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AN INNOVATIVE SPIN PRECESSOR FOR INTERMEDIATE ENERGY PROTONS*

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Abstract

A spin precessor has been designed to provide arbitrary orientation of the polarization in the external proton beam at LAMPF. The device utilizes two superconducting solenoids, three conventional dipoles, and conversion of polarized H^- to H^+ to provide an achromatic, undeflected beam with tunable spin orientation over a range of energies from 400 MeV to 800 MeV. A portion of this device is being installed to provide compatibility between two facilities which simultaneously use two branches of the external proton beam at LAMPF.

Introduction

The problem of arbitrary re-orientation of the polarization vector of a polarized beam has the well-known "Wien filter"[1,2] or "electrostatic separator" as a practical solution at low energies. The "Siberian Snake" has been proposed for use at very high energies[3]. A novel method developed at LAMPF and described elsewhere in these proceedings[4], utilizes the large magnetic moment of the electron in the neutral ion H^0. The methods previously used at intermediate energies have not been capable of arbitrary re-orientation. Particular orientations have been achieved using movable magnets[5] and by deflecting the beam to a new trajectory[6].

For 400-800 MeV protons, the Wien filter requires excessive electric fields and the "Siberian Snake" requires numerous magnets and large apertures. The method utilizing precession of H^0 has the disadvantage that only one-half of an 800 MeV H^- beam can be stripped to H^0 with conventional foil strippers.

The spin precessor[7] described here uses conversion of H^- to H^+ to achieve an undeflected, achromatic beam of protons with polarization vector orientation which is independent of the H^- polarization direction. Solenoids and dipoles are used in the conventional way to achieve precession about the longitudinal and vertical directions. The device takes advantage of the high relative speed of the polarization vector relative to the velocity vector for H^- ions in transverse magnetic fields to minimize the required horizontal dipole apertures. Conversion of H^- to H^+ is the crucial feature which allows a net precession of the spin vector while bending in one plane with no net deflection of the beam.

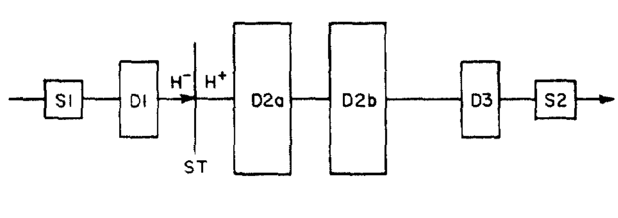

Fig. 1 - Diagram of the elements of the spin precessor. Solenoids are indicated by S and dipoles by D. D2a and D2b may be a single dipole D2. ST is the stripping foil which removes the two electrons from H^-.

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Spin Precessor Design

The spin precessor consists of 2 solenoids, 3 dipoles, a thin foil electron-stripper and beam position monitoring diagnostics. The order of the elements is shown schematically in Fig. 1 and a typical trajectory is shown in Fig. 2. For clarity, the second dipole is shown as two separate elements.

The angle of precession, Ψ, of the proton spin about parallel momentum (P) and magnetic field (B), vectors is

$$\Psi = \frac{e}{Pc}\left(\frac{g}{2}\right)\int B\,d\ell \qquad \text{(Gaussian units)}$$

where e is the proton electric charge. The g-factor is defined for a particle of spin s and magnetic moment μ, by $\mu = \mu_N g s$ where μ_N is the nuclear magneton. Because of the inverse dependence on the momentum, 90° precession is limited to momenta below ~13 GeV/c for practical solenoids. A field integral of 2.7 T·m is required for 90° precession at 800 MeV.

The precession of the proton spin in a magnetic field ($B_\perp$) which is transverse to the spin vector and to the direction of motion is given by the well-known expression[8,9]

$$\theta_R = \gamma\theta_B\left(\frac{g}{2} - 1\right)$$

where θ_R is the change in the angle of the spin vector relative to the direction of motion due to a bend of θ_B. The quantity $\gamma = (1 - \beta^2)^{-1/2}$ is the Lorentz factor. Writing this expression as

$$\theta_R = \left(\frac{g}{2} - 1\right)\frac{e}{mc^2}\int B_\perp d\ell\left(\frac{1}{\beta}\right) \qquad \text{(Gaussian units)}$$

shows that the precession is essentially independent of energy for relativistic particles. A field integral of 2.3 T·m provides 90° precession for 800 MeV protons.

The H^- ion (in the ground state) exhibits the magnetic moment of the proton but has opposite charge. Generalizing the derivation of Hagedorn[9], one obtains for H^- of mass M and charge Q

$$\theta_R = \gamma\theta_B\left[\left(\frac{eM}{Qm}\right)\left(\frac{g}{2}\right) - 1\right]$$

where m(e) is the mass (charge) of the proton. Since the charges for H^+ and H^- are opposite and the masses are nearly equal, θ_R is ~2.1 times larger for H^- than for H^+ and is opposite in sign relative to the bend angle. This increased polarization roation is used to reduce the aperture required for the spin precessor and the sign reversal is used to restore the original trajectory.

