820 GeV/c POLARIZED PROTONS IN HERA

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Abstract

The SPIN Collaboration and DESY Polarization Team have studied the possible acceleration of a polarized proton beam to 820 GeV/c in the HERA accelerator complex at DESY [1]. This paper summarizes suggested changes at various stages of acceleration that would allow to maintain the beam polarization to the top energy.

1 INTRODUCTION

The interest in spin phenomena has significantly increased in recent years. It is now clear that spin effects in high energy interactions provide essential information about properties of the elementary particles and their fundamental interactions. The polarized proton beam capability at HERA would provide a powerful tool for high energy physics; it would allow unique spin studies in a polarized *e–p* collider.

While high energy electron and positron beams have selfpolarization mechanism due to the synchrotron radiation, an intense high energy polarized proton beam could only be obtained by acceleration from the source to the ring's maximum energy. Wide range of spin instabilities that become stronger at higher energies make the polarized protons acceleration a challenging problem. However, recently developed methods and techniques of overcoming the spin depolarizing resonances allow one to consider polarized proton beam acceleration in the high energy proton machines such as RHIC (250 GeV), HERA (820 GeV) and Tevatron (900 GeV).

2 POLARIZED ION SOURCE

A state-of-the-art polarized H^- ion source should be acquired and installed at DESY. This might be either an atomic beam source (ABS), or an optically pumped polarized ion source (OPPIS). Both types of sources have made tremendous progress in the recent years; the best ABS at INR (Moscow) has now achieved a current of 1 mA in pulsed operation [2], while the best OPPIS at TRIUMF has recently obtained a DC current of 1.6 mA with an emittance of 2π mm·mrad [3]. The source performance together with accumulation efficiency will be crucial issues for attaining a high intensity polarized proton beam at 820 GeV/c. Recent improvements tests at TRIUMF indicate that a 20 mA polarized H^- current might be possible to obtain with the OPPIS technology. Such source would make the polarized beam intensity in HERA equal to the intensity of unpolarized beam.

3 POLARIZED BEAM ACCELERATION

Polarized protons encounter many depolarizing resonances during acceleration in high energy proton synchrotrons. An unperturbed proton's spin would normally precess around the ring's vertical magnetic field that forms particle closed orbit. The frequency of the spin precession is energy dependent; the spin tune, which is the number of spin rotations during one particle revolution around the ring, is proportional to the Lorentz factor γ:

$$\nu_s = G\gamma \; , \tag{1}$$

where $G = 1.792847$ is the proton's anomalous magnetic moment. This vertical spin precession becomes unstable when the spin precession frequency is synchronized with a frequency of a small horizontal perturbation field. Such resonant perturbations can rapidly depolarize the beam in a circular accelerator and are called spin depolarizing resonances. During acceleration a large number of depolarizing resonances are crossed, whenever $G\gamma$ passes through a resonance frequency.

Various methods will be used in HERA in order to preserve the beam polarization during the acceleration. The required changes for each stage of polarized beam acceleration are shown in Fig. 1.

No depolarization occur in the new 750 keV RFQ, which should match the polarized ion source, and in the 50 MeV LINAC. Polarimeter installed after the LINAC would monitor the source output polarization.

The 50 MeV polarized beam would then be injected into the 7.5 GeV/c DESYIII synchrotron, where five strong depolarizing resonances occur during acceleration. The one strong and about 13 weak imperfection resonances, that are caused by magnets missalignment, could be overcome using a solenoidal partial Siberian snake of about 5%. The snake would rotate the spin by 9^0 and would cause a spin-flip every time $G\gamma$ crosses the integer value. The partial Siberian snake can not overcome four strong intrinsic resonances in DESYIII, which are caused by vertical betatron oscillations in the quadrupole fields. These resonances occur at integer harmonics of the vertical betatron tune, $G\gamma = n \pm k\nu_y$, and would require either pulsed quadrupoles, to use tune jump method of overcoming an intrinsic resonance, or vertical beam kicker magnets, to induce the spin-flip through each resonance by making them stronger. The novice betatron kick method, which was recently tested at IUCF [4], could be significantly cheaper and easier to use than the pulsed-quadrupoles method. To avoid emittance blow up after the beam kick one could use an RF-dipole for exciting and damping coherent betatron oscillations. This RF-dipole method will soon be tested for polarized beam acceleration at AGS.

