

NEGATIVE ION SOURCE TESTS FOR H⁻ INJECTION AT THE BROOKHAVEN AGS*

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Summary

A magnetron ion source of Fermilab design has been adapted to provide an H⁻ beam of 40 mA for acceleration in the Brookhaven 200 MeV Linac and injection into the AGS. The source operates at a repetition rate of 5 Hz and produces pulses of up to 250 μ sec duration. Source stability, beam current and emittance have been studied as a function of several external source parameters. Beam emittance has been measured for two values of field gradient in the combined function magnet following the source. Evidence of neutralization of the space charge potential of the H⁻ beam has been noted. In the focussing plane the emittance was smaller by a factor of 2 for the higher magnet gradient.

Introduction

The development effort at the BNL Linac for H⁻ injection to the AGS has been previously described.¹ The ion source is a magnetron, surface-plasma source obtained from Fermilab.² It has been necessary to provide a transport system comprising a pair of pulsed quadrupole magnets to focus the beam into the BNL high gradient column. To match the new optics, the gradient index of the combined-function magnet which focuses the H⁻ beam in the direction transverse to the 90° bend was increased from the original 1.0 to 1.35. Figure 1 shows the cross sections of these two pole configurations. The BNL pole design includes extended width on the high field side of the aperture and a non-zero sextupole term ($b_2 \approx .008$) to offset aberrations from fringe field and finite pole effects.

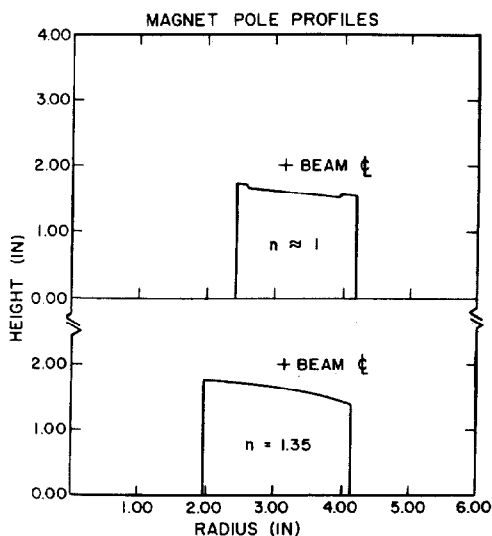


Fig. 1. Profiles of combined function magnet poles used in tests.

Procedure

For these studies the source was installed in an existing viewing box. The layout of equipment is shown in Fig. 2. The ion source and the pulsed gas valve were insulated from the box so they could be pulsed to the negative extraction potential. The source electronics were contained in a rack isolated from ground. The timing circuits were triggered from the ground through a fiber-optic link; adjustments were made by insulated rods. Because of the large capacitance of the floating equipment, the extractor pulse rise time was almost 100 μ sec. In the final installation the value will be about 20 μ sec. The extractor pulse fall time of 2 msec is determined by the same capacitance and the resistance of the high voltage divider (60 M Ω). It was found that many spark-overs occurred after the beam pulse, when gas was still flowing from the source. The problem was eliminated by installing a thyatron tail-biter circuit, which produced a fall time of about 2 μ sec when damped through a 1 K Ω resistor (to suppress noise).

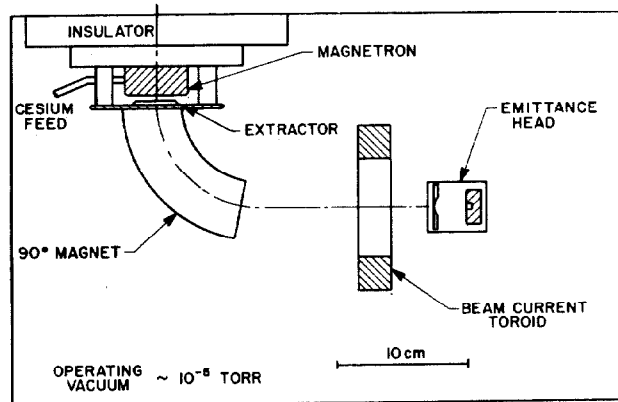


Fig. 2. Layout of test box (horizontal mid-section).

Gas flow to the source was controlled by means of a modified piezoelectric pulsed valve.² The drive circuitry for the valve supplied a pulse of 100-180 V, 200 μ sec duration. For a fixed pulse width, the pressure in the box tended to drift over a range of 2-3 μ Torr during a period of some seconds; so, a circuit was installed to monitor the average pressure and adjust the gas pulse width to maintain a chosen setting in the range from 6 to 200 μ Torr. The test box was pumped by a 1500 ℓ /s vertical turbo-molecular pump. With no gas flow the pressure was as low as 0.6 μ Torr, which permitted the use of a precision leak to measure the effect of background gas.