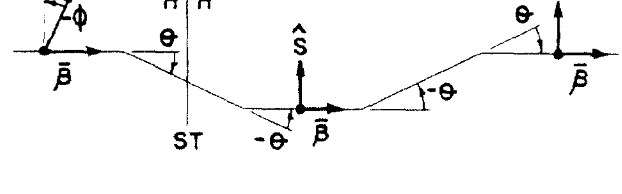

Fig. 2 - Schematic of the bends required to produce a polarization precession of $-\phi$ in the horizontal plane.

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The transport is symmetrical about the midplane to produce first order achromaticity and zero net deflection. The first bend of angle θ and the second bend of -θ are used to precess the polarization vector to the required orientation. The second two bends are used to restore the original trajectory with no net change in the polarization vector. Note that the second and third bends can be incorporated in a single dipole magnet to conserve length.

For this device the total precession angle, ϕ, of the polarization vector is related to the first bend angle, θ, by

$$\phi = -\gamma\theta\left(\frac{g}{2}\right) \quad \left(1 - \frac{eM}{Qm}\right) \simeq -\gamma\theta g.$$

A total magnetic field integral of only 1.5 T·m for the first two bends (2θ) produces a precession of 90° for an 800 MeV proton.

Successful operation requires that H^- be converted to H^+ between the first two dipoles. In Fig. 1 and Fig. 2, ST indicates a thin foil which removes the two electrons from H^- with 100% efficiency. The foil must be sufficiently thin to avoid undesirable emittance growth due to multiple coulomb scattering.

Integrating MWPCs placed between the first two dipoles, between the last two dipoles and after the last dipole will allow setting of the bend angles to better than 1 milliradian. This corresponds to an uncertainty in the polarization direction of less than 10 milliradians. The polarization will be measured downstream of the spin precessor by a pair of polarimeters which measure up-down and left-right asymmetries simultaneously. Orientation of the polarization vector to within 2 milliradians of any desired direction is expected to be achievable.

Example

To illustrate the use of this device, consider an incident beam of 800 MeV protons with polarization vector in the horizontal plane and 38.4° from the desired direction (ϕ = 38.4° in Fig. 2). To obtain a vertically polarized beam at the end of the spin precessor; the first solenoid is de-energized, the first dipole bends H^- by 3.71° and the second bends H^+ by -3.71°. At this point, the polarization and velocity vectors are perpendicular to each other. The third and fourth bends are equal and opposite to restore the beam to its original trajectory without changing the polarization orientation. This results in a polarization orientation 90° relative to the direction of motion and in the horizontal plane. The second solenoid is used to rotate the polarization vector to a vertical orientation.

Summary

For its useful energy range, this spin precessor produces an undeflected, undispersed proton beam of arbitrary polarization orientation if an H^- polarized beam is the initial beam. The device is tunable over a range of energies and polarization orientations which is limited only by the magnet fields and apertures available.

For high energy beams, the magnetic stripping of the H^- in the first dipole and in the radial field components at the ends of the solenoids may become a problem[10] since the electric field in the rest frame of the beam particle depends linarly on $\beta\gamma B_\perp$. At 800 MeV, the dipole strength is limited to ∿4-5 kG to keep the stripping process at negligible levels.

References

1. W. Wien, "Die Electrostatischen Eigenschaften der Kathodenstrahlen," Deutsche Physikalische Gellschaft, Berlin. Verhandlungen.Leipzig., 16, 165-172 (1897).

2. W. Wien, "Untersuchungen über die Elektrische Entladung in verdünnten Gasen," Ann. Physik, 8, 260 (1902).

3. Ya. Derbenev, "Siberian Snake," III International Symposium on High Energy Physics with Polarized Beams and Polarized Targets, Argonne, October 25-28, 1978, proceedings to be published.

4. O. van Dyck, "An 800 MeV Spin Precessor for Polarized H^- Beams Using H^- to H^0 Stripping," IEEE Particle Accelerator Conference, March 12-14, 1979, San Francisco, CA, to be published in these proceedings.

5. E. Colton et al., "A ZGS Beam Transport for Transverse or Longitudinally Polarized Protons," Nucl. Inst. and Meth., 151, 85-88 (1978).

6. J. D. Bowman et al., "Limit on Parity Nonconservation in p-Nucleus Scattering at 6 GeV/c," Phys. Rev. Lett., 34, 1184-1186 (1975).

7. E. W. Hoffman, "An Improvement for the Polarized Proton Beam Experimental Area Facility," Los Alamos Scientific Laboratory, MP-13 internal report (November 1977), unpublished.

8. V. Bargmann et al., "Precession of the Polarization of Particles Moving in a Homogeneous Electromagnetic Field," Phys. Rev. Lett., 2, 435-436 (1959).

9. R. Hagedorn, Relativistic Kinematics, New York, Benjamin, 132-137 (1963).

10. G. M. Stinson et al., "Electric Dissociation of H^- Ions by Magnetic Fields," Nucl. Inst. and Meth., 74, 333-341 (1969).