Measurements of Emittance and Species Fractions of a Positive Hydrogen Ion Beam Extracted from an RF-Driven Multicusp Source*

G. Gammel, T.W. Debiak, S. Melnychuk, and J. Sredniawski
Grumman Aerospace Corporation
1111 Stewart Ave., Bethpage, NY 11714 USA

Abstract

Measurements of the H^+, H_2^+, and H_3^+ fractions and emittances of a hydrogen beam extracted from an RF-driven multi-cusp source were made using a bending magnet and an electrostatic emittance scanner. The H^+ fraction increased with RF power. Fractions in excess of 90% were obtained. At a given RF power, the H^+ fraction increased with decreasing source pressure and increasing filter rod separation. When the "collar" surrounding the extraction aperture (used for H^- operation) was removed, the H^+ current increased by a factor of ≈4, without changing the H^+ fraction at a given RF power. With a large filter rod separation, H^+ currents on the order of 100mA were achieved at ≈20kW of RF power. Using a modified extractor [1] operating at 35kV, H^+ currents on the order of 60mA were obtained with a 90% normalized rms emittance of 0.012πcm-mrad.

I. INTRODUCTION

CW H^+ accelerators are receiving increased attention recently due to increased interest in projects such as accelerator transmutation of waste(ATW), accelerator production of tritium(APT), and accelerator-based conversion of nuclear weapons(ABC). The accelerators envisioned for these projects require a reasonable emittance and an ion source with a high H^+ fraction. This paper describes a technique used for measurements of the H^+, H_2^+, and H_3^+ fractions in a positive hydrogen ion beam, and presents some emittance, current, and H^+ fraction measurements. For all data, the beam was pulsed for 1 ms at 0.3% duty factor.

The emittance scanner on the Grumman Test Stand [2] was used with a dipole bending magnet after the extractor to measure emittance and hydrogen species fractions as shown in Fig. 1. The scanner entrance slit was 17 cm from the extractor. Current was measured using a 2-7/8" ID x 9" long cup. The ion source for most of the measurements was a 10 cm ID RF-driven multi-cusp source with a variable strength magnetic dipole filter field [3]. The strength** was changed by varying the spacing between the filter rods. The ID of the RF coil was 5.8 cm, and the aperture diameter was 6.4 mm. $\int B\partial l$ for the bending magnet was 4070 G-cm, which nicely resolved all three species. For some measurements, a 7.5 cm ID source was used with a 4.3 cm ID RF coil (reduced by the same ratio as the chamber ID's). The filter field strength was fixed at 120 G, the aperture diameter was 5.6 mm, and $\int B\partial l$ for the bending magnet was 3325 G-cm, which resolved the H^+ peak, but the H_2^+ and H_3^+ peaks were still overlapping.

Typical raw data for a scanner sweep at one position, using the large source, is shown in Fig. 2. The horizontal axis is proportional to time and deflection angle - i.e. the peaks are separated in angle rather than in spatial position. The three species are resolved, and a small impurity of mass 17 or 18 (OH^+ or H_2O^+) is usually observed. With a well baked out and pumped out gas line, the impurity is <1% of the total current. The current in each species is proportional to the area under each peak summed over all sweeps as the scanner moves through the beam. The fractions are obtained from the ratios of the summed areas, and the current in each species is the fraction for that species times the Faraday cup current. The analysis program also calculates the emittance of each species separately.

For small source operation, the most deflected particles entered the scanner at angles greater than the angular acceptance. Therefore, emittances are not quoted for this source. Also, the actual H^+ fractions are slightly higher than shown because relatively more H^+ was missed than the other species since H^+ is the most deflected. For large source operation, the problem was corrected by tilting the scanner 75 mrad, as shown in Fig. 1.

