THE TRIUMF HIGH-CURRENT DC OPTICALLY-PUMPED POLARIZED H$^-$ ION SOURCE

A.N. Zelenski
Institute for Nuclear Research, Russian Academy of Sciences, 117312 Moscow, Russia
C.D.P. Levy, K. Jayamanna, M. McDonald, P.W. Schmor,
W.T.H. van Oers, J. Welz, G.W. Wight and G. Dutto
TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C., Canada V6T2A3
Y. Mori
KEK, Oho 1-1, Tsukuba-shi, Ibaraki-ken 305, Japan
T. Sakae
Kyushu University, Fukuoka 812, Japan

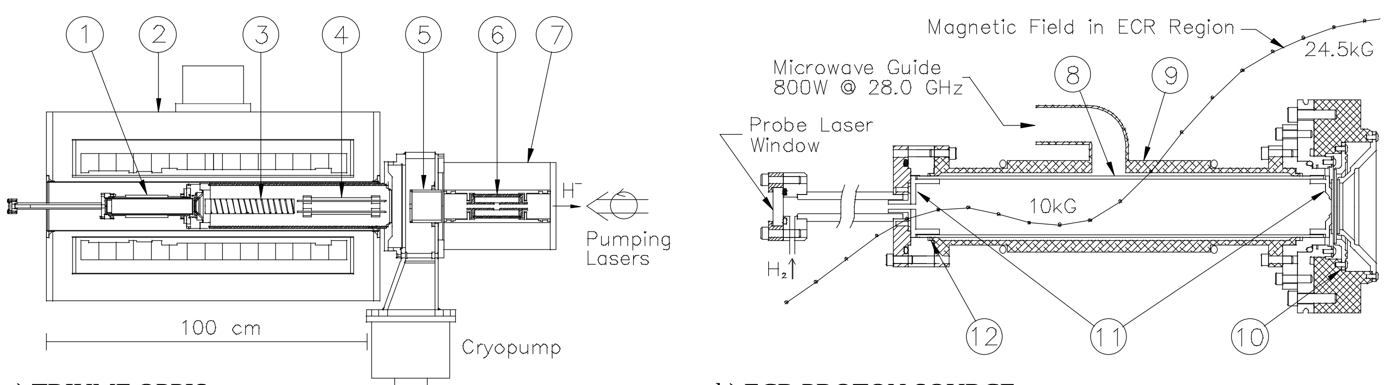
ABSTRACT

The TRIUMF optically-pumped polarized H$^-$ ion source (OPPIS) produces in excess of 150 uA DC of H$^-$ ion current at 85% polarization within a normalized emittance of 0.8 pi mm mrad. A 20 uA beam was accelerated to 500 MeV through the small acceptance of the injection line and the cyclotron. A feasibility study of higher current production for application to multi-GeV accelerators has been performed. A polarized H$^-$ ion current of 1.6 mA within a normalized emittance of 2.0 pi mm mrad was obtained after upgrading the ECR primary proton source. The source performance now well exceeds the original design parameters and clearly confirms the potential of the OPPIS technique for other accelerators.

I. INTRODUCTION

Early OPPIS development immediately demonstrated high current in pulsed mode [1,2]. Polarization was initially limited to 65-70% at the KEK, INR and LAMPF OPPIS's. At TRIUMF, the use of a higher magnetic field, Ti:sapphire lasers for optical pumping of Rb vapour and optimization of all source parameters resulted in 85% H$^-$ nuclear polarization, as measured in a beam injection line polarimeter [3]. Depolarization during acceleration due to weak imperfection resonances was recently studied and minimized by tuning the cyclotron harmonic coils so as to reduce betatron oscillations. As a result, a proton polarization of 82% was measured at 200 MeV, 79% at 350 MeV and 76% at the full 500 MeV beam energy. At present the TRIUMF OPPIS delivers polarized beam to a number of experiments for 30-40% of the cyclotron running time. The most demanding of these is study of parity violation in proton-proton scattering at 220 MeV [4]. Although the latter requires only 0.5 uA at the target, to satisfy requirements for beam quality - especially modulation of beam current, energy and emittance correlated with spin reversal - we must sacrifice most of the beam intensity by using a low Rb vapour thickness, a narrow stripping extraction foil and no buncher. Therefore, increasing the current is a high priority.

