BNL-44473

EMITTANCE MEASUREMENTS ON A VOLUME H^- ION SOURCE

Received by OSTI

MAY 07 1990

J.G. Alessi
Brookhaven National Laboratory, Upton, NY 11973

BNL--44473

DE90 010123

ABSTRACT

A current of 30 mA has been extracted from a volume production H^- source having a toroidal discharge chamber and rotational symmetry. This is a current density of 30 mA/cm^2. The emittance measurement gave a normalized, 90% value of $\epsilon_N(90\%) = 0.32\ \pi$ mm-mrad for a 13 mA beam. The ion temperature is estimated to be 0.57 eV for this case. For 25.5 mA, $\epsilon_N(90\%) = 1.11\ \pi$ mm-mrad was measured, but the true value is most likely smaller due to a limitation in the emittance resolution.

I. Introduction

Studies of volume H^- ion sources at BNL have, as the objective, a source producing an H^- ion current of 50 mA, in pulses of 1 ms duration at a repetition rate of 5 Hz. The source could then be used instead of a magnetron H^- source on the RFQ preinjector at the Brookhaven Alternating Gradient Synchrotron.[1] A volume H^- ion source with a toroidal discharge chamber has been designed and studied.[2,3] Its main feature is a full rotational symmetry, including a conically shaped filter field separating the main toroidal discharge from the central extraction chamber. This conical filter field is achieved by placing an additional magnet in the center of the flange opposite the extraction hole, perturbing in this way the cusp configuration, but still maintaining the rotational symmetry. Figure 1 shows a cross section of the source, with the calculated magnetic field lines also shown.[4] Parametric studies of this source have shown that an H^- current of 30 mA can be extracted through an aperture of 1 cm^2. The ratio I_e/I_{H^-} is less than 30 at the highest H^- currents. This paper will summarize measurements of the H^- emittance, including a comparison with the case where the source was reconfigured to have a standard dipole filter field.

II. Experimental Arrangement

The ion source, described in Refs. 2 and 3, was mounted on a vacuum box and pumped by a ≈ 400 l/s turbomolecular pump and an 1800 l/s oil diffusion pump. The source was typically operated with a 1.2 ms discharge pulse width at a 0.5 - 1.3 Hz repetition rate. All measurements were done with pulsed gas injection, and

*Work performed under the auspices of the U.S. Depart. of Energy.

the range of peak pressures in the source chamber was 5 - 15 mTorr, depending on the arc current. The peak pressure in the vacuum box was ≈ 2 x 10^{-5} Torr during the gas pulse. The plasma electrode was isolated from the chamber, and was floating. The anode and extractor apertures were 1.13 cm diameter, and the extraction gap was 0.97 cm. The extraction geometry was in no way optimized, and the extracted beam was quite divergent. The source was isolated and connected to a negative HV power supply (dc extraction voltage), and the extraction electrode was at ground potential. The extracted beam has a large electron component, so a strong dipole field (≈ 1.0 x 10^{-3} T-m) was placed near the source exit to remove electrons from the beam soon after the extractor, while deflecting the H^- only slightly. The emittance device was located 9.7 cm from the extractor, and a Faraday cup was also mounted at the emittance head location to monitor the beam current.

