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STATUS OF THE BNL TOROIDAL VOLUME H<sup>-</sup> SOURCE\*

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## Abstract

A volume H<sup>-</sup> source having a toroidal discharge chamber and conical filter field has been developed. Parametric studies of this source have been in progress for two years. Extraction apertures from 0.5 cm<sup>2</sup> to 1.87 cm<sup>2</sup> have been tried, and an H<sup>-</sup> current of up to 48 mA has been extracted. The electron-to-H<sup>-</sup> current ratio in the extracted beam can be as low as 10 for ≈ 25 mA H<sup>-</sup>. The measured emittance (normalized, 90%) of a 19 mA beam was 0.44 π mm mrad. When operating with deuterium, the D<sup>-</sup> output was 50-60% of the H<sup>-</sup> current under the same discharge conditions. The addition of cesium to the discharge increased the H<sup>-</sup> output and decreased the electron current so that at 30 mA of H<sup>-</sup>, one obtained an electron-to-H<sup>-</sup> ratio of 1. Using a two gap extractor, with a dipole field in the intermediate electrode, approximately 80% of the extracted electrons could be removed from the primary beam.

## Introduction

Volume H<sup>-</sup> ion sources have an advantage over surface production negative ion sources, which are more commonly used on accelerators, in that they don't need cesium for operation. Among the disadvantages, on the other hand, are the usually very large extracted electron current, and the relatively low extracted H<sup>-</sup> current density. At Brookhaven, the design and study of a novel volume H<sup>-</sup> source began in 1988.<sup>1</sup> The goal is to develop a source which will produce at least 50 mA of H<sup>-</sup>, in 500 μs pulses and a 10 Hz repetition rate, to replace the magnetron surface-plasma source in operation on the 200 MeV linac. The source has a toroidal geometry, with the discharge region surrounding the central extraction region. A conical filter field separates the two regions. The idea of the toroidal geometry was to get the best utilization of the discharge, and to maintain a full rotational symmetry of the source.

While at this point we can reach the desired current by "pushing" the source, it is still just the first prototype, and would probably not be able to deliver 50 mA for weeks of continuous operation. Presently, reliable operation at 30 mA is more realistic. In the following sections, features of the source are first given, and then the results of some parametric studies are presented.

## Features of the Source

Figure 1 shows a cross section of the source. The source chamber is cylindrical, 6 cm long and 20 cm ID. The walls of the chamber are lined with SmCo magnets, arranged to form ring cusps (typically 4 each on the front and back plates, and 3 rings around the side). A SmCo disc magnet opposite the extraction aperture produces the conical filter field. The calculated magnetic field lines are also shown in Fig. 1.<sup>2</sup> The cath-

ode is a single loop of tungsten wire placed outside the filter field region. The gas and discharge were pulsed for the following measurements, typically at 0.5-1.3 Hz, with a 1.2 ms discharge width. A negative dc extraction voltage was applied to the source, and the extraction gap was typically 0.97 cm. Most of the data presented here was taken at 12-18 kV.

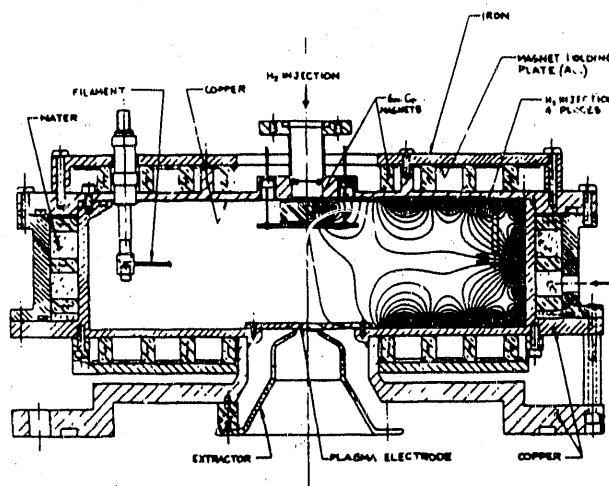


Fig. 1. Cross section of the volume source. The calculated magnetic field lines are also shown.

A Faraday cup and slit-and-collector type emittance head were located 10 cm from the source. A strong dipole field in front of the Faraday cup removed electrons from the beam, while deflecting the H<sup>-</sup> only slightly. A current transformer on the output of the extractor power supply measured the total supply drain current. The difference between the H<sup>-</sup> current measured on the Faraday cup and the total supply current was assumed to be electrons.

## Results

The following subsections give brief summaries of the some of the source studies.

## Conical vs. Dipole Filter Field

Normal volume H<sup>-</sup> sources use a dipole filter field to separate the discharge region from the extraction region. The conical filter field was removed from the source, and a dipole filter field was placed near the extraction aperture. Figure 2 shows the H<sup>-</sup> current vs. arc current for the two cases. The conical filter field increased the H<sup>-</sup> current by ≈ 50%.

## Dependence on Filament Parameters

Also shown in Fig. 2 is the dependence of the H<sup>-</sup> current on the circular W filament diameter. A higher output was obtained with the smaller diameter filament loop, but the arc current was limited to < 150 A due to the smaller emitting area.

