A NEW HIGH INTENSITY DC H^- ION SOURCE FOR TRIUMF

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Summary

We describe a dc volume H^- source, employing multicusp plasma confinement, which has been constructed for use with the TRIUMF cyclotron. An extracted H^- current density of 12 mA/cm^2 has been obtained. Beam emittance and brightness have been measured as a function of current density and beam fraction. Beam brightness values for normalized beam emittances at 81% beam fraction are typically 10 $mA/(mm{\cdot}mrad)^2$ (equivalent rms B = 200 $mA/(mm{\cdot}mrad)^2$). A 9.4 m long beam line containing only electrostatic optics is being built to transport up to 2 mA of H^- beam at 300 keV from the ion source into the existing cyclotron injection beam line.

1. Introduction

Volume production is presently the preferred mechanism for producing bright negative beams of hydrogen or deuterium. Several laboratories are investigating multicusp plasma generators as volume H^- ion sources for neutral beam injection in applications with fusion plasmas and for particle accelerators.[1→4] These sources are characterized by their good beam quality, i.e., low emittance, high brightness, stable output, and relatively long filament lifetimes. Since cesium is not required in the ion source, the associated voltage breakdown problems resulting from cesium contamination of the accelerating system are avoided. These properties, along with the inherent simplicity of the volume source, make it a practical choice for high intensity accelerators. We describe here the dc H^- source developed for the TRIUMF cyclotron, and present some measurements of its performance.

2. Cusp Source

The TRIUMF ion source, shown schematically in Fig. 1, is a cylindrical full-line cusp source employing 10 lines of 3.2 kG samarium-cobalt magnets deployed axially on the outside of an all-copper water-cooled plasma chamber. The plasma chamber is divided into two regions by a strong magnetic filter ($\int B{\cdot}dl$ = 200 G·cm) after the method of Leung et al.[1] Four lines of magnets across the back face complete the confinement of the plasma. The extraction face, which is insulated from the cusp chamber body, consists of a 20 cm diameter plasma electrode with a 6.5 mm diameter extraction aperture.

The extraction lens is an axially symmetric four-electrode structure similar to that employed at KfK.[3] The H^- is extracted through the 6.5 mm hole by applying a positive 3 kV potential (wrt the cusp body) on the second electrode (see Fig. 1). Permanent magnets in the first and second electrode, arranged such that they have a $\int B{\cdot}dl$ of zero, serve to sweep the simultaneously extracted electrons from the beam while giving the heavier H^- ions only a small net displacement. An additional voltage increase of ~22 kV between the second and third electrodes then brings the ion energy to 25 keV. The optimum dimensions of the extraction system were calculated using the computer code AXCEL[5] for a desired beam energy of 25 keV and current density of <10 mA/cm^2.

In order to reduce gas stripping in the extraction lens region and to run the source at optimum gas pressure, the extraction system was designed to allow differential pumping.

On-line tuning of the extracted beam is accomplished with the aid of the four wire scanners shown in Fig. 1. The first wire scanner is placed in a diagnostic box immediately after the extraction system. The remaining three wire scanners are placed in diagnostic boxes downstream of a solenoid magnet.

The beam emittance is determined by a two-slit scanner.[6] In this technique a portion of the beam passes through a narrow slit (0.06 mm) into a region where two parallel plates (2.8 mm gap by 38 mm long) impose a variable transverse electric field. The beam which passes through the second slit (0.06 mm) is detected by a Faraday cup.

3. Initial Measurements

The output of the final Faraday cup was examined on an oscilloscope and revealed only a small (~5%) high frequency component in the total extracted current.

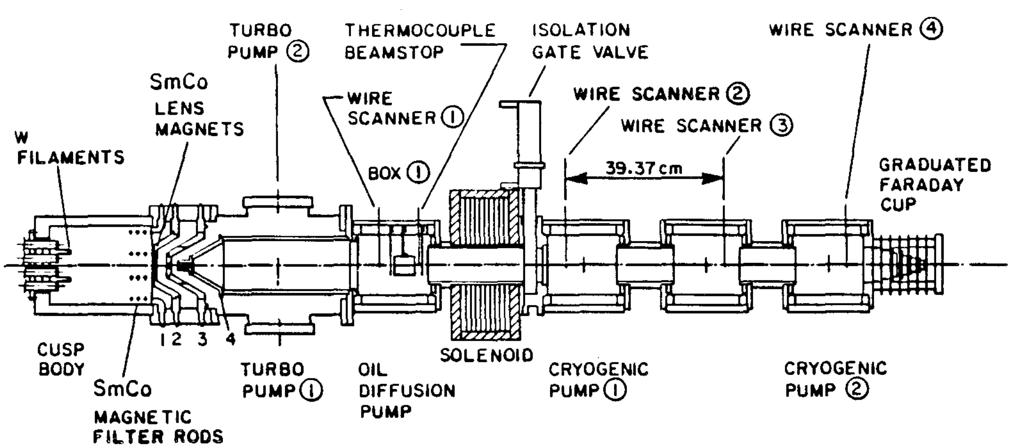

Fig. 1. Schematic diagram of the multicusp ion source, extraction system and diagnostics geometry.

