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A VOLUME H^- ION SOURCE WITH A TOROIDAL DISCHARGE CHAMBER*

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Abstract

A new volume H^- ion source has been designed with the objective to reach a current of 50 mA in 1 ms pulses, to be eventually used on the new RFQ preinjector at BNL's Alternating Gradient Synchrotron. Its main feature is a full rotational symmetry, with a toroidal discharge chamber separated from the central extraction region by a conically shaped dipole field. Preliminary studies consisted of measurements of the H^- yield and the accompanying electron component as a function of the discharge current, discharge voltage, pressure, and extraction voltage for several geometries of the conical field; effects of the filament heating current were also studied, both for dc and ac cases. So far, it was possible to extract an H^- current of 30 mA through an aperture of 1 cm^2, with an electron component of about 750 mA.

Introduction

Studies of volume H^- ion sources at BNL started with a standard cylindrical model,[1,2] of the tandem type. Several configurations of the cusp field were examined (line, circular, and checkerboard); maximum H^- current density was around 20 mA/cm^2 through an aperture of 0.8 cm^2, at an arc current of 400 A. The electron component was high, about 40-50 times higher than the H^- current.

The new toroidal discharge chamber source was designed with the idea of producing hydrogen molecules in highly excited states in a large volume surrounding the central extraction region. In order to fully utilize the discharge, the dipole field--an important feature of tandem sources--had to have a conical shape. This feature resulted in a full rotational symmetry of the source, a characteristic that may result in a smaller beam emittance. The source volume is relatively small, about 2,000 cm^3.

Source and Test Stand

Figure 1 shows a cross section of the source, Figure 2 shows a photo of the discharge chamber. There are 11 cusp rings held in place by means of iron plates enclosing almost completely the copper vacuum chamber. Only the side wall of the chamber is water cooled. At present a circular tungsten filament (1.25 mm diameter) is used as the cathode, but its replacement with an LaB_6 cathode is planned in order to reduce the heating power. Early studies have indicated that the H^- yield and the electron component may strongly depend on the value and direction of the filament heating current. Present results refer to a dc heating, with the current interrupted during the arc pulse, but the ac heating with the possibility of varying the phase with respect to the pulse was also investigated. Although a pure cusp field configuration was checked first as a reference case, all the results presented here were obtained with a conical dipole field established by mounting a 2.54 cm diameter SmCo disc in the center of the filament flange. The plasma electrode, opposite the extractor, served to study the effect of its bias on the source performance. Due to a rather low pumping speed of the test stand vacuum system, the gas was pulsed and the open interval of the valve recorded.

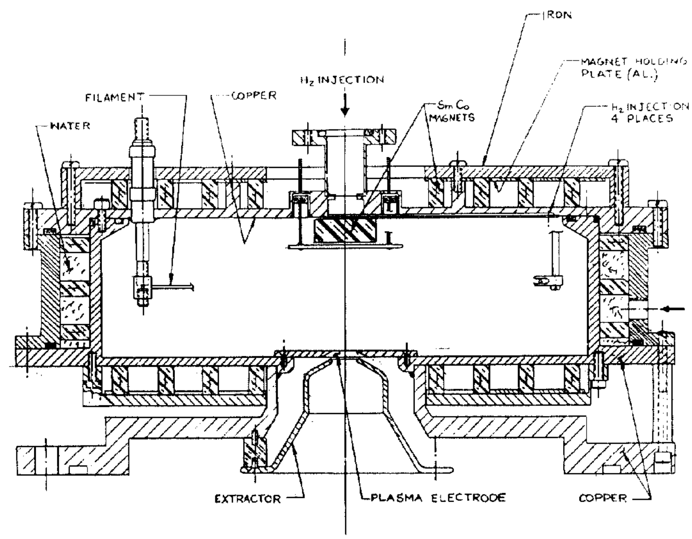

Figure 1. Cross section of the source.

