Proposal for a Pulsed Optically Pumped Polarized H^- Ion Source For High Energy Accelerators

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Abstract

The acceleration of polarized protons in multi-GeV machines is a great challenge for accelerator physicists. An essential part of such development is the primary source of polarized H^- ions. Recent studies at TRIUMF and INR, Moscow, showed that pulsed Optically Pumped Polarized Ion Source (OPPIS) could produce up to 1.2 mA H^- ion beam with polarization in excess of 80% within 1.5 π mm-mrad normalized emittance. This current is ten times higher than the best currently available from atomic beam sources. The pulsed OPPIS is quite inexpensive in comparison with atomic beam source, and is ideally suited for high energy accelerator applications.

I. INTRODUCTION

The importance of spin effects in the multi-GeV range of energies has been realized in recent years and as a result a number of experiments employing accelerated polarized proton beams have been proposed for KAON [1], FNAL [2], BNL [3], and SSC [4]. Accelerator physicists have met this challenge by implementation of the "Siberian snake" technique of preserving the polarization during acceleration [5]. Another important part of such facilities is the primary source of polarized H^-. Conventional atomic beam sources are gradually being improved, and recent progress on a D^- plasma ionizer will probably lead to increased polarized H^- currents of up to 100 μA in 1.5 π mm-mrad emittance, even though H^- is not a favored ion for atomic beam sources [6]. Typical currents of unpolarized H^- ion injectors are about 50 mA [7]. A big difference in the polarized and unpolarized current will substantially restrict the possibilities of studying polarization phenomena at the low duty-factor high energy accelerators.

II. PROPOSAL FOR A PULSED HIGH CURRENT OPPIS

An alternative to the atomic beam source is the comparatively new technique of optically pumped polarized ion sources, which is particularly suitable for H^- production. In the last few years optically pumped polarized H^- sources have been put into routine operation at KEK [8], LAMPF [9] and TRIUMF [10]. This has improved substantially the facilities for polarization studies at these laboratories.

Two basic OPPIS configurations are in use. At KEK, LAMPF and TRIUMF, ECR sources are used for producing the primary proton beam. Very similar results have been obtained with this arrangement for both pulsed and cw modes of operation, and presently the H^- current is limited to less than 200 μA in a 1.0 π mm-mrad normalized emittance. This limitation is to occur as a result of the ECR plasma temperature (higher than 2 eV). The KEK pulsed OPPIS, for example, nearly achieved this current limit [8]. The influence of rubidium ion space charge on emittance degradation is also very important and is not yet well understood. Another approach, implemented at INR, Moscow overcomes these problems [11] (see Fig. 1.). In this technique a high intensity neutral atomic hydrogen beam is injected into a strong longitudinal magnetic field, where it is ionized in a pulsed gas helium (or neon) cell. The resulting proton beam is then injected into an optically pumped Na (or Rb) cell, which is situated in the same solenoidal field as the ionizer. In effect, the ionizer cell acts as a proton source in a high magnetic field. The proton yield from He at hydrogen beam energies of 5-8 keV is about 70% and about 40% for neon. The He cell is isolated and biased at -1 kV, allowing energy separation of the protons from the primary neutral hydrogen beam. A conventional electromagnetic pulsed gas valve cannot be used in a high magnetic field and a piezoceramic or pneumatic valve must be used. A very bright neutral injector (the prototype was developed at the Budker INP, Novosibirsk) produces up to 30 mA equivalent transmitted atomic beam current through the ionizer cell and the optically pumped cell. It is based on production of a low divergence proton beam, which is extracted by a four-electrode multiwire system from an expanded plasma [12]. The proton beam is focused by a solenoidal magnetic lens and neutralized in a pulsed hydrogen or alkali vapour cell. The geometry of the source extraction system and focusing lens has to be chosen carefully to provide the conditions for space-charge compensation during beam formation, in order to avoid increasing the beam divergence.

The resulting polarized current is very close to estimates obtained from the measured initial beam and the efficiency of ionization and charge-exchange processes in helium and sodium. The polarized current doesn't depend on the magnitude of the magnetic field in the optically pumped cell, but there is a loss of about 30%, because some additional divergency is introduced during deceleration of the proton beam at the exit of the He ionizer. The polarized H^- current obtained at INR for a maximum polarization of 65% is 400 μA in an emittance of 1 π mm-mrad. At higher Na thicknesses in the optically pumped cell, the current

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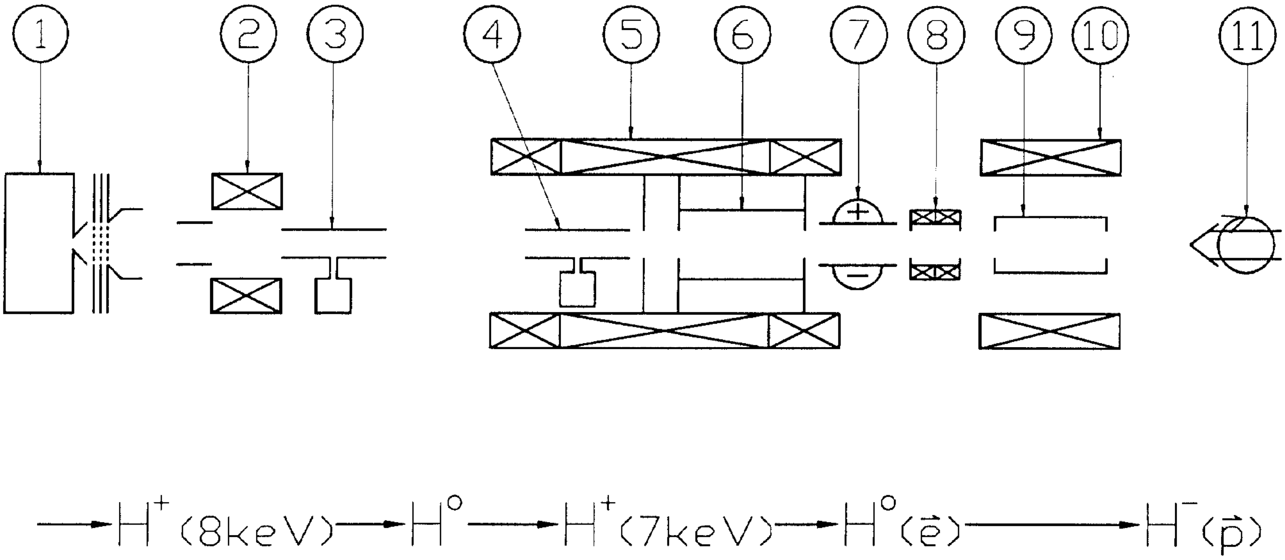