After PAC93, where a high current pulsed OPPIS for high energy accelerators was proposed [5], TRIUMF and INR Moscow joined the SPIN Collaboration, which is working on a proposal for polarization experiments at the FNAL Tevatron-Collider [6]. A pulsed polarized H$^-$ current of 1.2 mA is required to operate the Tevatron-Collider with equal luminosity, whether the beam is polarized or not. Demonstration of such current production was considered a major milestone in development of polarization facilities. We are approaching this goal in three ways. First, by upgrading the TRIUMF DC OPPIS, the results of which are presented in this paper. A second approach is based on the INR-type scheme which uses an external atomic hydrogen



a) TRIUMF OPPIS b) ECR PROTON SOURCE

Fig. 1. 1) ECR Proton Source, 2) Superconducting Solenoid, 3) Optically-Pumped Rb Cell, 4) Deflection Plates, 5) Sona Transition Region, 6) Ionizer Cell, 7) Ionizer Solenoid, 8) Quartz Tube, 9) ECR Cavity, 10) Three Grid Extraction System, 11) Boron-Nitride End Cups, 12) Indium Seals.

injector instead of an ECR primary proton source [5]. The third option, the use of spin-exchange polarization, has been studied experimentally at the INR [7] and TRIUMF OPPIS's [3]. Results are promising for future OPPIS's in the 10-20 mA range.

II. THE ECR PROTON SOURCE UPGRADE

The OPPIS current is essentially determined by the electron-cyclotron-resonance primary proton source (ECRIS), since the optimal neutralization efficiency in the optically-pumped Rb vapour is 50-70% , the sodium ionizer efficiency is constant (9% at 2-5 keV beam energy) and the emittance specification determines the ionizer diameter. The OPPIS ECR source operation is quite different from conventional ECR ion sources developed for multiply charged heavy ion production. Obtaining a high polarization requires a high 25 kG magnetic field in the optically pumped cell and ion extraction region. The highest frequency (28 GHz) microwave generator in use for an ECRIS is operating at the TRIUMF OPPIS. Despite that, the resonant field is only 10 kG and the mirror ratio of 2.5 is too large compared with other sources. Also the OPPIS ECRIS should be optimized for proton production, and therefore the electron temperature in the plasma should be of order 100 eV compared with several keV in a conventional ECR ion source.

The TRIUMF OPPIS and ECRIS are presented in Fig.1a, b. The microwave power up to 800 W which is required for saturating the proton current yield is produced by a CW extended interaction oscillator (VARIAN VKQ2435F3). The power is introduced transversely into the plasma cavity. The plasma volume is confined within a quartz tube and boron-nitride end cups. The latter prevents coating of the quartz by sputtered metal and extends the quartz liner lifetime. The tube also serves as the microwave input window. It is sealed at the ends by indium O-rings and is cooled by flowing nitrogen gas around it. A high sensitivity of the polarized current to the magnetic field shape and superconducting solenoid alignment was observed. The solenoid has three independent coils which allow control of the magnetic field shape. No multipole magnetic field is used because no substantial improvement was observed with a sextupole magnet in earlier tests. The magnetic field optimized for polarized current production is presented in Fig.1b. It is characterized by a very short and shallow ECR zone. Apparently we have a combined action of ECR and non-resonant microwave electron heating. In the latter case the microwave power is absorbed at magnetic fields above resonance. Non-resonant microwave heating is more efficient at higher gas pressures and results in low electron and ion temperatures, exactly what is required for high extracted current density and low emittance.

