Volume H$^-$ Ion Source Development at LAMPF

R. L. York, D. Tupa, D. R. Swenson, and R. Damjanovich
Los Alamos National Laboratory, Mail Stop H838, Los Alamos, NM 87545

Abstract

One method of increasing the intensity of the LAMPF Proton Storage Ring is to use a brighter H$^-$ ion source. To develop such a source, the performance of the small LBL dipole filter and the BNL toroidal filter volume H$^-$ sources are being investigated. Results of testing a new high-duty-factor design of the BNL toroidal filter volume source are discussed. Results of experiments to reduce the electron to H$^-$ ratio and modulate the beam intensity in the small LBL source are presented.

I. INTRODUCTION

The LAMPF Proton Storage Ring, PSR, and proposed new projects, such as the National Center for Neutron Research, NCNR, require a high-duty-factor H$^-$ ion source capable of producing a 35 mA beam with an emittance of 0.04 cm-mrad at 95% beam fraction. The LBL dipole-filter [1] and the BNL toroidal-filter [2] volume H$^-$ sources have both demonstrated, at low duty factors (<1%), the beam intensity and quality necessary for these facilities. A development program to determine the high-duty-factor capabilities of these sources has been in progress for one year. LAMPF has operational experience and facilities to evaluate high-duty factor H$^-$ ion sources.

Reducing the ratio of electrons to H$^-$ ions is essential to minimize operational problems and maximize the quality of the H$^-$ ion beam. Operational experience at LAMPF has shown that, at duty factors greater than 5%, impinging even a small amount of electron beam on the accelerating lenses can produce an arc down rate that can devastate the operational reliability of the source. Reducing the electron ratio at the source is especially important at high duty factors.

II. BNL TOROIDAL FILTER SOURCE

The BNL toroidal volume H$^-$ source, with its unique conical shape magnetic filter, has been under study at BNL since 1988 and its performance is well documented [2]. This source is very attractive for high-duty-factor applications because it produces H$^-$ beam in excess of 30 mA with an electron ratio of less than 5:1. With the assistance of Jim Alessi at BNL, a high-duty-factor version of this source has been designed and constructed. A drawing of this source is shown in Figure 1. Extensive magnetic field calculations were performed using PE-2D [3] to preserve the magnetic-cusp and filter-field geometry while incorporating the necessary changes to obtain reliable high-duty-factor performance. The interior of the source housing is stainless steel with individual recesses for each magnet arranged in circular patterns. The outer housing is aluminum rather than iron for maintenance and construction considerations; the PE-2D calculations indicated that the major features of the magnetic confinement and filter fields could be maintained without an iron return. The filament feedthroughs are of a concentrically cooled design that has been used reliably in the production operation of our surface source for 10 years. The cylindrical cavity at the back of the source makes it possible to optimize the filter strength by changing filter magnets without breaking vacuum. The unique clamshell design of the vacuum housing makes maintenance of the inside of the source possible without opening water passages. This design also permits the plasma electrode position to be optimized.

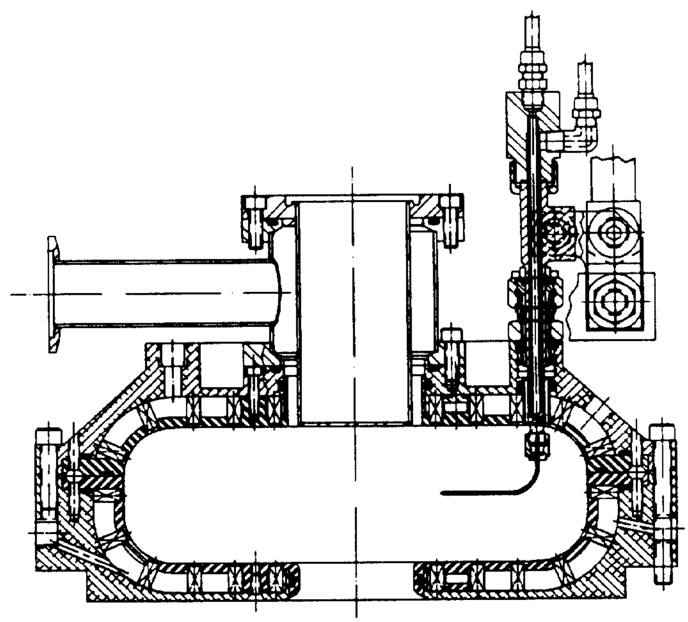

Figure 1. The LAMPF high-duty factor version of the BNL toroidal filter source.