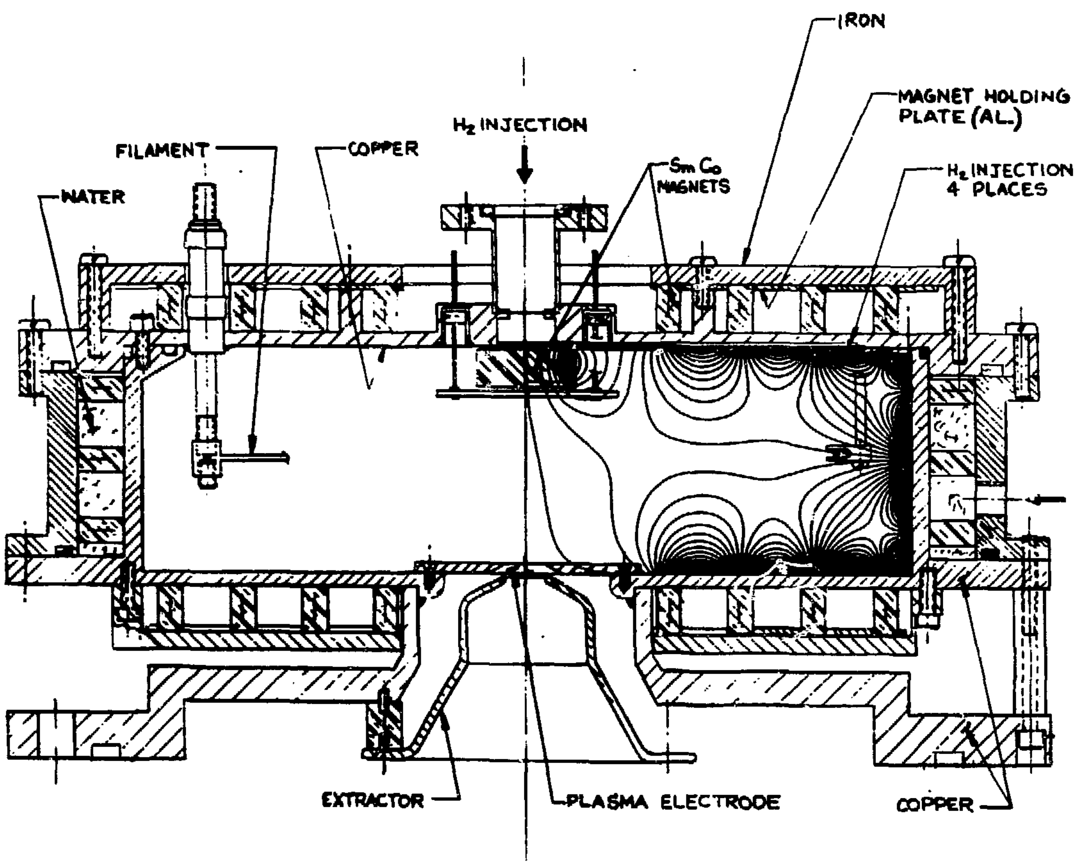

Fig. 1: Cross section of the H^- source. The calculated magnetic field in the source from Reference 3, is also shown.

The emittance measurements were done with a slit-and-collector type emittance head which was stepped through the beam in the vertical direction. The head has a 0.1 mm wide x ≈ 80 mm long entrance slit, and, to detect the angular spread in the beam at that position, an array of alternating collector foils and insulating strips, parallel to the slit. The 30 collector foils have a spacing of 0.26 mm, center-to-center. There is a grid in front of the collector array which can be biased, either negative, to suppress secondary electron emission when reading the H^- current, or positive to read instead the secondary electron current. The distance from slit to collectors can be adjusted, when the head is removed, to give the desired angular range for the measurement. The dimension chosen is a compromise between total angular spread that can be measured, and the resolution of the individual channels. Initial measurements were done with this dimension at 25.4 mm, which gave a total angular resolution of ± 150 mrad (10 mrad/collector). This was required in order to measure the full beam under a variety of operating conditions. Following these measurements, the slit-to-collector separation was increased to 50.8 mm (5 mrad/collector) in order to improve the resolution in cases where the total divergence was ≤ ± 75 mrad. The emittance head was stepped across the beam in 100 steps (1 step per beam pulse) over a total range of 2.5 - 5 cm. The current on the 30 collectors was sampled and held during a flat portion of each beam pulse (usually 0.6 ms into the pulse). The data was stored and analyzed via computer. Emittances in the two source planes were measured by rotating the source by 90° on the vacuum box.