An ion extraction system (IES) should take advantage of the low plasma temperature. To get high current at the low beam energy required for polarization by charge-exchange collisions, a multi-hole IES is used. The IES consists of three 1mm thick planar molybdenum electrodes spaced 1.2mm apart, having 0.95mm diameter apertures in a hexagonally close-packed configuration with a 1.15mm distance between centers. Precise manufacturing and alignment of multihole electrodes is required. The three electrodes are now drilled together (by a spark-erosion technique). Slight differences in hole sizes and positions don't degrade system performance, since each set of three holes is perfectly aligned. Equally important is that the cost of manufacturing is much lower now, so experiments with a large number of holes are possible.

As a result of the above improvement the polarized H^- ion current became rather reproducible and systematic studies of the current dependence on the proton beam energy, the IES gap width and the microwave power were made. The polarized H^- ion current dependence on the Rb vapour thickness for different sets of extraction grids is presented in Fig. 2.

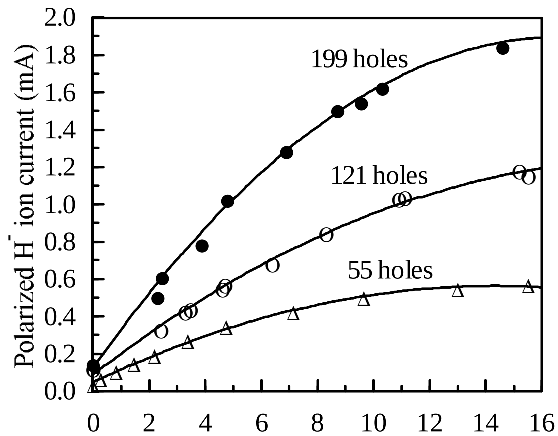


Fig. 2. Rb vapour thickness (10^{13} atoms/cm^2)

The currents are quite accurately proportional to the number of IES holes. The maximum polarized current per hole is about 8 uA at a Rb vapour thickness of 10^{14} at/cm^2, where 85% H^- nuclear polarization could be obtained. The diameter of the 199 hole IES is only 17.5 mm and, apparently, a larger diameter IES could produce higher current. The higher gas flow should be handled with a proper vacuum system. The possibility of gas flow pulsing could be also considered. DC operation imposes severe requirements on the IES. The electrode heating and sputtering reduces the grid lifetime. To balance cost and performance for the DC source we used grids with relatively thick walls between holes. For example, the wall thickness is 1.2mm for the 121 hole IES. The lifetime of such a grid is about 1500 hours in DC mode. In pulsed operation, the grid transparency could be increased, and hence larger currents could be obtained for the same beam size.

III. POLARIZATION MEASUREMENTS

The H^- nuclear polarization was measured at 300 keV in a polarimeter based on the $^6Li(p,^3He)^4He$ reaction. This polarimeter was calibrated by comparison with the reference 200 MeV polarimeter. In all experiments spin reversal at 40 s^{-1} and a synchronous detection technique for noise reduction were used. Proton polarization measurement accuracy was +/-1.5% with a 5 minute integration time. For Rb thickness and polarization measurements the well developed technique of Faraday rotation was used. The results of polarization measurements for a 61 hole IES - a 9mm diameter primary proton beam - are presented in Fig.3. With two Ti:sapphire lasers, laser power density of 14 W/cm^2 was available for optical pumping of the 9 mm diameter

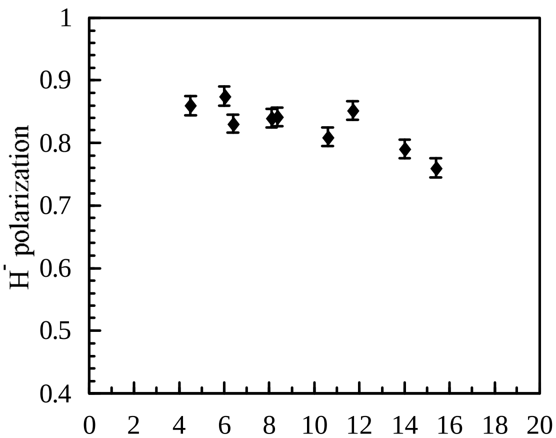


Fig. 3. Rb vapour thickness (10^{13} atoms/cm^2)