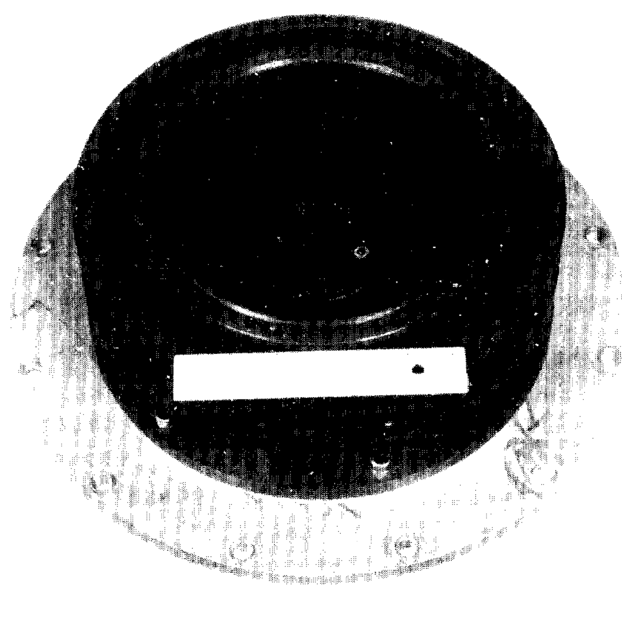

Figure 2. Discharge chamber.

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All the measurements were done with the source chamber grounded and the extractor-target assembly on a high positive voltage, up to 14 kV. The target current was measured as the voltage drop across a 1 kΩ series resistor, while the current falling on the extractor (including the 800 G dipole magnet to bend the electrons away from the target) was measured by means of a pulse transformer. Two small diffusion pumps were used on the test stand, achieving a base vacuum of 10^{-5} Torr.

Results

Effect of the Conical Field

To establish a reference point, the H^- yield and the electron component were measured for the cusp field only, without any dipole at all. Although the H^- yield as a function of the arc current was not lower than with the dipole field, the electron component was extremely large, corresponding to a ratio I_e/I_{H^-} of more than 200; due to an overloading of the H.V. power supply, it was not possible to increase the arc current above 20 A.

Figure 3 shows the yield as a function of the arc current, for three available SmCo discs (thickness: 9.5 mm; 12.5 mm; 19 mm). For each value of the arc current, the hydrogen pressure in the source and the arc voltage were optimized (a broad optimum was at 200 V); the plasma electrode was left floating and the extractor voltage kept at 12 kV. It may be noted that doubling the thickness of the disc results in a proportional reduction of the H^- yield; however, there was some improvement in the ratio I_e/I_{H^-} due to a stronger dipole field. Studies of other dipole field configurations are underway, as this seems to be one of the most important source design parameters. For the rest of the measurements in this paper, the 9.5 mm disc was selected.

Effect of the Hydrogen Pressure

Figure 4 shows again the same parameters, this time as a function of the gas pressure, for a constant arc voltage of 200 V. While there was no great effect of the arc voltage on the yield, the gas pressure is a critical parameter. There is always a clear optimum that moves toward higher values as the arc current increases. It has to be mentioned also that the waveform of the H^- current has a more or less good shape over 1 ms pulse for points above the optimum pressure; for lower values, there is a pronounced peak at the beginning of the pulse followed by a drop by up to 30-40% from the peak. The graphs show values at 0.5 ms in the pulse. The curves I_e/I_{H^-} show an even more pronounced dependence on the pressure: there is a minimum corresponding to the maximum H^- yield. The estimated pressure range on Figure 4 is 5-15 mTorr.

Effect of the Extraction Voltage

Figure 5 shows the H^- yield as a function of the extraction voltage, with arc current as parameter. In this set of measurements, the gas pressure was again optimized for each value of the arc current, the arc voltage was constant at 200 V and the plasma electrode floating. The family of curves shows a typical steep rise followed by a semi-plateau, similar to what was observed for other sources.[3] The extracted electron component, however, depended little on the extractor voltage.