Two full Siberian snakes would be needed in PETRA to overcome its many strong depolarizing resonances. The calculated maximum strength for the intrinsic and imperfection resonances in PETRA are $\varepsilon_{int} = 0.06$ and

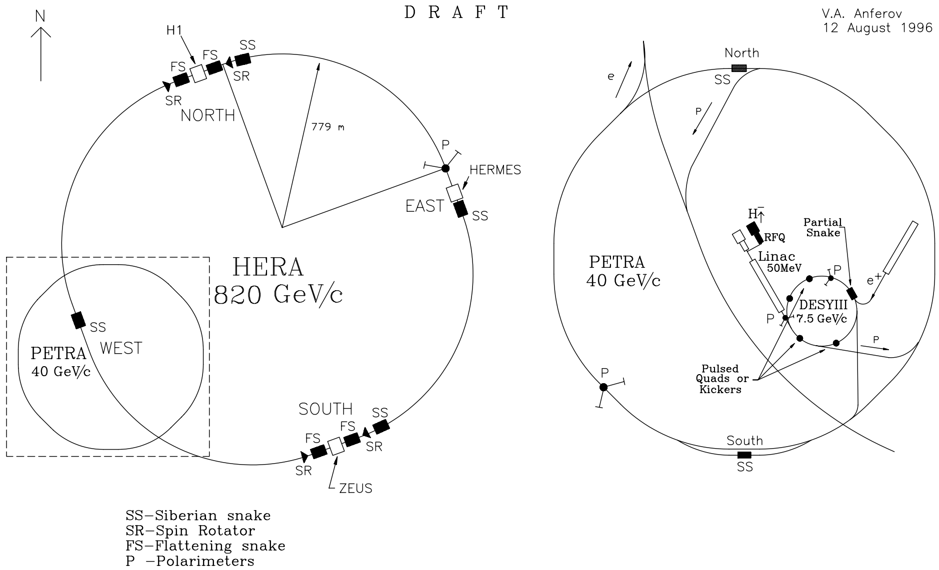

Figure 1: The proposed modifications for an 820 GeV/c polarized proton beam at DESY.

$\varepsilon_{imp} = 0.04$ assuming 25π mm mrad normalized beam emittance and 2.2 mm RMS vertical closed orbit distortion. Two snakes installed in the opposite straight sections would overcome all depolarizing resonances in PETRA and would provide vertical stable spin direction for easier polarization monitoring and spin matching during injection and extraction of the polarized beam. Each Siberian snake should rotate spin by 180^0 around a horizontal axis, while keeping the particle orbit unperturbed outside the snake. The spin rotation axes in PETRA snakes should be orthogonal to set the spin tune away from spin perturbations. The snake design is somewhat difficult in PETRA because, at its 7.5 GeV/c injection energy, full Siberian snakes would cause large orbit excursions. As a solution to this problem, a special helical Siberian snakes are proposed, which use helical dipoles to minimize the orbit excursions and normal dipole at the center to reduce the aperture of the helical dipoles.

Accelerating polarized protons to 820 GeV/c in HERA is difficult not only because of the very strong depolarizing resonances that occur during the acceleration, but also because of the requirement of a several hours polarization life time at the top energy in order to be useful for the experiments. Four Siberian snakes could be installed in each of the existing long straight sections. However, earlier studies by the DESY Polarization team have shown that the vertical orbit bumps around the interaction regions in HERA would interfere with any standard Siberian snake configuration. A solution to this problem was found, which would require four additional snakes to make the HERA ring "flat" for the spin motion. We called these snakes "flattening snakes" to emphasize their purpose of making the vertically bending beam lines near the interaction regions spin transparent.

Even after "flattening" the HERA lattice the spin perturbation remains very strong and four snakes in HERA would not provide adequate spin stability during the polarized beam acceleration. To reduce the strength of the spin perturbations one might consider various correction techniques that could reduce the rms orbit error to perhaps 0.2 mm and the emittance of the polarized beam to perhaps 5π mm mrad. One could also consider installing additional four snakes near the centers of each bending arcs. Both options are now under under careful analysis using various spin tracking techniques developed by the SPIN Collaboration and DESY Polarization team.

4 CONCLUSION

Polarized proton acceleration to 820 GeV/c at HERA would be an appropriate response to the growing interest in spin in high energy physics. It would extend the physics scope of the HERA collider and would enable unique studies of the spin and its role in the fundamental interactions at high energies. While most of the polarized beam problems appear to have straightforward solutions using existing techniques, two main problems will need further study:

• increasing the accumulated polarized beam intensity,

• providing adequate spin stability for polarized beam acceleration and storage in HERA.

This work was supported by the research grants from DESY and the U.S. Department of Energy.

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