Rb vapour column overlapping the proton beam. For the 199 hole IES the beam cross-sectional area is 2.5 cm^2 and a laser power of about 50 W is required to get 80-85% H^- polarization. This power can be easily produced by a pulsed laser. KEK has loaned a pulsed Ti:sapphire laser for experiments at TRIUMF. The laser was tested for long pulse duration, and 120 us was obtained with power above 1 kW. The polarization measurements were done with a relatively large 20 mm diameter ionizer aperture. The Sona region is very close to the ionizer, so the ionizer diameter determines the beam diameter in the transition region and hence possible polarization losses. The observed polarization is consistent with our best results for a 31 hole IES and 12 mm diameter ionizer, so we conclude that Sona depolarization is negligible with the larger beam diameter.

IV. PULSED OPPIS WITH THE BINP ATOMIC HYDROGEN INJECTOR

The results of the high current test with the TRIUMF OPPIS are important for estimates of the current expected from the INR-type pulsed OPPIS with BINP (Novosibirsk) atomic H injector [5]. The full ECRIS proton current was as high as 170 mA for a 199 hole IES and the corresponding emission current density was 120 mA/cm^2. The use of the atomic injector, having similar current density but much smaller beam divergence, should increase polarized current to at least 5 mA. Experiments at BINP are now in progress to study the limits on the OPPIS pulsed polarized current.

V. CONCLUSIONS

An accelerated polarized beam current of 20 uA was observed at the TRIUMF cyclotron. The polarization of the injected beam was 85%. Extracted beam polarizations of 82% at 200 MeV and 76% at 500 MeV were obtained. Following high current development, highly polarized 150 uA was obtained within a normalized emittance of 0.8 pi mm mrad, making feasible 50 uA accelerated polarized current for experiments at TRIUMF. We note that 10 times higher polarized proton current (i.e. 1.5 mA DC) can be obtained using a gaseous helium ionizer instead of sodium vapour.

Higher current production was studied for the proposed polarization facilities at the FNAL Tevatron-Collider. A polarized H^- current of 1.64 mA DC within a normalized emittance of 2.0 pi mm mrad was obtained at an optically pumped Rb vapour thickness of 10^{14} atoms/cm^2. H^- nuclear polarization of 85% was measured for a 61 hole IES with 14 W/cm^2 laser power at a Rb vapour thickness of 10^{14} atoms/cm^2 and a 20 mm diameter sodium ionizer cell. Modified for pulsed operation, the TRIUMF OPPIS should produce at least 2 mA polarized H^- ion current, so the 1.2-1.5 mA desired for the FNAL project could be comfortably met with the existing very reliable ECR source technique. The use of the BINP atomic hydrogen injector should boost pulsed polarized H^- current to at least 5 mA.

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VII. REFERENCES

1. A.N. Zelenski *et al.*, “Laser Source of Polarized Protons and H^- Ions”, in Proc. 6th Int. Symp. on Polarization Phenomena in Nuclear Physics., Osaka 1985, J. Phys. Soc. Japan. 55, 1064 (1986).
2. Y. Mori *et al.*, “Recent Progress on the Optically-Pumped Polarized H^- Ion Source at KEK”, AIP Conf. Proc. No.158, 605 (1986).
3. A.N. Zelenski *et al.*, “ Spin-Exchange Polarization Study at the TRIUMF OPPIS”, Proc. of SPIN'94 Conf., Bloomington, Indiana, Sept. 1994.
4. J. Birchall *et al.*, “Parity Violation in p-p Scattering”, Nucl. Phys. A553, 823 (1993).
5. A.N. Zelenski *et al.*, “Proposal for a Pulsed Optically-Pumped Polarized H^- Ion Source for High Energy Accelerators”, Proc. 1993 IEEE PAC, 2991 (1994).
6. 1994 SPIN Progress Report, Univ. of Michigan, spokesman A.D. Krisch.
7. A.N. Zelenski and S.A. Kokhanovski, “A Study of Spin-Exchange Polarization Transfer in H-Rb Collisions”, Madison 1993, AIP Conf. Proc. 293, 164 (1994).