III. Results

Based on our previous experience with a negative bias on the grid in front of the emittance collectors, one cannot prevent secondary electrons coming off a collector from hitting neighboring collectors. This then gives an emittance larger than the true beam emittance. Therefore, we normally choose to operate with a positive bias on this grid, and detect instead the current from the secondary electron emission caused when the beam hits the collectors. This gives a larger signal of positive polarity. When operating in this way, however, any neutral particles in the beam are also detected. With the positive grid bias, we were able to measure two emittances in the beam, separated in angle. Two examples of this, for different source parameters, are shown in Fig. 2. The lower emittance comes from the H^- beam, deflected by the electron-sweeping dipole field at the source exit. The upper emittance is primarily H^0, coming from H^- stripped in the extraction region and undeflected by the dipole. To verify that this was the case, we took some emittances with a negative grid bias. In this case only a very small component was seen at the location of the upper emittance, this being some heavy negative impurity in the beam (ex. O^-). The current in this emittance is < 4% of the H^- current. Thus, the great majority of the upper peak seen with a positive bias is due to neutrals. By comparing the integrated counts in the two emittances, we estimate that the intensity of the H^o beam is 25 - 50% of the H^- beam intensity under various conditions. (This component is not detected in the Faraday cup current). Fortunately, with this separation between the H^- and H^o beams, one could easily do an analysis of the H^- emittance alone.

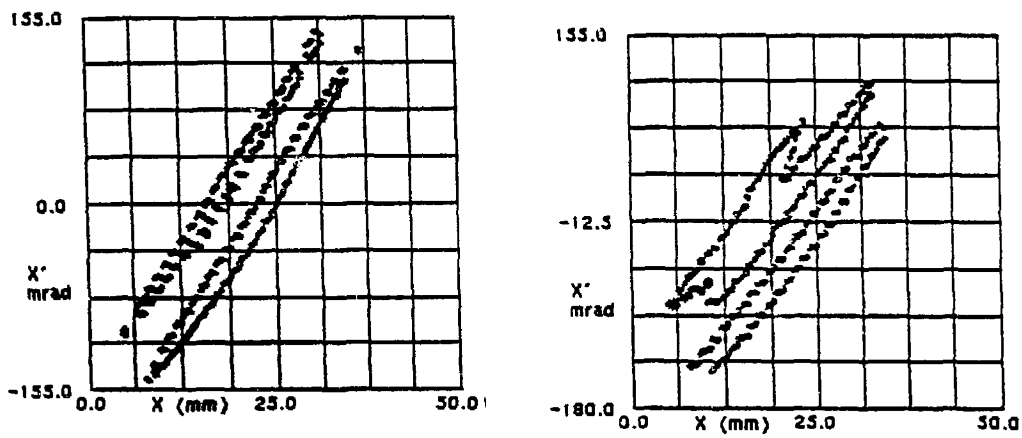

Fig. 2: Emittances with a positive grid bias, showing the H^- (lower) and H^o (upper) emittances.

Figure 3 shows an emittance measurement for a 14 kV, 18.6 mA beam (arc current = 100 A). The H^o beam emittance has been removed. This measurement gave a normalized emittance for 90% of the beam of $\epsilon_N(90\%) = 0.55\ \pi$ mm-mrad. The choppiness of the emittance in the 3-D plot was typical. This is due to the fact that the angular spread in the beam is less than the resolution of one collector, so the beam is essentially hitting only one collector at a time. Therefore, for many of the measurements the actual beam emittance is very likely smaller that what was measured with the 10 mm/channel resolution. As mentioned previously, the emittance head was readjusted at one point to have a finer resolution. For several cases a comparison could be made between measurements with 10 mrad/collector and the finer resolution 5 mrad/collector, under the same beam conditions. As expected, the total angular divergence of the beam and the spot size remained the same, but the width of the emittance was less. The choppiness on the emittance was reduced, but still present, indicating that the resolution still was not good enough (i.e., the beam was still hitting only 1 or 2 foils). In spite of this, the 90% emittance was reduced by 57 - 66%. A scaling by this ratio for the emittances measured with the coarse head setup would probably be valid in many cases. Figure 4 shows emittances taken under the same source conditions for 10 and 5 mm/channel resolution.