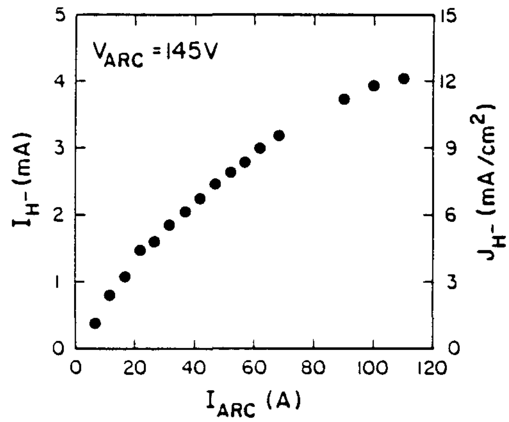

Fig. 2. Total extracted H^- beam current and density vs arc current for optimized plasma parameters at a constand arc voltage of 145 V and 25 keV extraction energy.

This was mostly due to noise on the power supplies controlling the source. The intrinsic plasma noise was only a small fraction of this figure.

The dependence of extracted current on source pressure displays a broad pressure optimum at ~ 7 mTorr (corresponding to a H_2 flow rate of 15 cc/min), in agreement with observations of other sources.[1-3] At high pressure the extracted current eventually decreases. This decrease is not, however, due to stripping in the beam transport section. The current measured on the Faraday cup at the end of the beam line is ~97% of the total current measured with the cup in the first box, indicating that gas stripping in the beam line is negligible. Evidence that stripping is also unimportant in the extraction region was obtained by measuring the ratio of extracted beam current to power as a function of gas load. This measurement was done using a Faraday cup-calorimeter in the first box.

The extracted current scaled with the extraction aperture. Initial measurements with a 13.2 mm diameter aperture yielded an extracted current of ~4.1 mA compared to ~1.0 mA under similar conditions with the standard 6.5 mm aperture. The beam brightness, however, improved with the smaller aperture probably due to a decrease in aberrations in the extraction system.

Figure 2 shows the total extracted H^- current, as measured by the Faraday cup, versus arc current for an arc voltage of 145 V with all other parameters optimized. The maximum extracted current density of 10 mA/cm^2 at an arc of 70 A - 145 V corresponds to a current of 3.1 mA at 10 kW of arc power. This is consistent with the value observed by the pulsed Los Alamos source.[2] The measurements were made with the magnetic filter rods installed in the position closest to the first electrode (5 mm). This position yielded the maximum extracted H^- current while minimizing the electron contamination as evidenced by the drain currents on the second and third electrodes (typically ~15 mA).

Figure 3 shows the measured normalized beam emittance ($\gamma\beta\varepsilon$) as a function of current density for the data in Fig. 2 for several beam fractions. The beam fraction f^2 is defined as the square of the measured one-dimensional fraction.

The brightness data is shown in Fig. 4, as a function of extracted current density, for several beam fractions. The normalized brightness is defined as:

$$B_n = 2If^2/\pi^2\varepsilon_n^2 \qquad (1)$$

where I is the Faraday cup current, f is the fraction of total beam within the one-dimensional emittance contour and ε_n is the normalized beam emittance. The brightness is nearly constant between 3 and 10 mA/cm^2. Above 10 mA/cm^2 the apparent brightness falls because the extraction geometry was optimized for currents less than this value. The maximum measured normalized brightness for 81% beam fraction was 14.0 mA/(mm·mrad)^2 at a current density 5.6 mA/cm^2. The corresponding emittance figure is shown in Fig. 5. For these data the emittance (area divided by π for 90% beam fraction in one dimension) is 0.147 mm·mrad and the normalized rms emittance is 0.038 mm·mrad yielding an rms brightness ($= 2I(\pi\beta\gamma\varepsilon_{rms})^{-2}$) of 250 mA/(mm·mrad)^2. The data of Fig. 5 show the qualitative features of a Maxwellian (semi-Gaussian) distribution. Moreover, four times the rms emittance contains very nearly 90% of the beam (in one dimension), and this is also true of the Maxwellian distribution.[7] The plasma temperature corresponding to these data is therefore 0.52 eV.[7]

4. Operational Status

The cusp source has proved to be operationally stable and easily tunable. The testbed measurements suggest that it should outperform the operational Ehlers' PIG source.[8] We have moved the system to a new high voltage terminal and will soon subject the source to the operational demands of H^- production in order to examine its reliability. A second cusp body is being built to serve as a spare and will be set up on the testbed to allow further source development.

