

# Further Development with Heavy Ion Sources at Brookhaven National Laboratory's Tandem Van de Graaff Facility

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## Abstract

The Ion Source Test and Development Group at Brookhaven National Laboratory's Tandem Van de Graaff Facility has been evaluating the Peabody Scientific [1] PSX-120 negative ion cesium sputter source for use as the source of pulsed negative ion beams for injection of the Brookhaven synchrotrons. The decrease in emittance due to the use of a spherical ionizer, as recently reported [2], may lead to improved brightness of the beam injected into the MP Tandem resulting in improved beam output. Emittance measurements with the PSX-120 are presented for dc beams and some of the first pulsed beam results are also discussed.

## I. INTRODUCTION

The two MP Tandem Accelerators at Brookhaven National Laboratory are, at present, the only devices [3-5] that can satisfy the requirements for injection of heavy ions into the AGS and will be used when the Relativistic Heavy Ion Collider, RHIC, now under construction comes on line. With the commissioning of the BOOSTER in 1992, the mode of operation of the Tandems has permanently changed from a three stage mode of operation [6] using both MP Tandem Accelerators to a two stage mode that uses only one of the MPs. This changes the conditions under which the ion sources can be run. In addition, although the current ion sources provide adequate intensities of negative ions for the Heavy Ion Physics Program, increased intensity and lower emittance from the ion source will enhance the program, providing a wider range of operating conditions and a greater margin for less than optimum performance.

## II. MULTIWIRE BEAM PROFILE MONITORS

The emittance measurements taken on the test bench were a first approximation but nonetheless a valid and reasonable representation based on the profiles of the beams. Two multiwire beam profile monitors or harps were constructed using 14 - 0.040" stainless steel rods set on 0.200" centers, in both the vertical and horizontal planes contained in a 3.5" square frame of Macor®. The two harps are located at distances of 1.21m and 2.78m from the center of an Einzel lens (Ortec Model 345 Gridded Einzel Lens [7]) which is approximately 0.6m from the extraction electrode of the source. Current measurements were made in the 'source' cup located 0.3m from the extraction electrode of the source and in the 'object' cup located 0.2m before the downstream harp.

The signals from the wires are fed into a standard HITL/AGS instrumentation package [8] for processing and display on an oscilloscope. These electronics are capable of reading all four sets of fourteen wires but sampling was usually done in the horizontal plane on one harp at a time.

The observed profile of positive currents for the negative ion beam is due to the secondary electron emission from those wires that intercept the ion beam superimposed onto the profile of the electrons picked up as 'cross-talk' from one wire to the adjacent ones.

The cross-talk of emitted electrons tends to skew the relative currents from one wire to the next and needs to be eliminated or at least greatly reduced. Studies [9] show that the majority of these secondary electrons have kinetic energies of less than 50 eV. The most prominent peak in the energy spectrum of the secondary electrons being the 'slow' peak, which occurs at very low energies, less than 6 eV.

The method of reducing the cross-talk uses both planes of wires on the harp, one to measure the current and one to apply a bias voltage. The upstream plane of wires was positively biased and the current measured on the downstream plane of wires. The electron cross-talk is not altogether eliminated but is greatly reduced with a positive bias of 20 Volts. Modeling the harps with SIMION [10], an electrostatic lens analysis code, shows that the small number of electrons still being picked up are those that are emitted from the outermost edges of the wires.

## IV. EMITTANCE MEASUREMENTS

Emittance as used in this paper is defined as  $\pi\epsilon$  which is the area of the phase ellipse. Values quoted are for the normalized emittance given by  $\pi\epsilon E^{1/2}$  with units of mm mrad MeV<sup>1/2</sup> where E is the energy of the ion beam in MeV.

The formula used to obtain a value for the emittance can be derived from the transport matrices using a lens followed by a drift region [11]. The one used for these emittance calculations is given by:

$$\epsilon = (W_2^2 / (L_2 - L_1)) \sqrt{(W_1^2 / W_2^2 - L_1^2 / L_2^2)}$$

This formula computes the emittance using the half widths of the beam profiles on the two harps,  $W_1$  (upstream harp) and  $W_2$  (downstream harp) and the distances of the harps from the center of the Einzel lens,  $L_1$  and  $L_2$ . This formula is derived for a configuration where there is a minimum spot size (not a waist) on the second harp.

The procedure was to minimize the beam on the down-

stream harp, record the profile, read the current on the object cup, put in the upstream harp without any adjustments of parameters and record its profile, then read the current on the source cup. The data was then fit to a Gaussian distribution where the standard deviation was determined. The half width used in the formula is obtained from 80% of the beam profile.

Several sets of data were taken on the test bench using the PSX-120 with the helical and spherical ionizers for gold and a few for silicon.

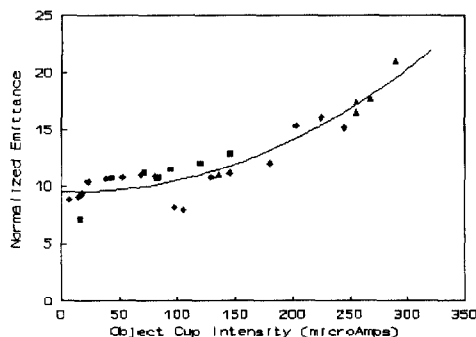


Figure 1. Emittance Measurements for the Helical Ionizer.

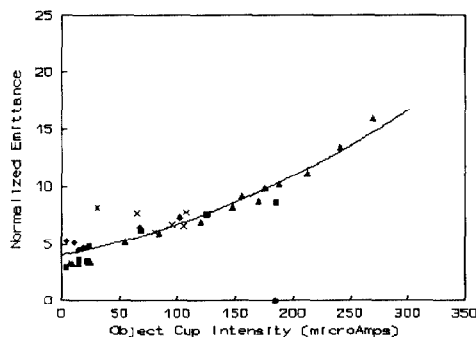


Figure 2. Emittance Measurements for the Spherical Ionizer.

