DEVELOPMENT OF HIGH-CURRENT POLARIZED H$^-$ ION SOURCES AT TRIUMF

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Abstract

The KEK optically pumped polarized H$^-$ source (OPPIS) has been transferred to TRIUMF, where it is being upgraded in current and polarization for eventual use at RHIC. The goal of the upgrade is to provide a DC beam of 1.5 mA H$^-$ with a pulsed polarization of 80% in 100 μs pulses at a repetition rate of 7.5 Hz. In parallel, a very high intensity pulsed source is being developed for use at HERA. The goal in that case is peak currents of at least 10 mA with 80% polarization. Peak current of 30 mA unpolarized has been demonstrated. In both projects, polarization will be provided by pulsed laser optical pumping. We describe the mode of operation of both sources and report on the latest progress.

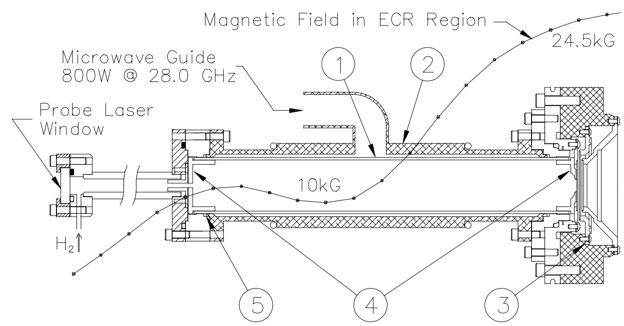

Figure 1: Schematic of ECR proton source; (1) quartz tube; (2) ECR cavity; (3) three plate extraction electrodes; (4) boron nitride end cups; (5) indium seal.

1 INTRODUCTION

Polarized source development at TRIUMF involves different types of optically pumped polarized H$^-$ ion source (OPPIS)[1]. In its essentials, the OPPIS is based on fast protons picking up polarized electrons from an optically pumped rubidium vapour in a high magnetic field to become electron spin polarized hydrogen atoms. (The proton source must be within the same solenoidal field as the Rb cell to prevent emittance blow-up of the proton beam as it enters the Rb cell). The hydrogen atoms then pass through a static magnetic field reversal which transfers the polarization to the nucleus. The nuclear spin polarized atoms subsequently pick up another unpolarized electron in a sodium vapour negative-ionizer cell to become polarized H$^-$ ions, which can then be accelerated to high energy. Typical magnetic fields are 2.5 T in the Rb cell region, and -0.13 T in the Na negative-ionizer.

OPPIS high intensity development at TRIUMF has taken two directions in recent years. In one direction, the high current limit of the operational DC TRIUMF OPPIS was explored[2]. This source uses a DC electron-cyclotron-resonance (ECR) proton source, shown in Figure 1, to provide the initial proton beam. The polarized H$^-$ current is approximately proportional to the number of close-packed, 1 mm diameter apertures in the planar ECR extraction electrodes. Both H$^-$ current and emittance are also approximately proportional to the area of the Na negative-ionizer aperture. A system containing 199-aperture ECR extraction electrodes and a sodium negative-ionizer aperture of 20 mm produced 1.64 mA DC H$^-$ current within a normalized emittance of 2π mm mrad at about 60% polarization. The polarization was limited by the 9 W of CW laser power available for optical pumping of the $\sim$2 cm diameter polarized Rb volume. In its operational mode at lower currents (and smaller Rb volumes) the TRIUMF OPPIS produces a polarization of 85%.

In the other project, pulsed peak currents of 10 – 20 mA H$^-$ with 80% polarization and normalized emittance within 2π mm mrad are the goal. Currents of this order are required to provide sufficient proton beam luminosity for polarization experiments at HERA. Feasibility studies carried out at TRIUMF have shown this to be possible using a pulsed OPPIS of a type invented at INR Moscow[3]. The INR-type OPPIS has no ECR proton source, and instead injects a high brightness, small emittance pulsed beam of atomic hydrogen into the solenoid. A He gas cell ionizer then acts as the proton source within the solenoidal field. The relatively large diameter Rb cell volume can be optically pumped economically with high power pulsed lasers.

2 ECR-TYPE SOURCE DEVELOPMENT FOR RHIC

The spin physics program at RHIC is based on colliding longitudinally or transversely polarized proton beams with

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centre-of-mass energies up to 500 GeV and a luminosity of 2×10^{32} cm^{-2} s^{-1}[4]. The polarized injector for RHIC must produce at least 0.5 mA H$^-$ ion current with 80% polarization during the 300 μs pulse, within a normalized emittance of 2π mm mrad. This is an ideal application for the ECR-type OPPIS. Again, inexpensive pulsed lasers can be used to optically pump the rubidium vapour.