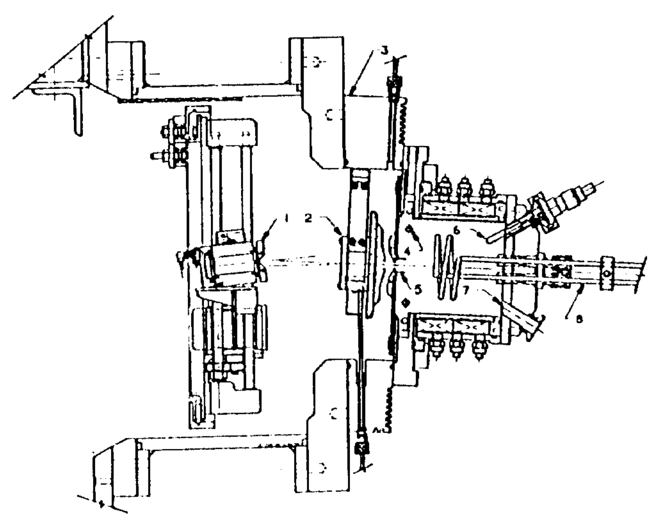

Fig. 1 Scale drawing of experimental apparatus. 1 = emittance scanner (tilted 75 mrad); 2 = bending magnet; 3 = 60° wedge plate; 4 = filter rod; 5 = collar; 6 = starter filament; 7 = gas inlet; 8 = RF antenna.

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** All references to filter field strength refer to the strength on axis in the midplane of the filter rods, which contain the magnets.

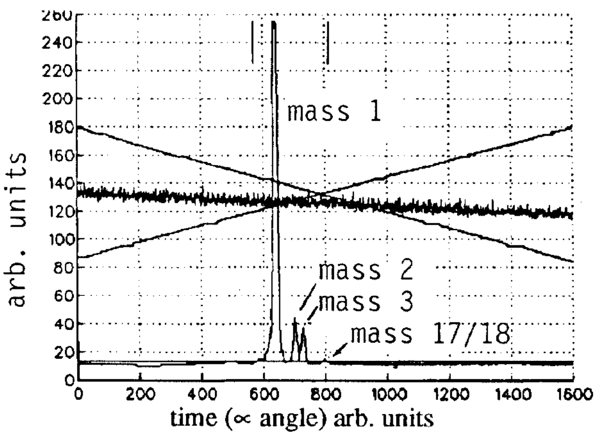

Fig. 2 Raw data from emittance scanner, showing the three species and a small impurity. The crossing lines are the voltages on the two deflection plates ($\Delta V = \theta = 0$ at the crossover point), and the hashy line in the middle is the current hitting the front face of the scanner.

II. RESULTS

A. Current and H^+ Fractions

Fig.'s 3 - 5 show total current density and H^+ fraction vs RF power for different filter field strengths. For the large source, at a given RF power, both the total current and the H^+ fraction increased as the filter field was decreased by pulling the filter rods apart. In future studies, we will increase the separation even further. We will also vary the filter field by changing magnets at a fixed spacing. Fig.'s 3 and 5 show that adding the collar (see Fig. 1) reduced the current by a factor of four without affecting the H^+ fraction. The current densities in Fig. 4 should therefore increase by a factor of four at a given RF power by removing the collar.

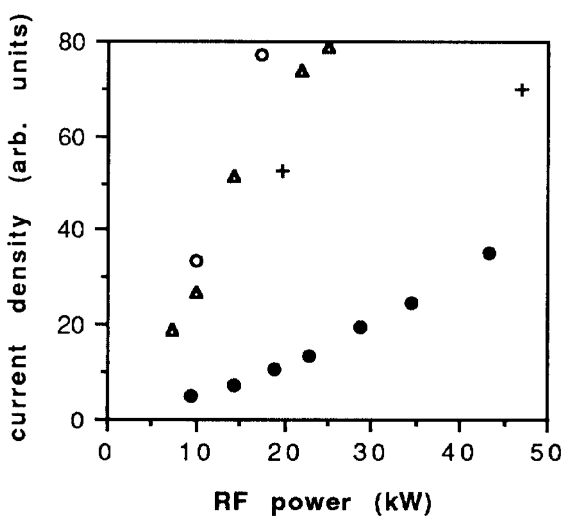

Fig. 3 Relative current density vs RF power for the large source. + = 400 G, no collar; Δ = 280 G, no collar; o = 190 G, no collar; • = 300 G, with collar.

