NORMALIZED EMITTANCE OF SITEX NEGATIVE ION SOURCE*

W. L. Stirling, W. K. Dagenhart, and J. H. Whealton
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

J. J. Donaghy
Washington and Lee University
Lexington, Virginia 24450

CONF-831180--4

DE84 003285

ABSTRACT

An emittance measurement employing two techniques are being made on SITEX. To this end, a 2-D calculation was performed to design the accelerator in order to reduce electric field aberrations. The calculated normalized emittance is 6×10^{-4} ncm mrad for an angular divergence $\theta_{\text{RMS}} \approx 0.28^\circ$. Status of the experimental findings are presented and a comparison made to the calculated value which will yield the ion sputter energy.

INTRODUCTION

An experimental determination has been made of the normalized emittance of the SITEX negative ion source.¹ To this end, an extraction system has been designed in conjunction with a newly designed, focussing converter system for minimum electric field aberration of the extracted ions. The converter geometry was determined self consistently with the accelerator geometry through an exact 2-D solution of the coupled Poisson-Vlasov equations.^{2,3} The geometry of the system and the computer determined beam envelope is shown in Fig. 1 for a converter bias of -150 V relative to the discharge chamber, a negative ion current density of 50 mA/cm² at the converter surface, a magnetic field of 1300 gauss directed out of the paper and an accelerating potential of 18 kV. Fig. 2 shows a plan view of the ion source. For the conditions stated above, the mean RMS divergence angle of the beam is calculated to be 0.28° . The beam is 0.5 mm wide perpendicular to the exit slit with a current density of 400 mA/cm² at the extraction grid. The aberrations of the beam in the direction parallel to the magnetic field (long slit dimension) were not important, because the transverse emittance was measured only over a short region of the beam extracted from the center of the slit. Assuming a successful reduction in electrostatic aberrations on beam divergence, one can determine an accurate estimate of the ion sputter energy originating at the converter and thereby determine a lower limit to the expected beam emittance.

MASTER

*

Research sponsored by the Office of Fusion Energy, U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

gmp
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

EXPERIMENTAL DESCRIPTION

An experimental layout is shown in Fig. 3. A segmented, shielded Faraday cup is used to locate the beam as well as estimate the beam profile width and angular divergence. The Faraday cup can be rotated out of the beam to permit a pepper pot scan⁴ of the beam to be made from which the beam emittance can also be determined. Since the Faraday cup, Fig. 4, is a current measurement, each segment of the cup was fabricated with upturned "lips" or "edges" on the ends to ensure secondary particles emitted from a plate would follow a magnetic field line back into the plate of origin. Various combinations of positive and negative biases on adjacent segments revealed no current leakage from one plate to another. The pepper pot geometry used is shown in Fig. 5. Mylar was chosen as a "film" due to experience with a pinhole camera diagnostic used in positive ion source development. A roll of mylar sheet, 0.15" thick, could be fed into the exposure position of the pepper pot as needed in order to make multiple exposures without breaking vacuum.

RESULTS

From the Faraday cup readings one can calculate the beam profile. The beam profile width yields the angular divergence at the extraction grid, which coupled with the calculated beam size at the extraction grid, permits a determination of beam emittance.

Typical operating conditions are summarized in Table 1 and a typical beam profile is shown in Fig. 6. The profile is a Gaussian peak riding on top of a rather broad, low intensity distribution. This profile distribution is always seen in a careful beam analysis. The Gaussian peak carries the ion temperature information and the low intensity spread results from electrostatic field aberrations. Fig. 7 is a semi-logarithmic plot of several profile scans for both hydrogen and deuterium. There is no significant difference in source operation or beam output between hydrogen and deuterium. Also plotted in Fig. 7 are the lines for $T_i = 0.5$ eV and $T_i = 1$ eV under the present operating conditions. The variation in T_i is from 0.7 eV to 1.25 eV corresponding to beam divergences of $\pm 0.48^\circ$ and $\pm 0.64^\circ$ respectively. The angular divergence of the beam is related to the profile width as shown in Fig. 8 through the expression

$$R \sin \theta = \text{profile width.}$$

The normalized emittance ϵ is now calculated from the expression

$$\epsilon = \beta \times \text{angular divergence} \times \text{beam size}$$

$$\beta = v/c$$

where v = beam velocity and c = velocity of light.

$$\epsilon = 10^{-3} \text{ n cm mrad}$$

A pepper pot scan requires 200 to 300 identical pulses to make an exposure. Calculations of the beam profile reveal that the beam divergence is a strong function of several parameters. Fig. 9 shows a variation of the divergence with accelerating potential. The variation with beam current density at the converter is shown in Fig. 10 for three different beam voltages.