A beam current transformer³ was installed 8 cm downstream from the gradient magnet. A soft iron backing plate shielded the transformer from the fringe field. Emittance measurements were made with two modified 750 keV analyzing heads.⁴ The electrode array was placed closer to the slit, reducing space charge errors and increasing the angular range to 180 mrad

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for the 30 foils. The step size was 0.5 mm for a total range of 5 cm. Previous tests in the proton beam had indicated that no bias was necessary on the electrodes. The first signals obtained with the H⁻ beam clearly indicated influence by the beam potential. It was found that application of -15 V to the collectors was sufficient to eliminate the effect. The emittance head data were collected by a DEC PDP-11/03 Lab System-3 and were analyzed, stored on floppy disk and displayed on a Tektronix 611 storage display. Beam current also was recorded for each pulse.

Tests were run over a range of source parameters for a period of about three months. Between runs with the two magnet pole configurations, the source was opened, cleaned, and reconditioned. A second run was then made with the first set of poles (n=1.35), which reproduced the original data but with reduced operating range because of deterioration of Macor ceramic in the source. The performance observed with the n=1 poles also may have been influenced by this deterioration. Emittance data were taken as functions of background gas pressure, time within the discharge, extraction voltage and discharge supply voltage.

Results

Nominal discharge parameters for the tests produced a 40 mA beam with the n=1.35 magnet. The discharge power supply was run at 320 V which gave a 300 V pulse at the source without gas. Typical discharge current was 120 A with an arc voltage of 160 V. A pressure of 10-11 μ Torr yielded the highest extracted current, while a higher discharge current at lower voltage (150A, 150V) occurred at about 20 μ Torr. The pulse rate was 5 Hz with a typical width of 160 μ sec. Tests were also run with 200 and 240 μ sec pulse widths; in which case, an increase in gas pressure produced a dramatic rise in the extracted current over the first 100 μ sec of the pulse to nearly double its initial value.

Parametric scans were made for both gradient magnets to determine effects on beam transmission and emittance. Focusing in the vertical plane (small slit dimension) is much stronger for the n=1.35 magnet. Emittance growth due to space charge is expected to be greater in this plane, favoring the higher index design. Indeed, the vertical emittance for the n=1.35 case was typically half that for the n=1 magnet.

Earlier observations⁵ indicated some vertical aperturing occurred with the n=1 magnet. Less beam scraping might be expected with the higher gradient. Although no direct measurement of transmission could be made, it was found for similar source parameters that 30-50% more beam was measured after the magnet for the n=1.35 case. Qualitatively, the emittance varied similarly within the parameter scans for the two magnets. Detailed results will be presented only for the n=1.35 configuration. The following emittance values were obtained with nominal operating conditions at 18 kV extractor voltage:

n	Vertical($\pi\epsilon\beta\gamma$)90%	Horizontal($\pi\epsilon\beta\gamma$)90%
1.0	0.22 cm-mr	0.65 cm-mr
1.35	0.11 cm-mr	0.44 cm-mr

These values are scaled to 40 mA by the square root of the current and represent a mean which was reproducible to within $\pm 10\%$.

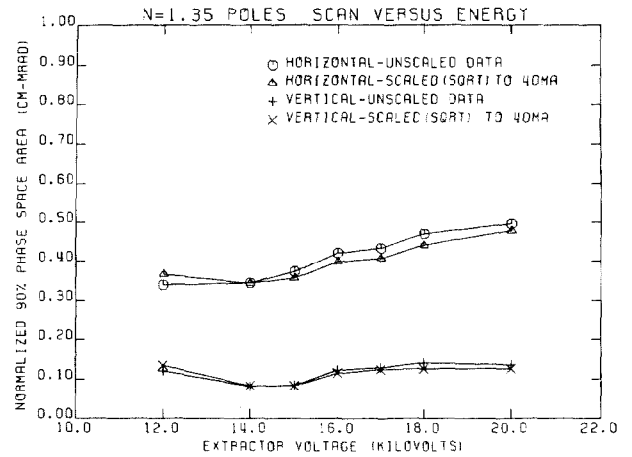


Fig. 3. Phase space area vs energy (scaling to square root of current).

As the extractor voltage was varied from 16 to 20 kV, the vertical emittance remained constant, while the horizontal increased (Fig. 3). From 12 to 16 kV the beam current increased and then remained constant. The angular acceptance of ± 90 mr resulted in the loss of an estimated 10% of the horizontal phase space area at 18 kV. As the energy increased, more of the beam fell within the collector giving the trend observed. The lower beam current and vertical phase space area below 16 kV may be due to aperturing on the magnet poles; a similar minimum occurred at higher energy with the n=1 poles.

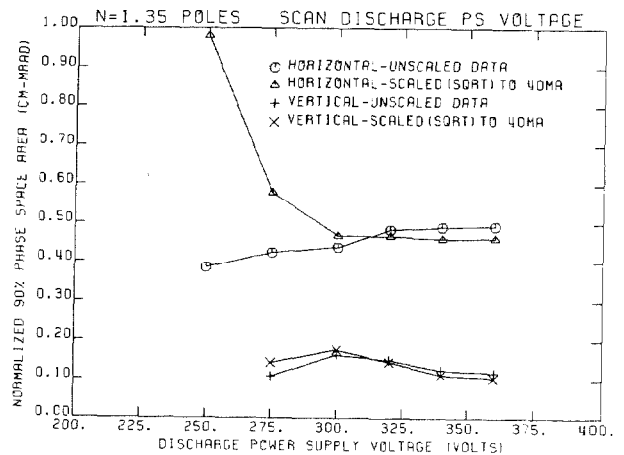


Fig. 4. Phase space area vs power supply voltage.