For evaluation, the new source was installed in the H$^-$ Cockroft-Walton dome[4]. To optimize the magnetic filter, different sizes and strengths of filter magnets were tested. The polarity of the magnets was changed from attracting (the filter magnets are opposite in polarity to the innermost ring of cusp magnets on the source front plate, as in the BNL design) to repelling (the filter magnets are the same polarity as the cusp magnets). A representative sample of these data is shown in Figure 2. Unlike BNL, for our source design, the performance of the repelling magnetic configuration is superior to the attracting one. In this configuration, the extracted H$^-$ current and electron ratio are

*Work performed under the auspices of the U.S. D.O.E.

comparable to the BNL results. An iron plate was added to the front of the source and the plasma electrode was moved to the inside front edge of the source to better simulate the BNL design, but this was detrimental to the source performance for both filter polarities.

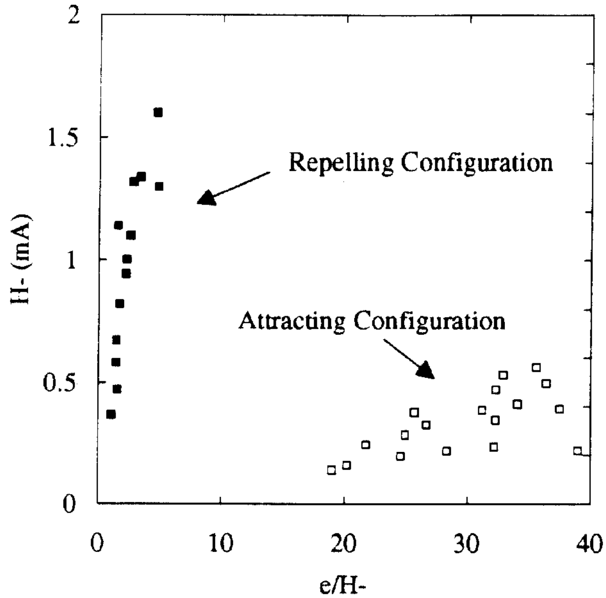

Figure 2. H^- current vs. electron ratio for attracting and repelling filter magnet configurations and filter strengths.

For these studies, two 1.5 mm diameter tungsten filaments shaped in semicircle loops with a radius of 6.5 cm were used. The performance of the source depended on the filament's heater current directions. The optimum heater current pattern was different for two filter polarities. This supports the BNL observation that there is an interaction between the filter magnetic field and the local magnetic fields produced by the filaments.

Plasma electrode positions beginning at the inner front face of the source and spacing outward 1.0, 1.5, and 2.0 cm were studied. Over this range, the H^- current only varied 10%, but electron ratio increased a factor of 5 as the plasma electrode was moved away from the source. However, the extraction optics are more difficult when the plasma electrode is more reentrant.

The plasma aperture was opened to 0.4 cm^2. The H^- current and electron ratio as a function of arc current are plotted in Figure 3. The pulse length was 800 µsec. Data taken at 4, 60, and 120 Hz showed no dependence on duty factor. The H^- current and electron ratio produced after cesium is added to the source are also plotted in this figure. Without cesium, the source produces an 8 mA beam, which corresponds to 20 mA/cm^2 with an electron ratio of 5:1. When cesium was added to the discharge, the H^- current increased to 40 mA/cm^2 with an electron ratio of 2:1.

