HIGH-CURRENT, OPTICALLY-PUMPED, POLARIZED H^- ION SOURCE DEVELOPMENT FOR HIGH ENERGY ACCELERATORS

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Abstract

The TRIUMF optically-pumped polarized H^- ion source (OPPIS) produces in excess of 0.2 mA dc of H^- ion current at 85% polarization within a normalized emittance of 0.8 pi·mm·mrad. OPPIS features contributing to highly reliable operation are described. Results are reported of a feasibility study of higher current production for application to multi-GeV accelerators and colliders. H^- dc currents of 0.55 mA at 85% polarization and 1.0 mA at 75% polarization, both within 2.0 pi·mm·mrad, were obtained after upgrading the ECR primary proton source. A maximum dc H^- current of 1.64 mA was obtained with lower polarization. Polarization drops at the highest dc currents due to insufficient cw laser power. An ~2 kW peak power pulsed Ti:sapphire laser produced near 100% Rb polarization throughout a large volume. Modified for pulsed operation, the TRIUMF-type OPPIS with ECR primary proton source is expected to produce H^- ion currents of at least 2.0 mA with 80-85% polarization. Polarized H^- ion peak currents of 10-20 mA are expected once the ECR proton source is replaced by a high intensity atomic hydrogen injector coupled to a He ionizer cell.

1 INTRODUCTION

There are a number of proposals for polarization phenomena studies at high energy proton accelerators and colliders /1-3/. Future polarization facilities require polarized beam intensities similar to unpolarized beam values. A 1.6 mA dc polarized H^- ion current was recently obtained at the TRIUMF OPPIS with a promise of further increase to the 2-3 mA range /4-5/. The dc current increase is limited by the ECR primary-proton-source beam quality and shortage of laser power for optical pumping. In pulsed operation the ECR source limitations have been overcome by using a high brightness proton source outside the magnetic field /6/. A feasibility study of a 10-20 mA pulsed H^- source is in progress at TRIUMF in collaboration with INR, Moscow and BINP, Novosibirsk.

The ECR-based OPPIS's are proven, very reliable sources. The TRIUMF OPPIS delivers a polarized beam to a number of experiments for 30-40% of the cyclotron running time. The beam quality meets very demanding requirements from the precision experiment at TRIUMF on parity violation in pp scattering at 230 MeV.

2 POLARIZATION TECHNIQUE

Polarization in an OPPIS is produced via electron-transfer (spin-transfer) collisions between the primary proton (atomic H) beam of 3-5 keV energy and optically-pumped alkali-metal vapor /7/. Ionization to H^- beam can be easily done by passing the atomic beam through a sodium negative ionizer cell. The acceptance of the OPPIS downstream of the primary proton source is limited by the optically-pumped cell diameter (especially in dc operation due to insufficient laser power to pump large diameter volumes) and by the ionizer cell diameter. The latter also determines the polarized beam emittance which should not exceed 2.0 pi·mm·mrad, the typical acceptance of an RFQ injector. The optically pumped cell is situated in a high (~2.5 T) solenoidal magnetic field to preserve polarization. The closely coupled ECR proton source operating in the same field is a quite efficient configuration in dc operation. Another scheme -- injection of a high intensity atomic H beam into the solenoidal field -- is advantageous for pulsed operation /8/.

3 DC OPPIS DESIGN FEATURES AND PERFORMANCE

The dc TRIUMF OPPIS general layout is presented in Fig.1.

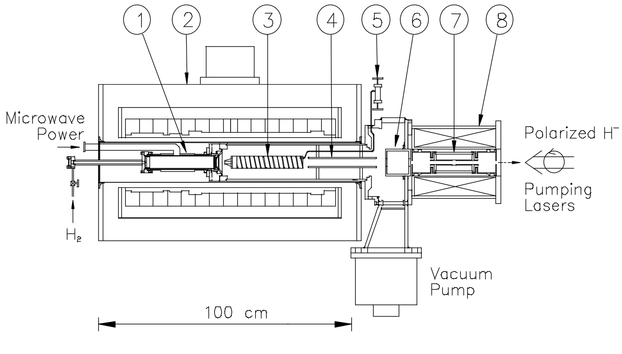

Figure 1: TRIUMF OPPIS general layout: (1) ECR proton source; (2) superconducting solenoid; (3) optically-pumped Rb cell; (4) deflection plates; (5) Rb loader; (6) Sona transition region; (7) ionizer Na cell; (8) ionizer solenoid.