Effect of the Plasma Electrode Bias

It has been known that the bias on the plasma electrode affects both the H^- yield and the electron component.[3,4] Figure 6 shows the extracted H^- current and the ratio I_e/I_{H^-} as a function of the bias, for several values of the arc current. Both the arc voltage and the extraction voltage were kept constant at 200 V and 12 kV, respectively. For the whole range of arc currents, there was some increase of H^- yield when a negative bias was applied to the plasma electrode, accompanied by a disproportionally larger electron component. A positive bias always resulted in a reduction of the H^- yield and a still steeper reduction of the electron component (see curves for 200 A arc current).

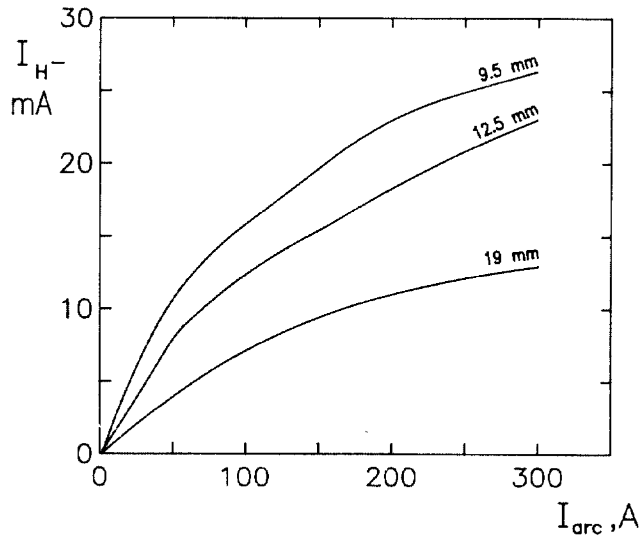

Figure 3. H^- yield vs. arc current, with the conical dipole field as parameter.

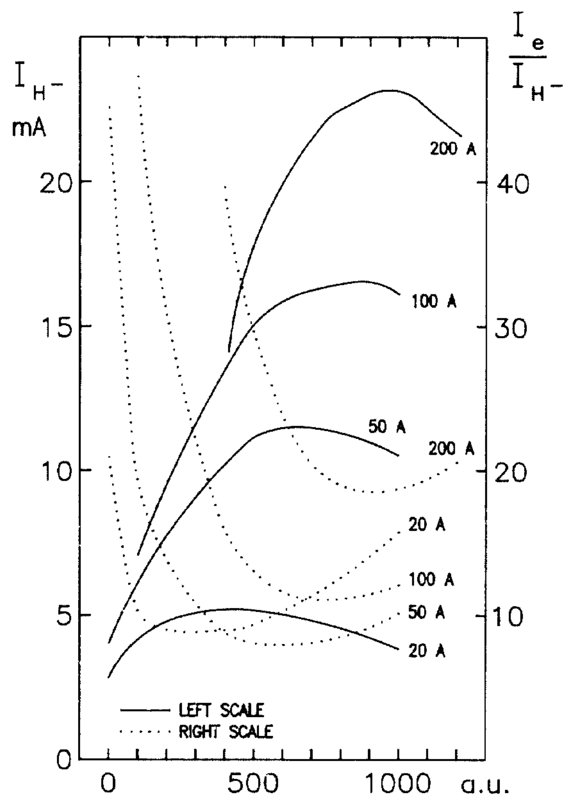

Figure 4. H^- yield and the ratio I_e/I_{H^-} vs. gas pressure.