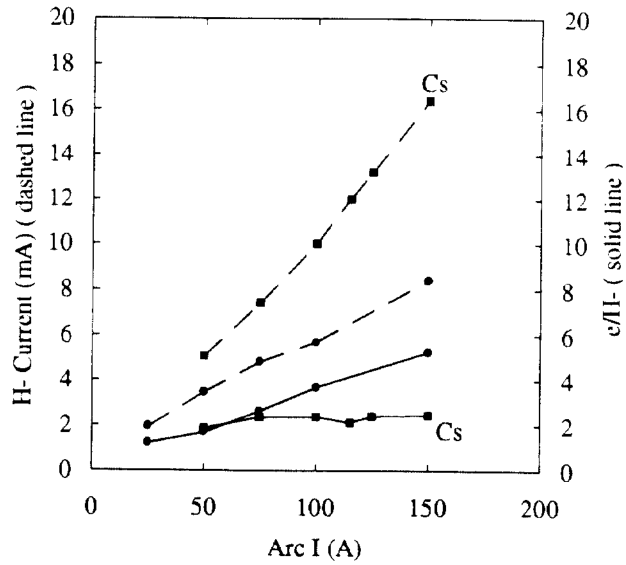

Figure 3. H^- current and electron ratio vs. arc current with and without cesium.

The emittance was measured using a slit and collector emittance station 1.5 meters from the source. For arc currents of 50 to 150 A, the 95% values of the emittance are plotted in Figure 4. This shows that the emittance increases almost linearly with arc current. The reason for this increase is not understood, but the beam emittance did not appear to be increased by aberrations. The emittance of an 8 mA beam with cesium at 100 A of arc current is also plotted. We were unable to measure the emittance of the 40 mA/cm^2 beam because the high-voltage electrode spacing was inadequate to transport a beam of this density

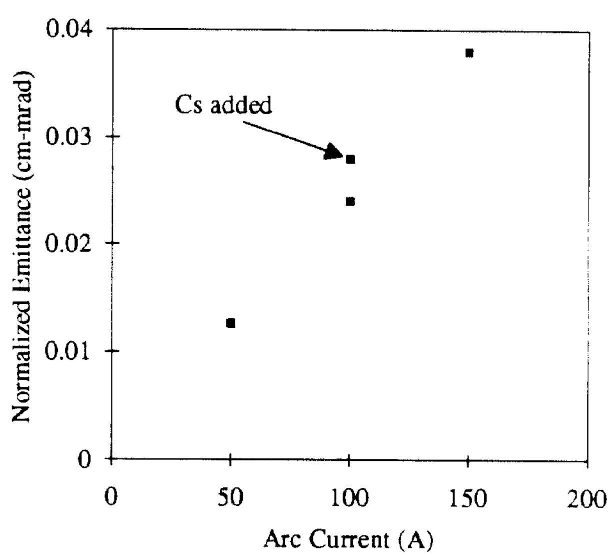

Figure 4. Normalized emittance vs. arc current.

III. SMALL LBL VOLUME SOURCE

The small LBL volume H⁻ source also has very impressive performance at low-duty factor. The 2 MHz rf driven version of this source has produced currents greater than 40 mA without cesium at a 1% duty factor[1]. However, reducing the electron ratio of this source would enhance its reliability for high-duty operation. Studies have shown that using a plasma electrode aperture with an aspect ratio (aperture diameter/thickness) of one greatly increases the ability to reduce the electron ratio by biasing the plasma electrode. This technique reduces the electron current by a factor of 10 while reducing the H⁻ current by only a factor of 2. The effects of magnetic filter strength, plasma electrode spacing from the filter, and the use of a collar have also been studied. These studies have revealed the effect of electron ratio on the beam emittance. Figure 5 shows how the beam brightness increases as the electron ratio is reduced. For the 240 A case, when the electron ratio was reduced by a factor of 7, the beam brightness increased by a factor of 5 while the H⁻ current only decreased 25%. Using a combination of these techniques, we have measured current densities in excess of 35 mA/cm^2 with a normalized emittance of 0.03 cm-mrad at 95% beam fraction and an electron ratio of less than 5:1 without cesium. To study the high-duty-factor performance of this source, a 2 MHz, 100 kW rf drive capable of 10% duty operation has been ordered.