The results of a scan of power supply voltage are shown in Fig. 4. Below 275 V the discharge was unstable and could not be maintained for the vertical scan. From 275 to 325 V, the beam current increased linearly by a factor of two. Above 325 V the current remained constant. Cathode temperature increased linearly from 320°C at 275 V to 487°C at 360 V.

The vertical emittance decreased by a factor of more than 2 during the period from 20 to 75 μ sec into the discharge (Fig. 5). A corresponding increase in beam current was observed over the same period. More dramatic still was the change in the shape and orientation of the vertical phase space contour. Figure 6 shows a composite of the data through 100 μ sec.

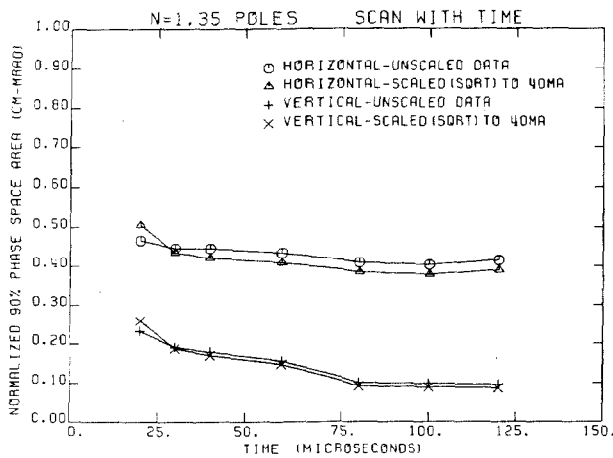


Fig. 5. Phase space area vs time.

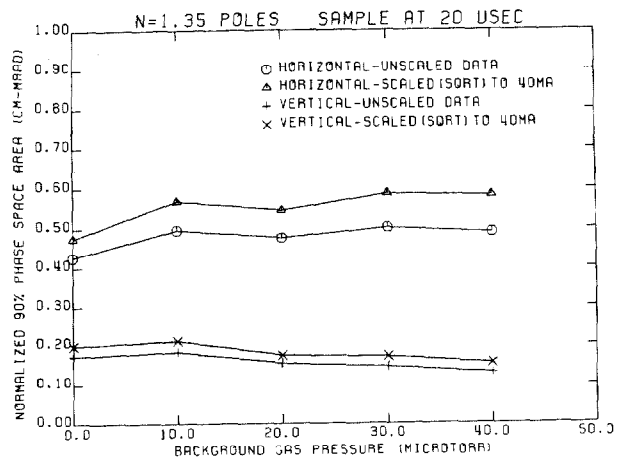


Fig. 7. Phase space area vs background gas pressure.

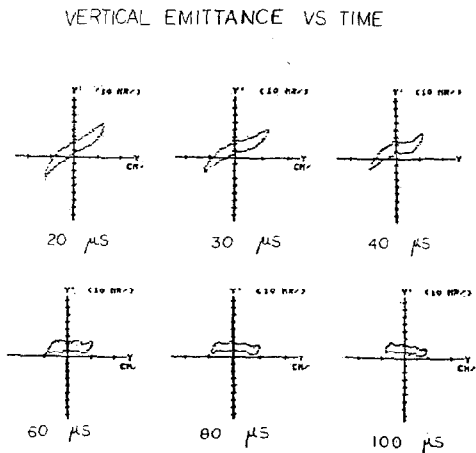


Fig. 6. Vertical phase space contour (90%) vs time.

Growing space charge neutralization during the early part of the pulse is believed responsible. Since neutralization of an H⁻ beam requires positive ions which are too massive to move with the beam, they must be created along the beam path. The effect of background gas pressure was studied by injecting hydrogen into the test box by a precision leak. The data taken at 20 μ sec into the pulse are shown in Fig. 7. A scan made at 100 μ sec showed similar trends to a lesser degree. The increase in horizontal emittance may be due to gas scattering. Figure 8 shows the variation of the vertical phase space contour over the pressure scan. The rotation caused by the background gas is clear and confirms the hypothesis of poor neutralization in early part of the pulse.

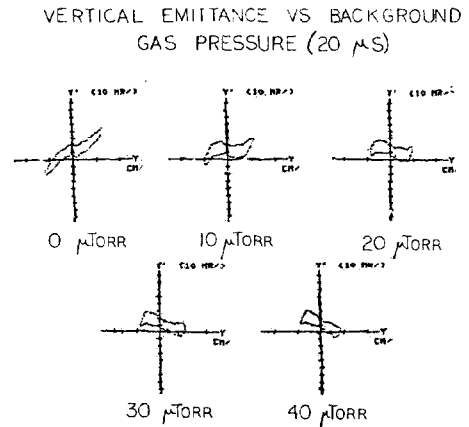


Fig. 8. Vertical phase space contour (90%) vs time.

Acknowledgments

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