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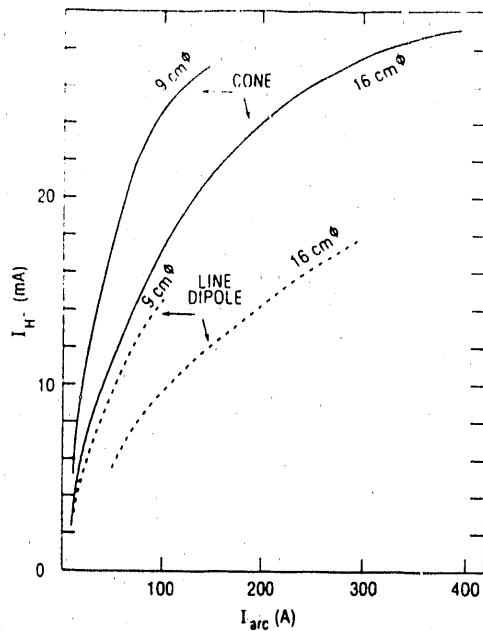


Fig. 2.  $H^-$  yield vs. arc current for the dipole and conical filter fields. Shown for each filter type are two different filament diameters.

The output also depended on filament wire diameter (1 mm is approximately the optimum), axial position of the filament, and direction and magnitude of the instantaneous ac or dc filament current.<sup>3</sup> Normal operation is now with the filament current interrupted during the discharge pulse.

#### Plasma Electrode Bias

The plasma electrode is isolated from the discharge chamber. With this electrode floating, the output is usually slightly higher, but the electron current is much higher, compared to operation with it grounded. If the electrode is biased, going from a negative to a positive bias reduces the  $H^-$  slightly, but the electrons much faster.<sup>4</sup>

#### Source Pressure

As the source pressure is varied, one can go through a broad maximum in the  $H^-$  current, and at the same point one goes through a broad minimum in the electron current.<sup>4</sup> The pressure measured in the discharge chamber is typically  $5-10 \times 10^{-3}$  Torr.

#### Extraction Aperture Size

Figure 3 shows the  $H^-$  current vs. aperture area. With the largest aperture, the extracted current density dropped significantly. However, by putting a thin tungsten wire cross across the aperture the  $H^-$  current density returned to near that of the smaller apertures. Operating at a 400 A discharge with the 1.87  $cm^2$  aperture gave an  $H^-$  output of 48 mA.

#### Extracted Electron Current

The ratio of electron current to  $H^-$  current depends on many parameters. Figure 4 shows a scatter plot of the  $e^-/H^-$  ratio vs.  $H^-$  current for a variety of operating conditions. This

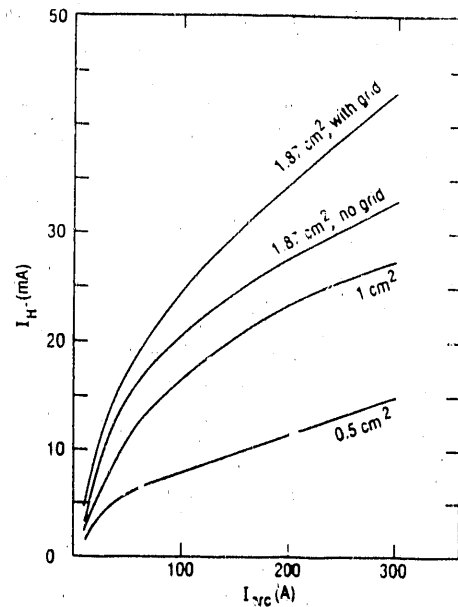


Fig. 3.  $H^-$  current vs. arc current for three different extraction apertures. The "grid" is a thin tungsten cross put over the aperture.

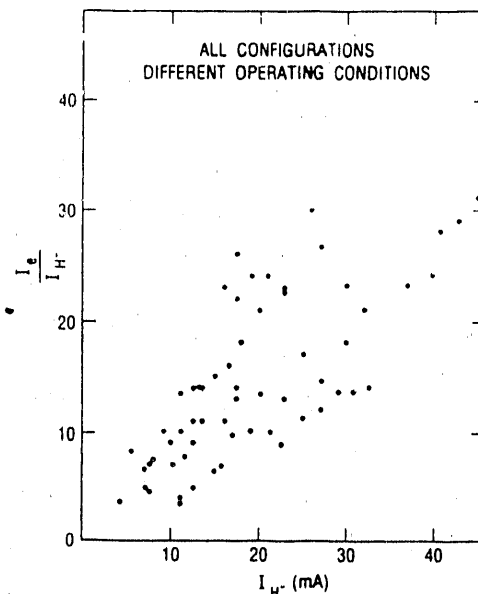


Fig. 4. The ratio of electron to  $H^-$  current as a function of arc current. The points are values taken under many different operating conditions, source geometries, etc.

includes different arc currents, aperture sizes, plasma electrode biases, filament geometries, etc. Details of the dependence on various parameters can be found in the references.