Fig. 1. Schematic layout of the pulsed optically pumped polarized H^- ion source: 1-source of primary protons; 2-focusing lens; 3-neutralizer cell; 4-pulsed helium ionizer cell; 5-superconducting solenoid 25-30 kG; 6-optically pumped Rb cell; 7-deflecting plates; 8-Sona transition magnetic shield and trim coil; 9-sodium ionizer cell; 10-ionizer solenoid 1.5 kG; 11-pulsed Ti:Sapphire laser.

increases to 600 μA but the polarization drops to 45%, because of radiation trapping within the sodium vapour.

Recent progress in OPPIS development has been the result of switching from dye lasers and optical pumping of sodium to solid state Ti:sapphire lasers and optical pumping of rubidium [13] and potassium [9]. The advantages of Rb as a medium for optical pumping and the high power of Ti:sapphire lasers have greatly improved the OPPIS parameters. At TRIUMF even in a cw mode of operation, up to 8×10^{13} Rb atoms/cm^2 with an electronic polarization of over 95% was produced. An efficiency of 50% for capture of polarized electrons by the incident proton beam was obtained. A high power pulsed Ti:sapphire laser was tested in the INR source, where a 90% neutralization efficiency at the highest polarization was achieved, nearly doubling the polarized H^- current compared with using sodium. In such a way, it should be possible to produce at least 800 μA polarized H^- beam in a 1.0 π mm-mrad emittance. This current is expected to scale with emittance and, if 1.5 π mm-mrad emittance is acceptable – such emittance is specified in the FNAL proposal on acceleration of polarized protons [2] -1200 μA could be available from a pulsed OPPIS. As for possible improvements, the current scales with the neutral beam intensity and development in that area is definitely not exhausted. For example, the above current of 400 μA was measured at only half the neutral hydrogen beam intensity, which has been obtained from the Budker Institute prototype source.

This technique is particularly suitable for high energy accelerators having low repetition rates of 10-15 Hz (FNAL, SSC). At such low rates, the ionizer helium consumption is only 3×10^{17} atoms/sec and vacuum pumping of the He ionizer cell is accomplished easily by one 1000 l/sec turbomolecular pump. A very simple, inexpensive laser system based on a pulsed Ti:sapphire laser could be used to produce high polarization of the Rb vapor. The INR pulsed Ti:sapphire laser produces up to 1 kW power in a pulse duration of 200 μsec, with a linewidth of 10-12 GHz and a repetition rate up to 25 Hz. A longer pulse duration could be realized by using two such lasers, or an alexandrite laser.

Very important results have been obtained recently at TRIUMF [14]. Proton polarization of over 80% was obtained in a cw mode of operation, at a high magnetic field of 25 kG in the optically pumped cell. In the INR-type source, energy separation of the protons produced by ionization of the primary neutrals provides better background conditions and the polarization should be even higher.

Combining the INR results of highest current production and the experience with pulsed Ti:sapphire lasers and the TRIUMF results of highest polarization, we propose the development of a pulsed polarized ion source which will produce high current polarized H^- beam having the specifications shown in Table 1.

Table 1. Pulsed OPPIS parameters.

Repetition rate	10-15 Hz
Pulse duration	100 μsec
Pulsed polarized H^- current	> 1.0 mA
Pulsed polarized H^+ current	10 mA
Polarization	80-85%
Normalized emittance	1.5 π mm-mrad

Such a pulsed OPPIS will produce at least a factor of ten times higher polarized H^- current than the best atomic beam source currently available. It's construction is less expensive than that of an atomic beam source and we believe it is ideally suited to be used at high energy accelerators. An important feature of the proposed OPPIS is the capability of further development by using a spin-exchange technique of polarization [15]. In that technique there is no space-charge current limitation, since polarization takes place in collisions between neutral hydrogen and alkali-metal atoms. Future spin-exchange optically-pumped sources will likely produce polarized H^- ion currents in excess of 10 mA, and may finally solve the problem of a polarized injector for high energy accelerators.

III. CONCLUSION

There is a great deal of interest in high energy spin physics experiments at fixed target, collider and storage ring setups. The development of a high performance pulsed optically pumped polarized H^- ion source should be considered for the most efficient use of these facilities with polarized beams.

Anderson (Univ. of Wisconsin USA) and Mori (KEK National laboratory, Japan) were awarded the 1993 IEEE Particle Conference Technology Award for their invention and development of the optically pumped polarized negative ion source and in recognition of successes of the first generation OPPIS. We believe the optically pumped polarized H^- ion sources of the next generation, which have been discussed in this paper, will produce polarized H^- ion currents of 1-10 mA, i.e. close to the currents of unpolarized ion sources.

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