The source per se is very compact partly due to its low gas consumption and comparatively simple vacuum system. The superconducting solenoid keeps power consumption moderate (~16 kW). The cw laser system is quite complicated and power hungry, but can be placed in a convenient remote location. The superconducting solenoid, manufactured by Oxford Instruments, comprises three independent coils for shaping the magnetic field in the ECR source. The adjustment is rather critical and care is required to give reproducible parameters for different ECR source assemblies. The maximum operational magnetic field (limited by quenching) in the extraction system and optically-pumped cell is 2.45 T. A significant polarization improvement was observed when the magnetic field was increased from 2.25 T to 2.5 T /9/, suggesting that fields up to 3.0 T may be worthwhile. Helium consumption is less than 3 liter/day, and the solenoid requires refilling every 10 days. The TRIUMF OPPIS is the only dc OPPIS, and numerous technical problems were solved on the way to its present reliable operation.

The ECR primary proton source is excited at 28 GHz by microwaves produced by a 1 kW extended interaction oscillator (VARIAN VKQ2435F3). About 800 W is required for optimal operation. The microwave tube is very reliable, with an operating time over the last 6 years exceeding 20,000 hrs. The microwave power enters the ECR cavity transversely through a quartz liner, which is sealed at the ends by indium O-rings and cooled by a flow of nitrogen gas around the outside. The liner together with boron nitride end cups confine the plasma volume. Despite operating in close proximity to the Rb vapor cell, no Rb deposition was observed inside the ECR plasma tube or on the extraction electrodes, owing to their raised temperatures and the high ionization efficiency of Rb in the proton beam. The proton extraction system consists of three 1 mm thick planar molybdenum electrodes spaced 1.2 mm apart, having 0.9 mm diameter apertures in a hexagonally close-packed configuration with a 1.1 mm distance between centers. The three electrodes are drilled together by a spark erosion technique. The cost of manufacturing was dramatically reduced, compared with the initial technique of separate drilling, and the quality has improved. The grid lifetime in dc operation is on average 1500 hrs, and cost reduction is quite important. For experiments with large numbers of apertures it is essential.

Rb^+ ions, produced in the Rb vapor by charge exchange with the incident proton beam, are slow and confined radially by the high magnetic field, creating a high positive space-charge in the Rb cell. Electrons emitted from the third extraction electrode compensate the space charge. This process must work quite well, otherwise the proton beam would blow up immediately.

Numerous optically-pumped Rb vapor cell designs were tested. The present cell consists of two coaxial tubes. The outer tube is a heated Rb reservoir. The inner tube is 14 mm in diameter and has slot openings connecting it to the Rb reservoir (see Fig.2).

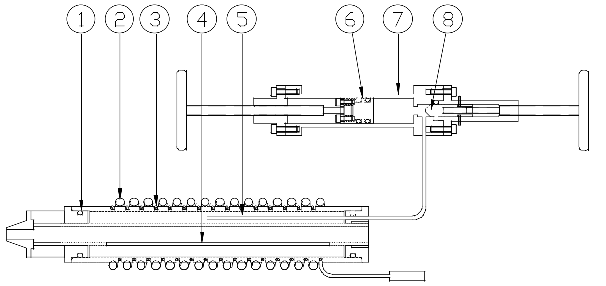

Figure 2: Optically-pumped Rb vapor cell and loader: (1) O-ring; (2) circulating liquid heating tube; (3) electric heating coil; (4) slot; (5) Rb loading tube; (6) piston; (7) cylinder; (8) valve.