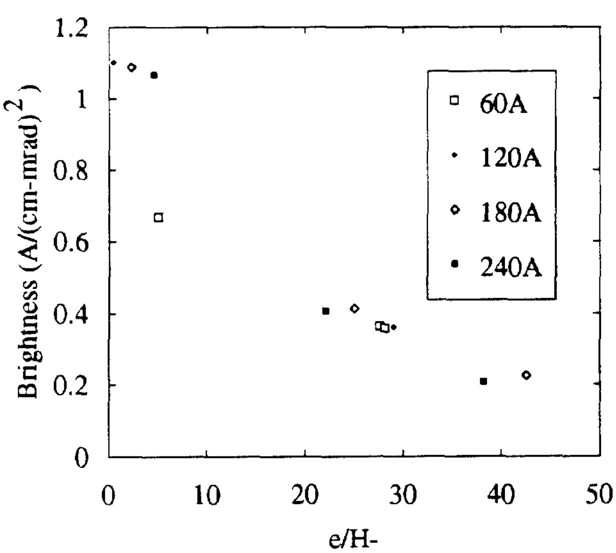

Figure 5. Beam brightness vs. electron ratio at different arc currents.

IV. BEAM MODULATION

Neutron spallation sources such as PSR require 100 to 200 ns gaps in the beam for extraction purposes. Designs of the NCNR accelerator propose this chopping at energies of approximately 100 keV. Calculations indicate that space-charge effects will make this process very difficult. Modulating the beam intensity at the source with rise and fall times of 100 ns or less would make final beam chopping easier by reducing the space-charge effects. This capability would also be useful at accelerators such as SSC where beam pulses with sharp rise and fall times are desired.

Our studies show that the beam intensity of the small LBL Volume H⁻ source can be modulated by biasing the plasma electrode. The geometry of the plasma electrode is very important to this process. For these tests, a collar[1] and plasma electrode aperture that is 3 mm in diameter and 3 mm thick were biased at the same potential with respect to the source housing. The tests showed that, with an arc current of 150 A, 90% of the extracted beam current could be suppressed if the plasma electrode was biased at -150 or +40 volts. Using a simple Hexfet modulator circuit, the plasma electrode can be pulsed to -150 volts in approximately 100 ns. The time response of the beam intensity was measured to exactly correspond to the applied voltage. This result proves that the plasma response is adequate to modulate the beam intensity at the source with a beam turn-off time of 100 ns. The plasma electrode discharge time and beam turn-on time of 100 ns were also been measured. Developing a voltage modulator with faster response that operates reliably floating at 80 kV has proven to be quite challenging. We hope to determine the time response limit of the beam-intensity modulation. We are also studying the geometry dependence of the beam modulation.

V. CONCLUSION

Both types of volume H⁻ sources show the potential of providing the brighter beams required for PSR and NCNR. If the toroidal filter source beam intensity continues to scale with plasma aperture, it will provide adequate beam current with small electron ratio. If the techniques to reduce electron ratio work as well for the rf driven source as for the filament source, it will also produce adequate beams. Modulating the beam intensity at the source on a time scale of less than 100 ns has numerous applications.

VI. ACKNOWLEDGEMENTS

We would like to acknowledge the contributions of J. Wieting, H. Williams, W. Potter, and J. D. Paul to this work.

VII. REFERENCES

[1] K. N. Leung et al., Rev. Sci. Instrum. 64, 970,(1993).

[2] J. G. Alessi and K. Prelec, "The BNL Toroidal Volume H⁻ Source," *Conference Record of the 1991 Particle Accelerator Conference*, Vol. 3, pp. 1913-1915.

[3] Vector Fields Limited, 24 Bankside, Oxford OX5-1JE, England.

[4] Ralph R. Stevens Jr. et al, *Proceedings of the 1984 Linear Accelerator Conference*, pp. 226-228.