#### Emittance Measurements

Emittance measurements were taken with a 1  $cm^2$  extraction aperture, and a 0.97 cm extraction gap.<sup>5</sup> For a 13 mA beam, a normalized, 90% emittance of  $0.32 \pi$  mm-mrad was measured, or an RMS value of  $0.07 \pi$  mm mrad. This corre-

sponded to an effective ion temperature of 0.57 eV. At 19 mA the emittance was  $\epsilon_N(90\%) = 0.44 \pi$  mm-mrad.

### Double Gap Extractor

A two-gap extractor was tried, in an attempt to remove the electrons from the beam at less than the full energy. All three electrodes had apertures of 1.13 cm diameter. The intermediate electrode was 1 cm thick, and had permanent magnets imbedded in it in order to produce a dipole field to dump the electrons. We were able to dump more than 80% of the electrons on this intermediate electrode, operating at  $\approx 5$  kV relative to the source. There was a 10-20% loss of beam current due to an insufficient gradient in the first gap, and further optimization of the geometry is planned. Also, while the emittance area was the same as with the single gap extractor, the beam divergence could be reduced.

### Isotope Effect

When the source was operated with deuterium, the  $D^-$  output was 50-60% of the  $H^-$  output obtained under the same arc conditions.<sup>6</sup> At a given  $D^-$  current, the extracted electron current was at least 4-5 times higher than that obtained when running with hydrogen.

### Cesium Vapor Effect

A small cesium oven was installed inside the discharge chamber, and the effect of cesium on the source performance was studied.<sup>6</sup> Figure 5 shows the  $H^-$  output vs. arc current with

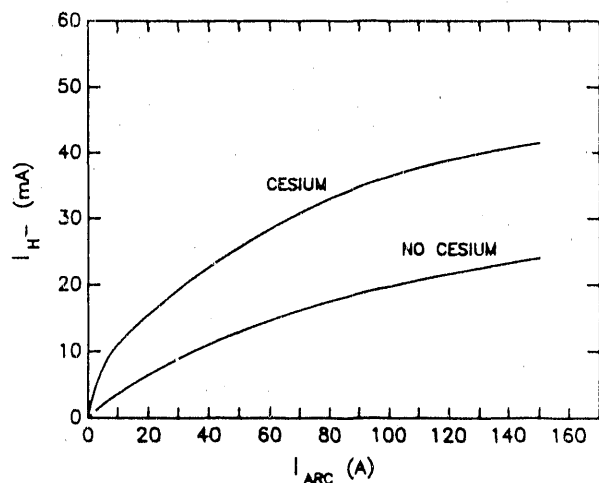


Fig. 5.  $H^-$  current vs. arc current with and without cesium in the source. The extraction aperture was  $1.87 \text{ cm}^2$  and the voltage 16 kV.

and without cesium, for a  $1.87 \text{ cm}^2$  aperture (single gap extractor). Generally, the output approximately doubled with cesium, while at the same time the electron current dropped. Figure 6 shows the  $H^-$  current and  $I_e/I_{H^-}$  ratio as a function of the plasma electrode bias. Note that with cesium added, one can adjust the electrode bias to get a very low  $I_e/I_{H^-}$  ratio without

much loss of  $H^-$  current. We could obtain  $>30 \text{ mA}$  of  $H^-$  with  $I_e/I_{H^-} < 1$ . In addition, the operating pressure could be reduced by approximately a factor of two with cesium. The effect of the cesium remained after the Cs supply was turned off, and even when the source was opened to air, some effects of the Cs remained. While the  $H^-$  current went back to near the levels before Cs was introduced, the operating pressure remained low, and the  $I_e/I_{H^-}$  ratio remained near unity. The source had to be thoroughly cleaned to bring it back to its original "cesium-free" levels.

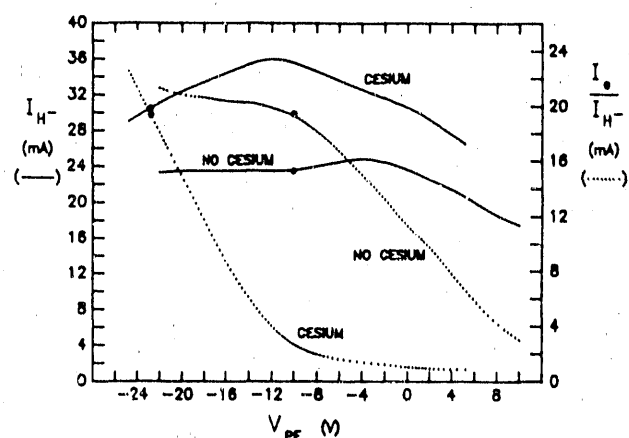


Fig. 6.  $H^-$  current and ratio of electrons to  $H^-$  as a function of the plasma electrode bias, with and without cesium.  $I_{arc} = 150 \text{ A}$ ,  $V_{arc} = 250 \text{ V}$ , and  $V_{ext} = 16 \text{ kV}$ . The dots indicate the floating potential.

### Acknowledgements

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