DEVELOPMENT OF A VOLUME H⁻ ION SOURCE FOR LAMPF

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We have continued the development of a toroidal-filter volume H^- ion source with the goal of providing a better ion source for the proton storage ring at the Los Alamos Neutron Scattering Center (LANSCE). A prototype source has produced H^- beam currents of 6.3 mA from a 3-mm-diameter emission aperture (89 mA/cm^2) and 18 mA from a 10-mm-diameter emission aperture (23 mA/cm^2). These results were achieved when cesium was added to the discharge. The cesium increased the H^- current by a factor of 2-3 while the extracted electron current was strongly suppressed. The magnetic filter can be configured so that the electron to H^- ratio is 2:1 and is weakly dependent on operating parameters, with only a moderate loss of H^- current. Tests indicate there is essentially no explicit dependence of extracted beam current on duty factor up to 10% duty-factor. Emittance data were taken for various operating conditions in a mass-analyzed beam line and a comparison is made to the surface conversion H^- ion source now in operation for the storage ring.

I. INTRODUCTION

High-intensity proton compression rings, such as that now in operation at the Los Alamos Meson Physics Facility (LAMPF), are being considered as drivers for the next generation pulsed spallation neutron sources. Substantial increases in beam intensity can now be considered if the necessary high-brightness ion source can be developed. The requirements for the LAMPF ring entail operation with moderate peak beam currents but high duty factor in order to obtain the desired average currents. Although there are several candidate ion sources that meet many of the requirements needed in the application, none has yet demonstrated the simultaneous combination of intensity, emittance, duty factor, reliability, and availability, that are required in this application.

After a preliminary evaluation of available ion sources was made, work was initiated to evaluate the BNL toroidal-filter volume source and the LBL dipole-filter volume source. A high duty factor version of the BNL source was then built and tested on the LAMPF injector [1]. The present work reports on the further testing of this source.

II. EXPERIMENTAL SETUP

The toroidal-filter ion source was mounted on an ion source test stand which operates up to 80 kV with 12 % duty factor and provides all necessary beam diagnostics on a mass-analyzed beam line. The ion source is described and diagrammed in reference [1]. Ion beams were accelerated with a four electrode accelerating column which permits independent variation of the extraction voltage on the first gap and the total beam energy. Thus, the extracted beams can be perveanced matched at a given energy over a range of operating conditions of the ion source. The electron current was inferred by subtracting the measured mass-analyzed H^- beam current from the drain current of the high voltage power supply. No significant contamination of higher mass ions (mostly O^-) was observed in the mass-analyzed beams. Emittance measurements were carried out with a conventional slit and collector scanner. Beam currents were measured both with beam current toroids (CM) and with a suppressed Faraday cup. In the mass analyzed line, the two methods of measuring the H^- current agreed with each other within a few percent. The operating vacuum in the test stand depended on

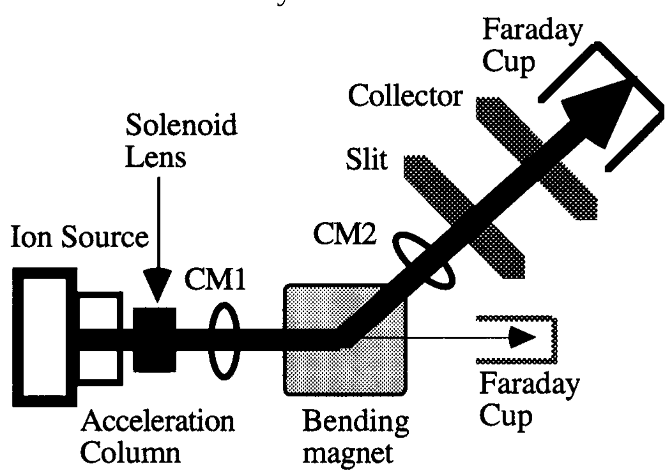

Figure 1: Layout of LAMPF's high-duty-factor ion source test stand.

the gas flow from the ion source but was typically in the 10^{-6} to low 10^{-5} range. For the higher gas pressures, some stripping loss (≈10%) was observed, and somewhat higher mass-analyzed currents could have been obtained if more pumping were used in the beam line. Our reported H^- currents have not been corrected for stripping losses.