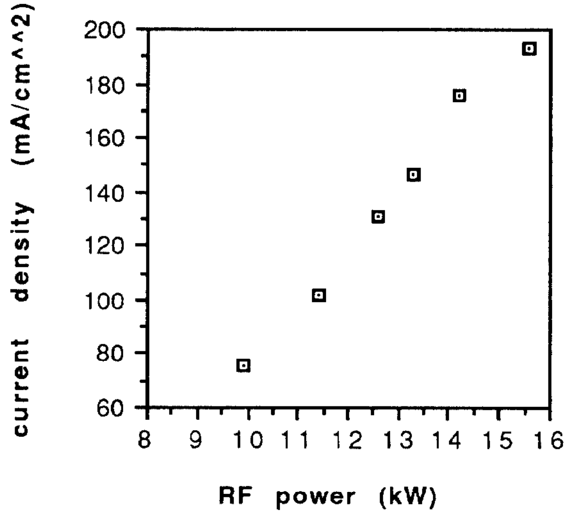

Fig. 4 Current density vs RF power for the small source with a collar. Aperture radius = 2.8 mm.

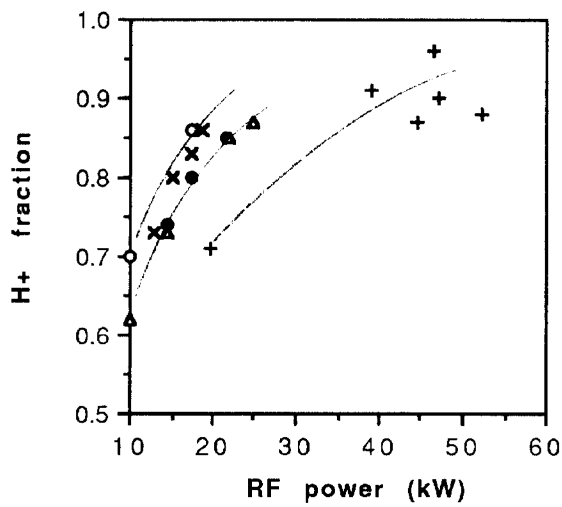

Fig. 5 H^+ fraction vs RF power for some of the data from Fig. 3 plus additional small source data (x) with collar.

As the H^+ fraction rose with power, we found that the $H_2{}^+$ fraction remained roughly constant, while the $H_3{}^+$ fraction decreased. Fig. 6 shows that the H^+ fraction starts decreasing if the source pressure is too high.

B. Emittance

Fig. 7 shows results of a typical emittance scan for the large source at 35 kV. The results for $H_2{}^+$ and $H_3{}^+$ are similar, except the centroids shift due to the mass differences. The measured angular centroids scaled approximately as $1/\sqrt{\text{mass}}$ as expected, and were close to the predicted values based on the measured $\int B\partial l$ of the bending magnet:

$$\Delta\theta = (\sqrt{e/2m_p})\int B\partial l/\sqrt{AV_{ext}}$$

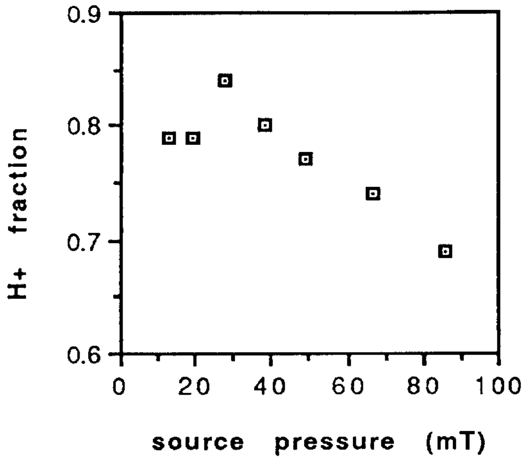

Fig. 6 Pressure scan using the small source.