The input collimator diameter is closely matched to the proton beam diameter (about 8 mm for the 31 hole extraction system) for gas flow reduction. The cell temperature is stabilized by circulating hot liquid (water below 90° C and ethylene glycol up to 120° C). The temperature control stability in the circulator bath is 0.01° C. An electrical heater on the Rb reservoir, run at a low constant setting, compensates for heat losses in the circulator plumbing. Ripple in the source current due to changes in Rb vapor density has been eliminated with this system. The Rb is loaded into the cell through 1/8" copper tube from an external reservoir situated outside the source vacuum chamber. The external reservoir consists of a cylinder and piston sealed by a double Viton O-ring and valve (see Fig 2). It is filled with 25 g of Rb in a glove box, attached to the copper connecting line, and warmed up with a hot air gun to more than 39° C (the Rb melting point). Liquid Rb, which has a low viscosity, is then easily transferred to the cell reservoir. The cell is vacuum baked at 200° C for 8 hours before loading. During loading the cell is kept at 60-80° C. 25 g of Rb is sufficient for more than 1000 hrs cell operation. A nice feature of the system is that the external reservoir can be refilled without breaking source vacuum, since solid Rb provides a perfect vacuum seal. The external reservoir and loader greatly ease Rb handling and contribute to overall source reliability.

The low energy beam diagnostic system consists of a 45 degree bending magnet which directs the H^- beam to a Faraday cup for source tuning, or to a split-plate beam-position monitor for measuring spin-flip-correlated beam energy modulations. The resolution of the latter of about 1 meV was attained using a synchronous detection technique.

4 PULSED OPPIS DEVELOPMENT

Increases in the dc polarized current are limited by the comparatively low emission current density and high beam divergence of the ECR proton source. Only about 20% of the electronically polarized atomic H beam is produced within the Na ionizer cell acceptance. This is an inefficient use of the available laser power.

The possibility of increasing the polarized H^- ion current to 10-20 mA in a pulsed mode, based on the INR, Moscow OPPIS scheme, is discussed elsewhere /7,8,10/. The pulsed OPPIS general layout is presented in Fig. 3.

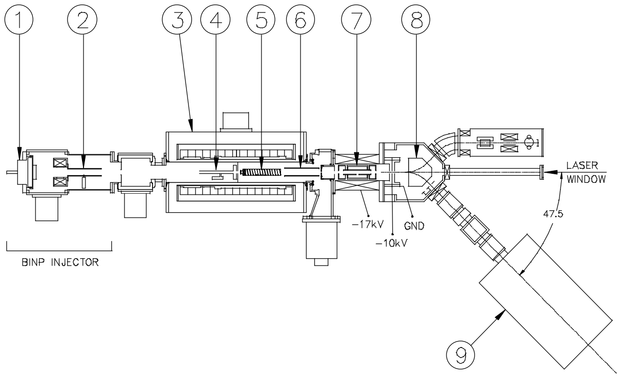

Figure 3: Proposed neutral injector OPPIS setup: (1) plasmatron proton source; (2) H_2 neutralizer; (3) superconducting solenoid; (4) He ionizer; (5) Rb neutralizer; (6) deflection plates; (7) Na ionizer; (8) bending magnet; (9) RFQ.

In recent experiments at a test bench in BINP, Novosibirsk, 360 mA of equivalent atomic H peak current was obtained within the acceptance of a simulated sodium ionizer matching the geometry of a pulsed OPPIS /8/. The ionization efficiency in the He cell is about 80 %, the neutralization efficiency in the Rb cell is also about 80% , the H^- ion yield in the sodium ionizer cell is ~9 %, and the current losses due to multiple scattering should not exceed ~3 %. Therefore a polarized H^- ion current of ~20 mA should be attainable with this atomic injector. For polarization studies including experiments on spin-exchange and combined techniques of polarization /7/, an experimental setup similar to Fig.3 is under preparation at TRIUMF. An atomic H injector based on BINP and INR prototypes has been designed and manufactured /8/. The experiments will be done at the operating TRIUMF OPPIS with some modifications of the vacuum system. A pulsed Ti:sapphire laser was built and successfully tested for optical pumping of a high density Rb vapor in a relatively large 2.0 cm diameter cell.

Design of a polarized injector including the source, low energy beam transport line, polarimeters and RFQ is in progress within the framework of the SPIN collaboration feasibility study for proton polarization facilities at HERA.

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