Most of the results were obtained for 30 Hz, 500 μs beams to limit power loading on the emittance scanners, but some data were taken up to 12% duty factor. A single solenoid lens was used to provide the focusing of the beams and a 45° bending magnet was employed for the mass analysis. A diagram of the test stand is shown in Fig. 1.

The previous tests on the toroidal filter source prototype, were performed in the LAMPF injector using the low-gradient accelerating column employed with LAMPF's surface-conversion production ion source. For our tests, it was anticipated that higher current densities would be produced, and hence a higher gradient accelerating column was designed and built. The plasma electrode was fitted with an insert so that the extraction gap could be varied. The gap was set at 1.7 cm so the space-charge limited current at 16 kV was 30.0 mA which was more than adequate for the present operation where a maximum of 18 mA was obtained.

III. EXPERIMENTAL RESULTS

The dependence of the beam current density on the discharge (arc) current for the two emission apertures studied is shown in Fig. 2. The hydrogen flow was adjusted to give the optimum extracted beam current. We see that the dependence is linear with arc current up to the maximum value (160 A) that was run. The arc voltage was run above 150 volts where there is only a weak dependence of beam current on arc voltage. . We note that for this source, there is an explicit dependence of extracted current density j on aperture radius R consistent with a jR = constant scaling law. Thus, extracted beam current will scale linearly with aperture radius. Similar behavior has been observed in other volume ion sources. This conclusion is also consistent with the previously reported j value of 40 mA/cm^2 with a 7-mm-diameter aperture [1]. The dependence of the electron/H^- ratio is shown in Fig. 3. This ratio varies from 6:1 to 1:1 depending on the emission aperture size and the filter field strength.

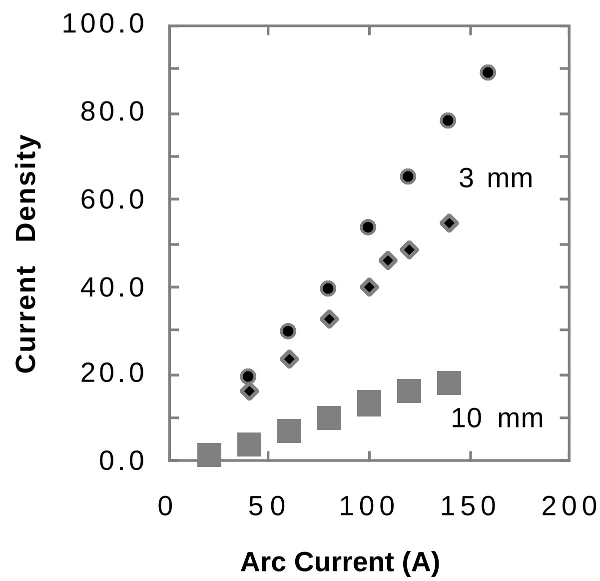

Figure 2: The current density (mA/cm^2) as a function of arc current for a 10-mm emission aperture and a strong filter field, and for a 3-mm aperture (• weak filter field, ♦ intermediate filter field).

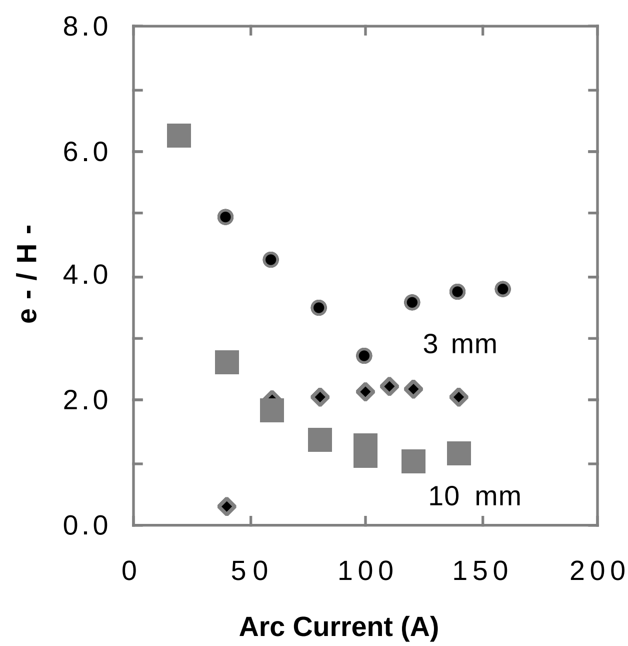

Figure 3: The ratio of electron current to H^- current as a function of arc current for a 10-mm emission aperture and a strong filter field, and for a 3-mm aperture (• weak filter field, ♦ intermediate filter field)..