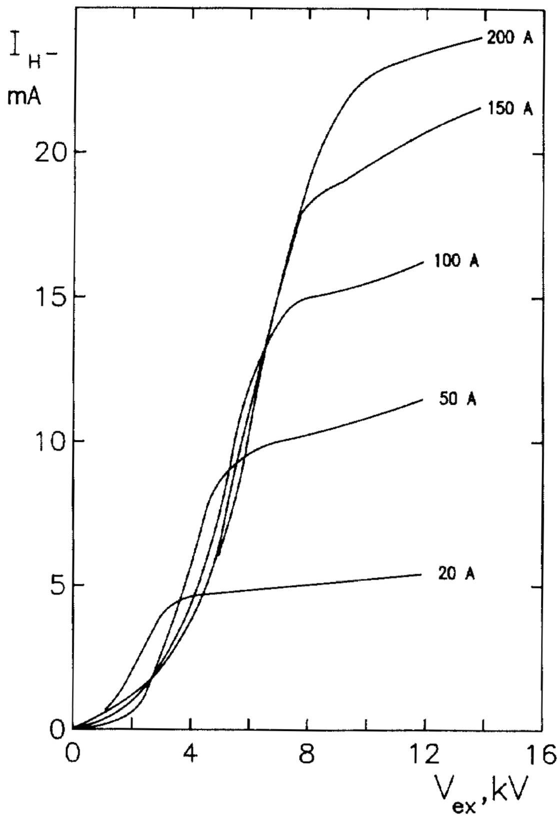

Figure 5. H^- yield vs. the extraction voltage.

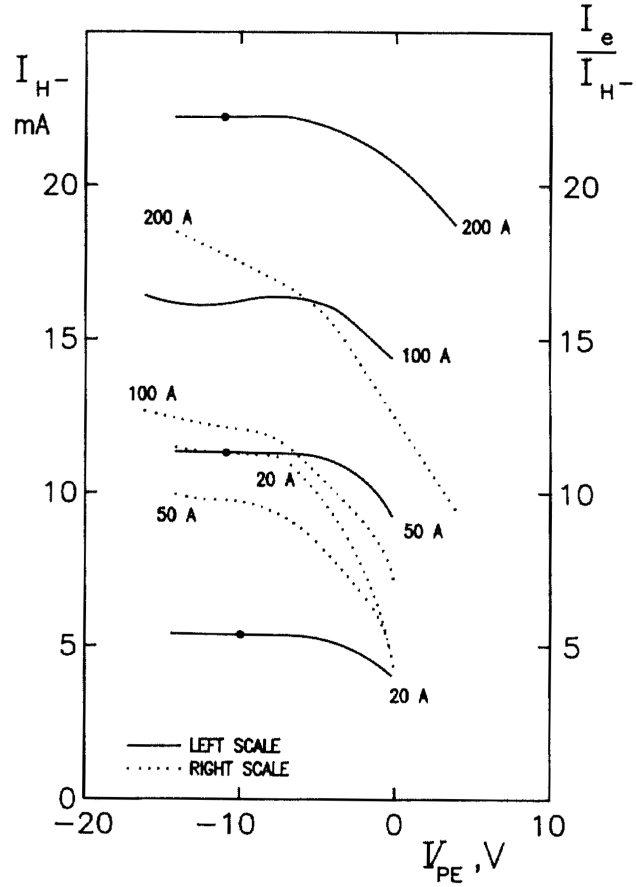

Figure 6. H^- yield and the ratio I_e/I_{H^-} vs. plasma electrode bias.

Effect of the Filament Heating Current

The importance of the direction and amplitude of the filament heating current was discovered during early studies. Subsequently, the yield and the electron component were measured with source parameters constant, as a function of the phase between the 60 Hz filament current and the arc. The H^- yield was the highest when the arc was triggered within $\pm$ 10° of the ac zero crossing; however, for phase shifts corresponding to the ac peaks, the yield not only was at the minimum, but the value of the minimum depended on the instantaneous direction of the current. We have no explanation for this result. Following the ac studies, a circuit was added to the dc filament power supply to interrupt the filament current during the arc pulse; an improvement of 20-30% in the H^- yield is usually achieved compared to the full heating current, especially at lower values of the arc current. The ratio of the electron component to the H^- current follows roughly the shape of the H^- current, as a function of the phase shift.

Conclusions

The source, as designed, has produced so far an H^- pulsed current on the target of about 30 mA. There are, however, other source parameters that may be important, like for example electron component, gas flow, and arc power. Optimizing for all of them simultaneously is not possible and often the best results for one parameter means sacrificing the source performance with respect to one or more of other parameters.

This paper presents results of preliminary studies of the source. They seem to be encouraging enough to justify further work, which will include measurements of the beam emittance, development of a LaB_6 cathode, studies of different cusp configurations, and possibly an increase of the extraction aperture to 2 cm^2, all with the objective of reaching a pulsed H^- current of 50 mA with a good emittance.

Acknowledgment

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