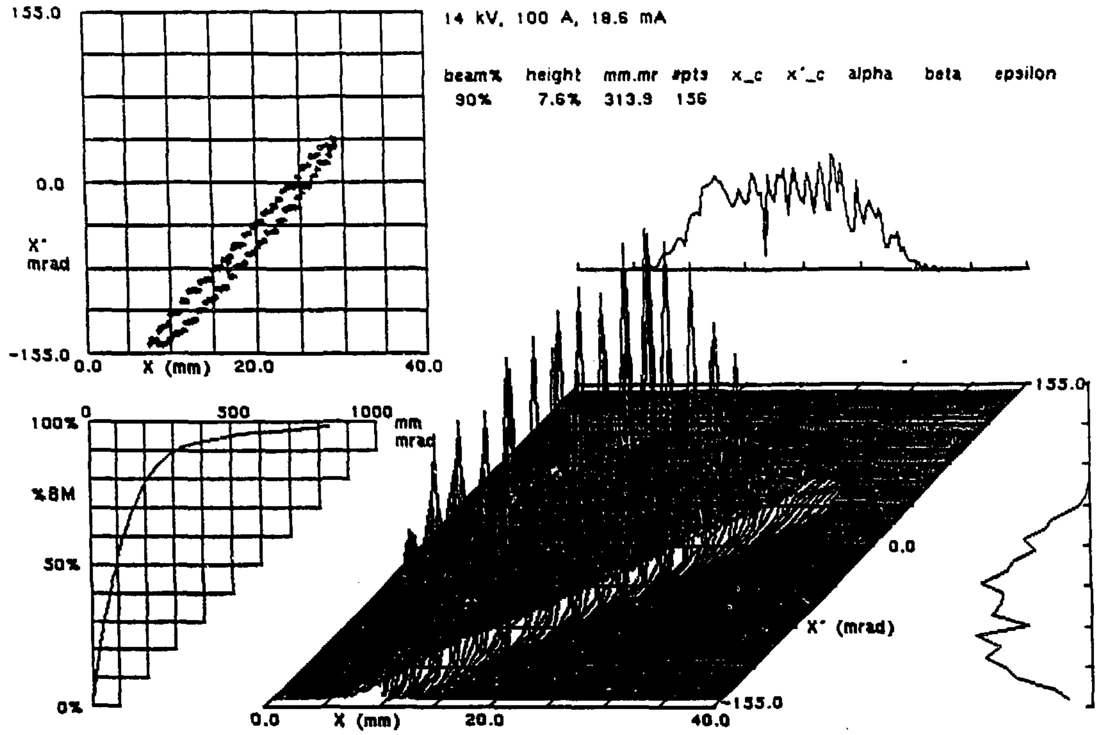

Fig. 3: Emittance measurement for an 18.6 mA, 14 keV beam. $\epsilon_N(90\%) = 0.55\ \pi$ mm-mrad (10 mrad/channel).

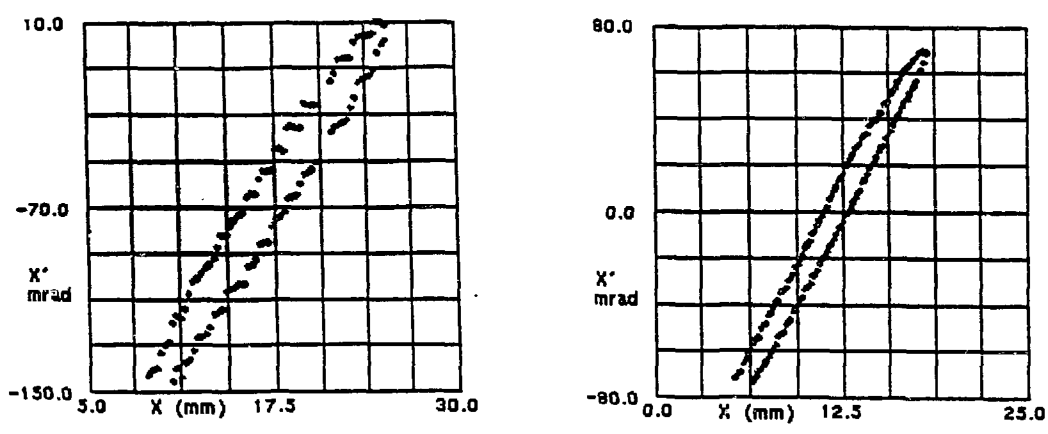

Fig. 4: Emittances for a 13 mA, 12 kV beam with a) 10 mrad/channel and b) 5 mrad/channel emittance head resolution. Except for an offset, both emittances are shown on the same scale. a) $\epsilon_N(90\%) = 0.53\ \pi$ mm-mrad b) $\epsilon_N(90\%) = 0.32\ \pi$ mm-mrad.