The original BNL design for the toroidal filter employed a magnet configuration in which a conical, transverse magnetic field was set up between the filter magnet and the inner-most ring of cusp-field magnets in the front of the source. If the filter magnet polarity is reversed, a cusped-field filter, similar to that on the present LAMPF surface conversion source is formed. It was found that the best operation (highest current density and least electron/H^- ratio) for the high duty factor source we built, occurred for the cusp-field filter. All results presented here are for this case. It was possible to vary the strength of the filter field by using combinations of magnets of various strengths and sizes. As the filter field increased, both the H^- current and the extracted electrons decreased as well as the electron/H^- ratio. For a moderate filter strength of 170 μWeber (the product of the peak magnetic field and the area of the filter magnet), an electron/H^- ratio of 2:1 can be obtained with only a moderate decrease in the maximum current of H^- ions.

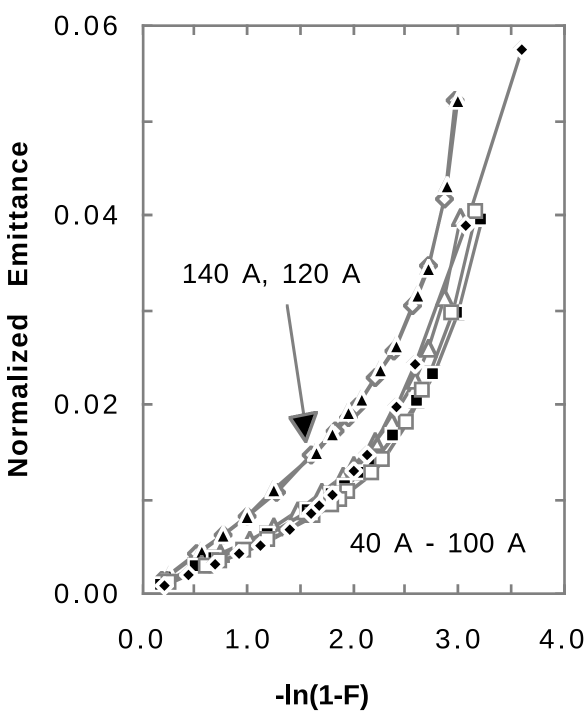

Figure 4: Normalized emittance (π cm mrad) as a function of -ln(1-F) for arc currents from 40 A to 140 A. These data correspond to the 3-mm-aperture weak-filter data of figures 2 and 3.

Emittance measurements were taken with both emission apertures and for wide range of ion source parameters. For the 3-mm-diameter aperture, the observed normalized emittance at a given beam fraction F is plotted against -ln(1-F) for various arc currents. Figure 4 shows such a plot for a weak filter field. An rms emittance can be obtained from the slope of these plots at low beam fraction and was typically 0.007 πcm-mrad with only a weak dependence on arc current, except for the highest arc currents. For the 10-mm-diameter emission aperture, the larger beam sizes resulted in emittance growth in the third order aberrations in the solenoid lens. The rms emittances, however, scaled as the aperture size and 0.02 πcm-mrad was typical. Large bore solenoid lenses will be needed for the 10 mm-diameter case to limit this emittance growth.

IV. CONCLUSIONS

The toroidal filter volume H^- ion source compares favorably with LAMPF's surface conversion source. Higher beam currents can be achieved with comparable emittances. The cesiated operation is much simpler and more reliable; a much smaller amount of cesium is needed; a precise constant flow of cesium is not required; the source can run for days after being cesiated once; the source recovers quickly from interruptions to the arc current. These qualities and the absence of the converter's water-to-vacuum seals, should make the volume source more reliable. The source lifetime also appears to be good. The prototype source has accumulated approximately 400 hours service in intermittent operation using the original 1.5-mm-diameter tungsten filament cathodes.

Future development will focus on refinement of the extraction and transport optics to reduce the aberrations that are apparent in Fig. 4. We will also continue our investigation of the RF-heated dipole filter volume source developed at Lawrence Berkeley Laboratory.

V. ACKNOWLEDGMENTS

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VI. REFERENCES

[1] R.L. York, et al., Conference Record of the 1993 IEEE Particle Accelerator Conference, 3175