The first ECR-type OPPIS was constructed at KEK[5]. Polarized beam is not presently required at KEK, and the KEK OPPIS is on loan to BNL to supply polarized H$^-$ for RHIC. The source is at present being upgraded at TRIUMF to meet the RHIC requirements. It will be delivered to BNL in the first half of 1999, and design of the matching optics between the source and the RFQ has begun. Table 1 compares the RHIC requirements with what was previously demonstrated on the TRIUMF OPPIS, and with the estimated KEK OPPIS parameters. (The KEK source was last operated for polarized D$^-$ production [6]). The table shows that the existing TRIUMF design meets the RHIC requirements if 300 μs pulses are extracted, even with CW laser pumping. However, 100 μs pulse durations with peak currents of 1.5 mA would be preferred, since that would improve injection efficiency. The preference for the higher current, combined with the much lower cost of pulsed lasers relative to CW lasers, dictates the use of pulsed optical pumping. In previous tests at TRIUMF, near 100% Rb polarization was measured in a 2 cm diameter Rb cell having a vapour thickness of 1×10^{14} atoms cm^{-2} and a length of 30 cm, using a pulsed Ti:sapphire laser[7].

Table 1: Comparison of OPPIS parameters.

	KEK	TRIUMF	RHIC
Current (mA)	0.1	0.5	0.5 – 1.5
Pulse duration (μs)	100	DC	100 – 300
Charge/pulse (mA μs)	10	150 (in 300 μs)	$\geq$150
Polarization (%)	75	85	$\geq$80
Normalized emittance (mm mrad)	2π	2π	$\leq 2\pi$
Repetition rate (Hz)	25	DC	7.5

The KEK OPPIS as delivered to TRIUMF used a pulsed 18 GHz ECR proton source and CW laser pumping. At TRIUMF the KEK OPPIS is being optimized using a DC 28 GHz ECR proton source. Preliminary results give 520 μA of H$^-$ DC current, using a 121-aperture extraction electrode with an overall diameter of 13 mm. This already satisfies the minimum RHIC beam current requirements, and a 199-aperture system will do proportionally better.

A new Na-jet negative-ionizer target is being developed, which has some advantages over the original canal and condensation chambers arrangement. A jet target can be shorter and the beam apertures larger, since Na vapour is more effectively confined. The condensed Na is recycled. Large apertures reduce secondary electron emission caused by the intense polarized atomic hydrogen beam striking the cell, and therefore may allow biasing the Na cell up to 32 kV. If so, a 35 keV beam from the source will be injected into an RFQ, without requiring that the whole source be placed on a high voltage platform.

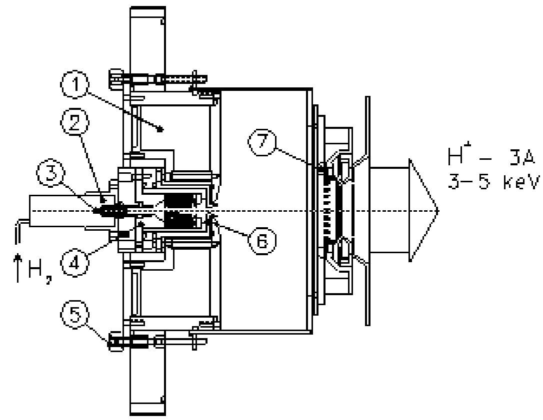

Figure 2: The BINP-type proton source: (1) solenoid; (2) pulsed valve; (3) trigger electrode; (4) cathode; (5) alignment screw; (6) anode; (7) proton extraction grids.

The flashlamp-pumped pulsed Ti:sapphire laser produces pulse durations of 80 μs (FWHM) at a repetition rate of 1 Hz, using a simple power supply. The laser cavity is tuned with a 2-plate birefringent filter and a 0.5 mm thick etalon, producing a laser bandwidth of 15 GHz. The peak power density is 28 W/cm^2 over the 3 GHz Doppler broadened absorption width of Rb, for a 2 cm diameter laser beam. Previous results have shown that 14 W/cm^2 is enough to produce nearly 100% Rb polarization[2]. Future development will concentrate on extending the pulse duration and repetition rate of the laser, mainly by increasing the capacitance of the power supply. Longer pulses may require the use of a different laser crystal, or two consecutive pulses.