Table I

Filter Geometry	H^- (mA)	V (Ext) (kV)	Arc Current (A)	Emittance Resolution (mrad/channel)	Normalized 90% Emittance (π mm mrad)	RMS Emittance (π mm mrad)	H^- Ion Temp (eV)
Conical	13.0	12	50	5	.32	.070	0.57
Conical	12.7	12	50	10	.53	.110	1.41
Conical	19.0	14	100	5	$\leq$ .44		
Conical	18.6	14	100	10	.55	.115	1.54
Conical	25.5	18	190	10	1.11	.238	6.61
Dipole	12.0	12	100	5	.38	.080	0.75
Dipole	15.0	12	100	10	.67		
Dipole	16.5	14	150	5	.49	.100	1.17
Dipole	19.5	14	150	10	.74		

A detailed analysis of the emittance as a function of various source parameters has not been carried out. Measurements have been done for arc currents in the 50 - 200 A range and extraction voltages from 10-18 kV. The maximum current from the source with the conical filter field was 30 mA, while with the dipole filter field only 20 mA could be obtained. Table 1 shows some emittance values measured for both the conical and dipole filter field configurations. At higher currents than shown in the Table, the divergence of the beam was greater than the maximum angles that could be detected.

Emittances in the other plane were measured by rotating the entire source assembly by 90^o. The emittances were larger by $\approx$ 70% for both the conical and dipole filter configurations. Presumably, this is due to the fact that in this plane the H^o and H^- emittances were not separated. The electron sweeping magnet which produced the separation rotated with the source, so the deflection was now in the other plane. Except for this sweep magnet, the conical configuration is perfectly symmetric.

If one plots the normalized emittance as a function of $\ln[1/(1-F)]$, where F is the beam fraction, then if the beam has a Gaussian distribution one will see a linear dependence from which the RMS emittance can be determined[5,6]. This was done for several of the above measurements, and this dependence was always linear up to > 80% beam fraction. The departure from Gaussian at higher beam fractions is presumably due to extraction optics effects. The results of this analysis is also shown in Table 1 for several cases. If one assumes that the emittance is determined by a Maxwellian energy distribution of the ions of temperature kT, then the emittance $\epsilon_{4RMS} = 2r(kT/Mc^2)^{1/2}$ [6], where r is the anode aperture radius. Estimates of the ion temperature based on this are also given in Table 1. The lowest ion temperature measured was 0.57 eV at 13 mA of beam current.

IV. Conclusion

Emittances were measured for a toroidal volume H^- source with both a conical and standard dipole filter field. A value $\epsilon_N(90\%) = 0.32\ \pi$ mm-mrad was measured at 13 mA, or $\epsilon_N(\text{RMS}) = 0.07\ \pi$ mm-mrad. This corresponded to an ion temperature of 0.57 eV. The maximum H^- current obtained with the conical filter field is higher than the standard dipole, and emittances for the conical filter were somewhat lower than those for the dipole filter, for approximately equal H^- currents. We are, at this point, limited by the resolution of the slit-and-collector emittance device. An electric-sweep scanner type device is probably required to improve the measurement.

Acknowledgements

The support of the BNL Advanced Source Development Group is greatly appreciated. Special thanks go to Krsto Prelec, who designed the source, for helpful discussions, and to Dan McCafferty, who skillfully operated the source and made the many modifications required for these measurements.

References

1. J.G. Alessi, J.M. Brennan, and A. Kponou, "H^- source and low energy transport for the BNL RFQ preinjector", these Proceedings.

2. K. Prelec, Proc. 1989 Particle Accelerator Conference, Chicago, March 1989.

3. K. Prelec, "The BNL volume H^- ion source", these Proceedings.

4. C.R. Meitzler, "Magnetic field of a toroidal volume H^- source", these Proceedings.

5. P. Allison, Proc. Fourth International Symposium on Production and Neutralization of Negative Ions and Beams, Brookhaven, 1986, AIP Conf. Proc. 158 (1987) 465.

6. R.R. Stevens, Jr., R.L. York, K.N. Leung, and K.W. Ehlers, ibid, p. 271.