These two effects are coupled through the internal impedance of the high voltage supply thus requiring some means of voltage regulation. In the runs thus far, the regulation has been poor with the voltage varying $\pm 2\%$ from pulse to pulse. From Fig. 9, a 2% voltage swing produces an angular divergence increase from 0.28° to $\sim .50^\circ$. In addition the beam moves radially at the pepper pot by the same percentage as the voltage shift of $\pm 2\%$ or $0.12''$ which is about equal to the calculated beam size. Voltage regulation of about 0.1% must be achieved in order to make a meaningful pepper pot scan.

DISCUSSION OF RESULTS

M. Seidl and A. Pargellis⁵ have recently reported the measurement of the energy distribution of negative hydrogen ions for Cs^+ ion energies varying from 500 eV to 2000 eV. They found that a universal relationship exists between the energy distribution and the ratio of the H^- ion sputter energy, E , to the incident Cs^+ ion energy, U , independent of incident Cs^+ ion energy. The peak in the energy distribution occurs for $E/U \approx 0.013$ with a full width half maximum (FWHM) of $E/U \approx 0.005$. Extending these results to a Cs^+ ion energy of 150 eV as used in this experiment, the peak of the distribution would be 1.95 eV with a FWHM of 0.75 eV. Our peak value of 0.7 eV is nearly a factor of three lower.

REFERENCES

1. W. K. Dagenhart, W. L. Gardner, W. L. Stirling, and J. H. Whealton, Nucl. Tech./Fusion, 4, pp. 1430-1435, September 1983.
2. J. H. Whealton, paper presented in these proceedings.
3. J. H. Whealton, Nucl. Instrum. Methods, 189, 55-70 (1981).
4. J. J. Donaghy, private communication.
5. M. Seidl and A. Pargellis, Phys. Rev. B, 26, pp. 1-9, July 1982.

* Research performed under Purchase Order No. AFWL PO 83-123 with the Air Force Weapons Laboratory under Union Carbide Corporation contract No. W-7405-eng-26 with the U. S. Dept. of Energy, OFE.

Figure 1
2-D OPTIMIZED SITEX ACCELERATOR

ORNL-DWG 83-3638 FED

SITEX ELEVATION

ORNL-DWG 83-3728 FED

Figure 2
EXPERIMENTAL LAYOUT

ORNL-DWG 83-3725 FED

Figure 3

ORNL/DWG/FED 78-1107A

Figure 4
FARADAY CUP

ORNL-DWG 83-3726 FED

Figure 5
PEPPER POT GEOMETRY

ORNL-DWG 83-3727 FED

TABLE 1

PARAMETER	H ⁺	D ⁺
I_{accel} (mA)	550	250
V_{accel} (kV)	18	10
$j_{\text{extracted}}$ (mA/cm ²)	110	100
Pulse Length (s)	10	5
Normalized Emittance $E_{N\perp}$ (n cm mrad)	not measured	10 ⁻³
Source Pressure (mT)	4	4
Electron/Ion Ratio (%)	15	5
Electron Recovery at 10% V_{accel}	yes	yes
Arc Efficiency (kW/A)	5	5

Figure 6
BEAM PROFILE DETERMINED
FROM FARADAY CUP
(DEUTERIUM GAS)

Figure 7
ION TEMPERATURE FOR 10-keV BEAM

Figure 8
DETERMINATION OF BEAM DIVERGENCE FROM
PROFILE WIDTH

ORNL-DWG 83-3735 FED

Figure 9
VARIATION OF θ_{rms}
WITH ACCELERATING VOLTAGE

ORNL-DWG 83-3733 FED

Figure 10
VARIATION OF BEAM DIVERGENCE WITH
CURRENT DENSITY

ORNL-DWG 83-3731 FED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.