The agreement between the two codes is almost perfect.

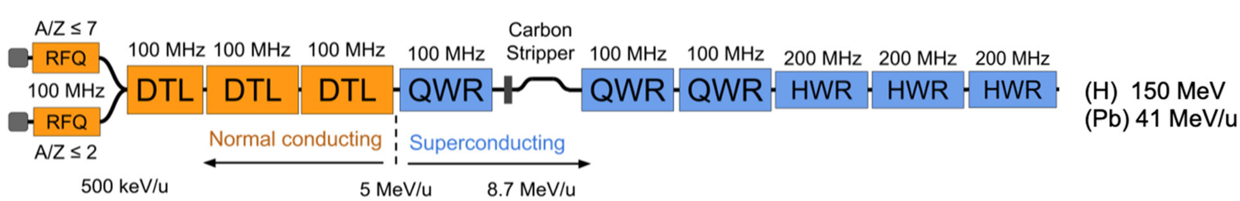

Figure 2: A schematic layout of JLEIC ion injector linac [4].

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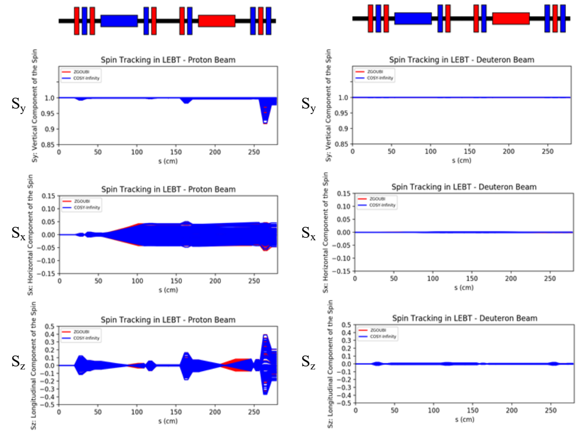

Figure 3: Evolution of the spin components along the LEBT for vertically polarized proton (left) and deuteron (right) beams. The red curves are from Zgoubi while the blue curves are from COSY-Infinity.

Similarly, Fig. 4 shows the evolution of different spin components along the DTL for both protons and deuteron beams. The simulation was also performed for a beam of 100 particles starting with vertical spin. The agreement between the Zgoubi and COSY-Infinity codes is excellent.

There are no significant losses of polarization in either sections.

Superconducting Section

The superconducting section of the compact linac is based on solenoid focusing inside long cryomodules and is made of 3 quarter-wave resonator (QWR) modules and 3 half-wave resonator (HWR) modules. There is a stripper section for heavy-ions after the second QWR module. The original full-energy linac before adopting the more compact linac from the alternative design had 3 QWR modules and 9 HWR modules and went up to 280 MeV proton energy. The full-energy linac was studied first, the half-linac, with up to a 150 MeV proton beam, was later added to the study.

For the superconducting section, in addition to proton and deuteron beams, helium was also considered. Both cases of longitudinally and transversely polarized beams were investigated using both Zgoubi and COSY-Infinity codes. There is an excellent agreement between the codes, (see Fig. 5).

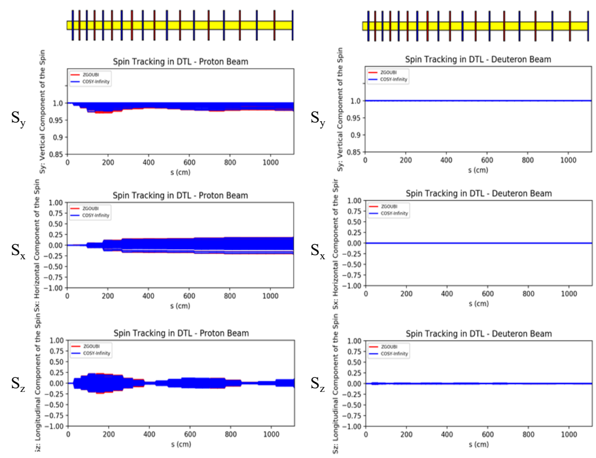

Figure 4: Evolution of the spin components along the DTL for vertically polarized proton (left) and deuteron (right) beams. The red curves are from Zgoubi while the blue curves are from COSY-Infinity.

Spin Correction Following the spin dynamics studies, different schemes to maintain and or restore the initial spin orientation after the linac were investigated.

- In the longitudinal case, the spin was conserved but this requires spin rotators before and after the SRF linac.
- In the transverse case, the spin rotates significantly from its original direction and will require a relatively strong solenoid to restore it, especially for deuteron due to their small g factor.

Figure 5 shows the spin oscillations for vertically polarized beams of proton, deuteron and helium-3 along the SC linac for the case where all solenoids have the same field orientation. In this case, a 1.4 meter long 8-Tesla solenoid will be needed to restore the deuteron spin, which is the most challenging to restore due to its very low g-factor.