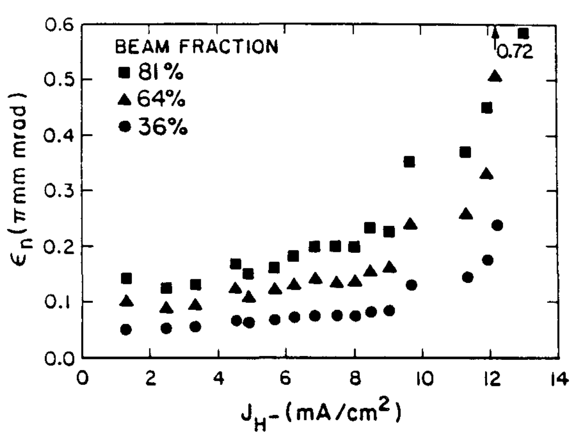

Fig. 3. Normalized beam emittance vs. current density at several beam fractions for the data in Fig. 2.

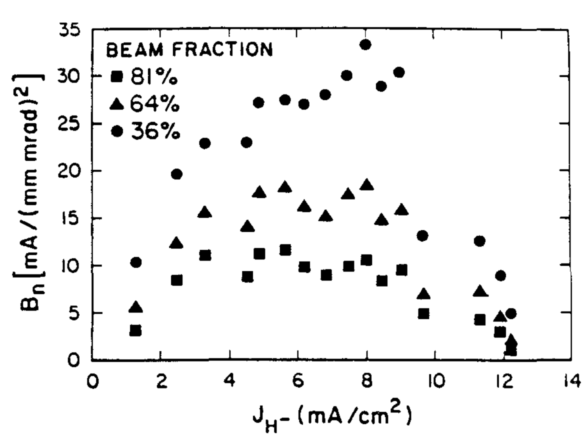

Fig. 4. Normalized brightness vs. current density at several beam fractions for the data in Fig. 2.

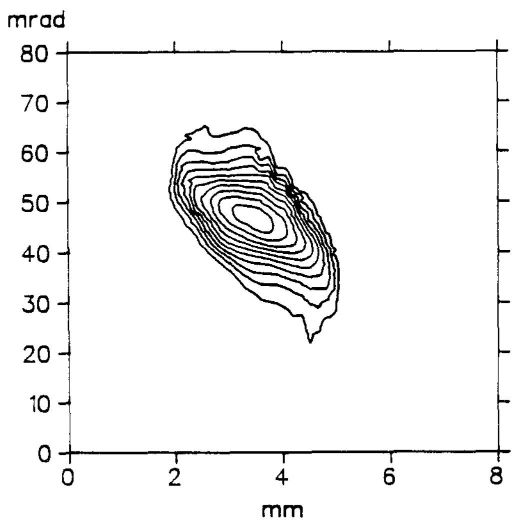

Fig. 5. Emittance figure for an extracted current of 1.85 mA. The outermost contour contains 93.4% of the beam and the other 9 contours divide the beam fraction roughly equally.

To transport an H^- beam of up to 2 mA with a normalized emittance ($4\beta\gamma\varepsilon_{rms}$) of 0.20 mm•mrad to the existing injection line, a new beamline has been designed and is being built. It consists of a 25 keV region (1.8 m) followed by an accelerating column (0.9 m) to 300 keV and a 9.4 m beamline consisting of electrostatic elements. The optics in the 25 keV region (one solenoid and two correcting dipoles) are exclusively magnetic in order to maintain space charge neutralization. In order to trim the beam emittance, a cooled aperture is placed in the location after the solenoid corresponding to 90° of betatron phase advance from the source. The 300 keV section consists of 20 electrostatic quadrupoles (0.10 m long) and 16 electrostatic dipoles (0.08 m long). The first four quadrupoles will match the beam to the rest of the beamline which consists of 8 periods, each 1.0 m long. The quadrupoles in the periodic section are arranged in doublets to allow easy placement of the dipoles, bellows, and assorted diagnostics in the long drift (0.57 m). The phase advance per cell can be varied between 0° and 150° though it is intended to be 90°. The 2 mA beam will depress the incoherent phase advance per cell from 90° to 65°. Recent measurements[9] indicate that this depression is still safe from the point of view of beam stability and emittance growth. Motor driven horizontal and vertical slits are placed in the first two cells so that the emittance can be cropped in all 4 dimensions. Provision has been made for two-slit scanners at either end of the new 300 keV section so that emittance growth can be measured. Also, a pulser, operating across the accelerating stack, will allow one to control the time structure of the beam so that time-dependent neutralization effects can be measured.

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