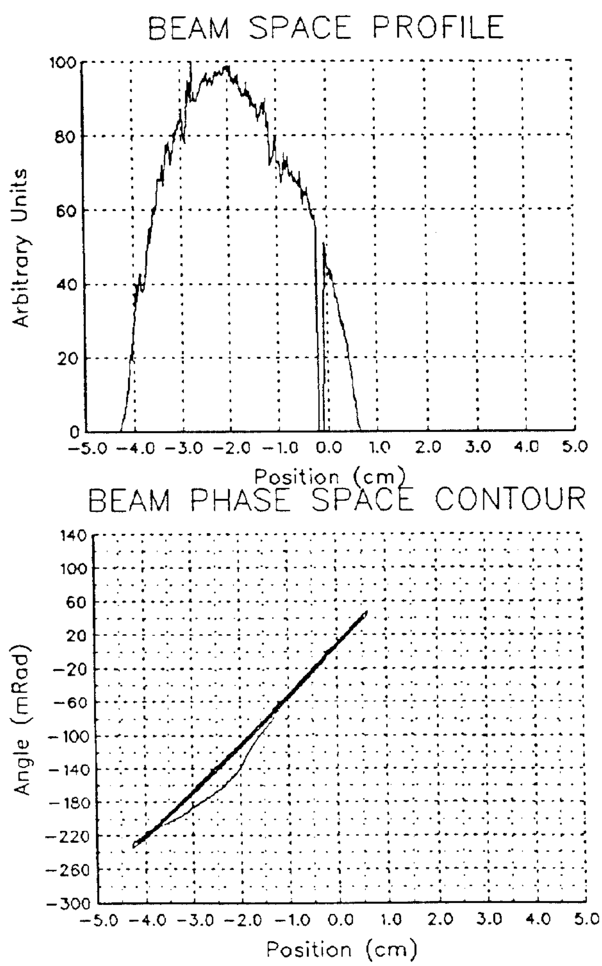

Fig. 7 Typical emittance scan data for the H^+ peak only. The plots for the other species show the centroid shifts, but are otherwise similar. The wedge plate angle (60°) must be added to obtain the net deflection.

We observed that the H^+ phase space is bowed (see Fig. 7). At least part of the reason for this is that the scanner moves vertically through the beam, which is not transverse to the H^+ beam since H^+ emerges from the dump at a downward slant. Since the heavier species are not deflected as much, they come out more on axis, so the bow should be less obvious in their phase space plots. We do, in fact, observe this. The bow makes the rms emittance artificially high.

Fig. 8 shows the normalized 90% H^+ rms emittance after straightening out the bow in the analysis program, vs RF power at 30 kV and 35 kV. The extractor was running overdense at 30 kV, and on perveance to overdense at 35 kV. The highest power corresponds to an H^+ current on the order of 60 mA.

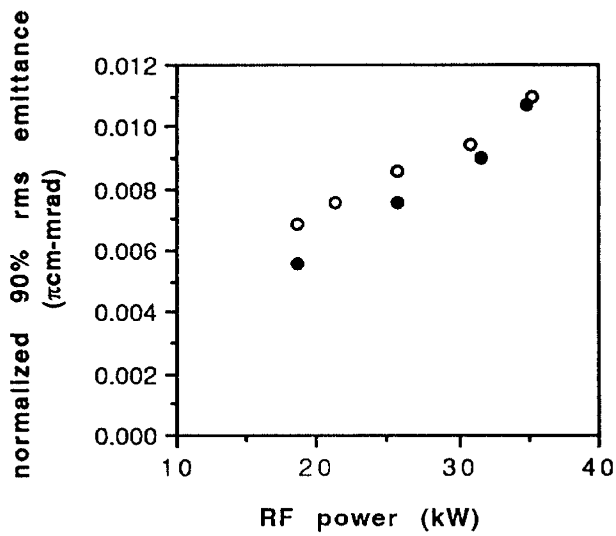

Fig. 8 Large source; o = 30 kV, • = 35 kV.

III. SUMMARY

Based on the large source species measurements, it is clear that increasing the filter separation is desireable for obtaining a high H^+ fraction at low power, but the effect on emittance must still be determined. It is also clear that the H^+ fraction increases with power, and that a collar around the emission aperture cuts down the current by a factor of four without affecting the H^+ fraction.

Further work is planned to optimize the geometry and operating parameters of the RF-driven source for high H^+ fraction and high current at low power for ATW/APT applications, including full CW testing by late '93.

IV. REFERENCES

[1] design provided by C. Geisik (LANL)

[2] R. Heuer et.al., "A New Stand-Alone Beam Emittance Measurement System", *Nucl. Instrum. and Meth. in Phys. Research*, B42 (1989), p. 135.

[3] K. Leung et. al., "RF-Driven Multicusp H^- Ion Source", *Rev. Sci. Instrum.* 62(1), Jan. 91, p. 100.