Another scheme that was investigated is to alternate the solenoid fields in the SC linac. The spin turns one way or another depending on the direction of the magnetic field, alternating the fields makes the spin rotation from one solenoid be compensated with the next solenoid. Figure 6 shows the spin oscillations in this case for protons, deuterons and helium-3. It can be seen that for deuterons, the

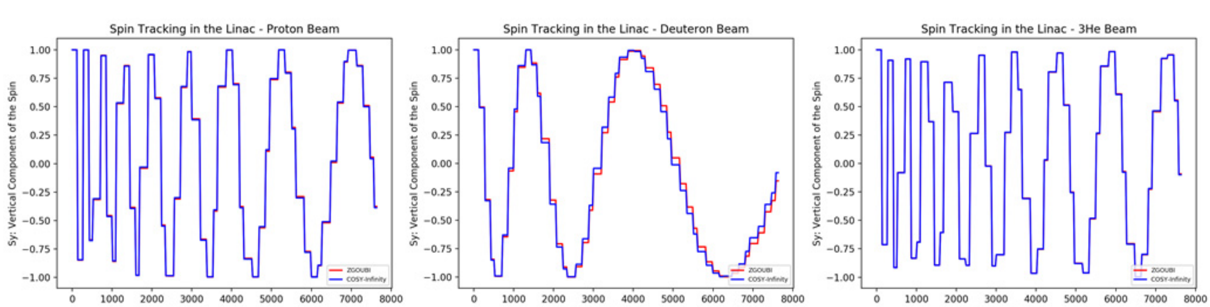

Figure 5: Evolution of the vertical spin component along the SRF linac for vertically polarized proton (left), deuteron (middle) and helium-3 (right) beams. This is the case where all solenoids have the same field orientation.

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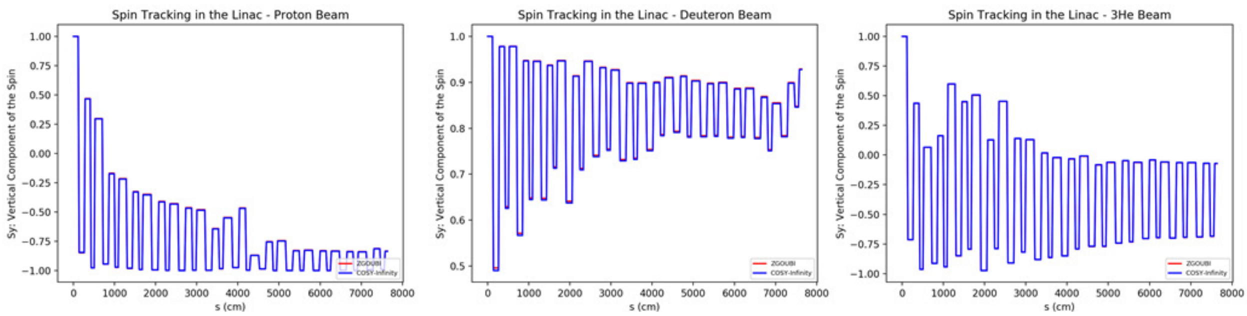

Figure 6: Evolution of the vertical spin component along the SRF linac for vertically polarized proton (left), deuteron (middle) and helium-3 (right) beams. This is the case of alternating solenoid fields in the linac.

maximum departure from the initial spin is less significant, which would require a shorter solenoid to restore it.

The requirements for spin correction in both cases of the same and alternating solenoid field orientation are listed in Table 1 for the full-energy linac, and Table 2 for the half-energy linac.

Table 1: Field requirements for a 30-cm long spin correcting solenoid in both cases where the focusing solenoids in the linac have the same field direction (column 4) and alternating field direction (column 5).

Beam	g-factor	Energy (MeV/u)	Solenoid Strength (T) [1]	Solenoid Strength (T) [2]
Proton	1.793	298	-6.3	-8.2
Deuteron	-0.143	172	25.6	-5.2
Helium	-4.191	218	-6.0	-6.0

[1] Same solenoid fields direction. [2] Alternating solenoid fields direction.

As indicated in Table 1, for alternating focusing solenoid fields, an 8 Tesla – 30 cm long solenoid would be enough to restore the spin of all polarized light ion beams to their initial transverse orientation.

Table 2: Field requirements for a 30-cm long spin correcting solenoid in the case of the half-energy linac for solenoids with the same field orientation (column 4) and alternating field orientation (column 5).

Beam	g-factor	Energy (MeV/u)	Solenoid Strength (T) [1]	Solenoid Strength (T) [2]
Proton	1.793	157	1.9	-4.8
Deuteron	-0.143	90.5	4.1	-5.0
Helium	-4.191	115	-4.7	-4.1

1 Same solenoid fields direction. 2 Alternating solenoid fields direction.

Table 2 shows the field requirements for the half-energy linac that has recently been adopted for the JLEIC baseline design. In this case a ~ 5 Tesla - 30 cm long spin correcting solenoid would be sufficient.

CONCLUSIONS

Spin Dynamics in both the low-energy room-temperature section (except for the RFQ) and the superconducting section of the linac were investigated. The spin correction requirements in the case of the same and alternating solenoid field direction are compared for the full-energy and half-energy JLEIC injector linac. It is possible to keep all or almost all of the initial beam polarization with the correction schemes proposed. The spin dynamics results from COSY-Infinity were nearly identical to those of Zgoubi. An end-to-end simulation is planned for the future following the development of a solution to simulate polarization in the RFQ using Zgoubi.

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