3 INR-TYPE OPPIS FOR HERA

In the INR-type OPPIS, the ECR proton source is replaced by two components – an atomic hydrogen ”neutral injector” outside the magnetic field surrounding the Rb vapour cell, and a pulsed He gas ionizer cell inside the magnetic field. Hydrogen atoms pass unaffected through the magnetic fringe field and enter the He cell, forming a small emittance proton beam that in turn enters the Rb cell.

The intense neutral injector, based on a BINP Novosibirsk prototype, has been developed and tested at TRIUMF. The test bench consisted of a setup that simulated the geometry of a working polarized source, minus the He ionizer and polarized Rb vapour cells necessary for actual polarized operation. The neutral injector consists of a primary plasmatron proton source (shown in Figure 2), a focussing solenoid and a pulsed H$_2$ gas neutralizer. At each ignition

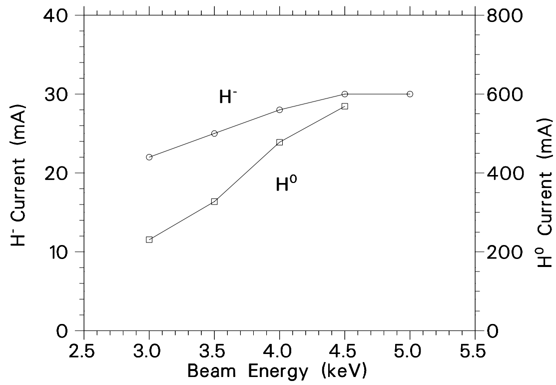

Figure 3: H^- ion current and H^0 beam intensity within the Na negative-ionizer acceptance versus beam energy.

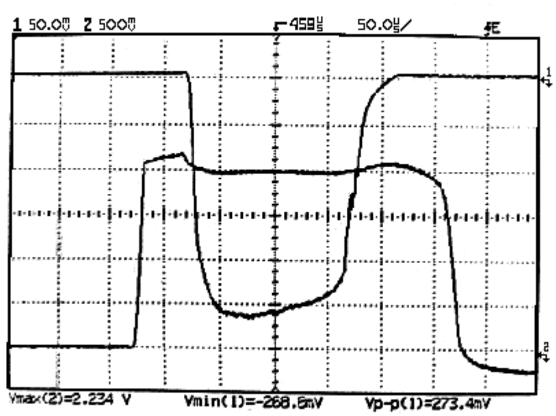

Figure 4: H^- beam current (negative pulse) and 4.0 kV extraction voltage, 50 μs/div.

pulse, a rapidly cooling plasma expands towards the proton extraction electrodes. These consist of a 4 cm diameter, 4-plane, accel-accel-decel wire grid extraction system. The high brightness, converging proton beam is neutralized in the H_2 cell with 95% efficiency. Total extracted proton current is $\sim$8 A.

Space charge compensation is important in such high current proton beams. This is achieved using a positively biased grid in the centre of the focussing solenoid, and by injecting CO_2 or Freon into the region. This gives an increase in ultimate H^- current of 30%.

The atomic H beam was transmitted through the Na negative ionizer on the test bench. The beam intensity was measured both by calorimetry and from ionization in the Na cell. Figure 3 shows the measured H^- ion current and H^0 beam intensity within the Na ionizer acceptance as functions of the beam energy. Figure 4 shows typical pulse shapes of the extraction voltage and H^- beam current.

Following the test stand measurements, the test stand was dismantled and the operational TRIUMF OPPIS ECR-proton source was removed and replaced by the neutral injector, for further pulsed source development between scheduled polarized beam runs at TRIUMF. The previous result for unpolarized H^- current was reproduced. Use of the full TRIUMF OPPIS as a development stand will in future permit testing of the entire INR-type OPPIS, using the superconducting solenoid to generate a fairly flat 1.2 T field over a length of 70 cm. The resulting polarization will be limited in that case to about 60% due to the relatively low field. (The superconducting solenoid at TRIUMF can produce 2.5 T only over a length of 30 cm.)

4 CONCLUSION

The BNL-KEK-TRIUMF collaboration to develop new polarization facilities at RHIC is proceeding, and the OPPIS upgrade is on schedule. The development work on a 10 – 20 mA pulsed H^- OPPIS for HERA shows great promise.

5 ACKNOWLEDGEMENTS

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