In Figures 1. and 2. above, the data for the normalized emittance of the gold beams using the helical and spherical ionizers is shown. The energy of the extracted ions was 30 kV with cesium accelerating voltages of 3.8 - 10 kV. The spread in the data is representative of the difficulty in determining the emittance by this method. These difficulties are due to 1) moderate resolution on the harps from the diameter and spacings of the wires, 2) the deviation of the beam from a purely gaussian shape, and 3) measuring emittance of a beam before mass analyzing (only trace amounts of elements other than gold but  $Au_2^-$  and  $Au_3^-$  each have an intensity of up to 10% of that of the  $Au^-$  beam). In addition, the secondary electron emission coefficient of each wire can change as the wires are coated by the ion beam.

The normalized emittance as measured with both ionizers can be seen to increase with intensity. A quadratic line was fit to the data points using a least squares program. The emittance growth is a result of the increase in space charge forces but the form of this dependence is not straight forward [12] and will be addressed in a later paper.

If we compare the two graphs we can conclude that the emittance of the gold beams with the spherical ionizer is 45% of that with the helical ionizer at lower intensities, but gradually increases to 75% over the range of intensity shown. A few measurements of 30 kV  $Si^-$  beams with both ionizers have also been made over the same range. These data average, for 80% of the beam, to about  $3.5\pi$  mm mrad  $MeV^{1/2}$  for the spherical ionizer and  $8.2\pi$  mm mrad  $MeV^{1/2}$  for the helical ionizer. The number of measurements are too few to determine how the emittance grows but is definitely less than that for gold. This is consistent with space charge arguments for lower vs. higher mass ion beams.

### III. PULSED BEAMS

Most of the data taken on the test bench and at the Negative Ion Injector of the Tandem has been for the dc mode. A 15 kV, 500  $\mu$ sec pulser was built, tested and added to the test bench in November 1992.

The PSX-120 with the spherical ionizer was run in the pulsed mode with a gold target. Although in-depth studies have not yet been done, some initial results and observations deserve mention. The procedure was to characterize the pulses in the source and object cups while working toward improved transmission to the object cup.

The input to the pulser is usually a 500  $\mu$ sec square pulse at a repetition rate of 2 Hz. This high voltage pulser is capable of producing up to a 15 kV, 500  $\mu$ sec pulse or an equivalent voltage-time combination. The output voltage from the pulser has a 30  $\mu$ sec rise time and a 60  $\mu$ sec fall time. In addition, there is an initial 6% overshoot with a settling time of 110  $\mu$ sec.

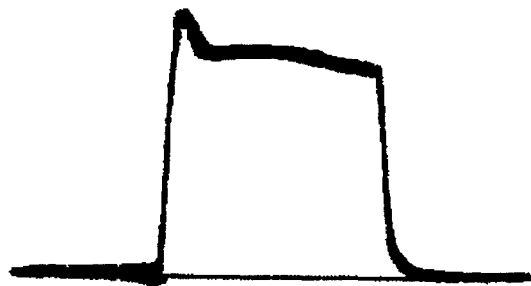


Photo 1. 920  $\mu$ A Pulse as seen in the Source Cup.

Photo 1. above, taken from the oscilloscope display shows a 920  $\mu$ A, 500  $\mu$ sec negative gold beam pulse observed at the source cup close to the source. The extraction voltage was 35 kV and the cesium acceleration voltage was pulsed to 10 kV from a base of 600 VDC. Part of the apparent beam pulse overshoot is due to electrical cross-talk but otherwise the rise and fall times are similar to the ones of the high voltage cesium acceleration pulse. The other feature that distinguishes the source cup pulse from the HV source pulse is that the intensity falls off from the max of 920  $\mu$ A to about 840  $\mu$ A. This, it is believed, is due to the change in cesium and/or

target conditions during the pulse. It remains to be studied if this can be compensated for by adjusting the trace voltage, heating the cesium boiler or some combination of both.

The 920  $\mu\text{A}$  pulse was sent down the line through the

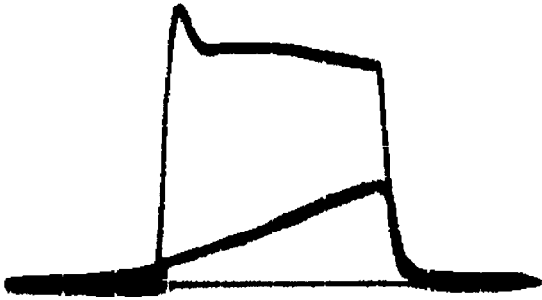


Photo 2. Object Cup Pulse showing Time-Dependent Space Charge Effects.

Einzel lens to the object cup. Photo 2., above, shows what was seen at the object cup overlaid on the pulse from the source cup. This pulse rises from 100  $\mu\text{A}$  up to about 375  $\mu\text{A}$  and would probably continue to rise if the pulse width was longer. The slow increase in the intensity suggested a process that was occurring during the pulse. Space charge neutralization was the suspected process. Since vacuums are usually in the  $10^{-7}$  through the  $10^{-6}$  Torr range space charge neutralization might be enhanced if one or more of the cryopumps on the beam line was closed off. After trying a few combinations, the best results were produced when the cryopump 0.2m downstream of the source (at the source cup) was closed off. The difference in vacuum at the source cup went from  $3 \times 10^{-6}$  Torr with the cryopump opened to  $3 \times 10^{-5}$  Torr with it

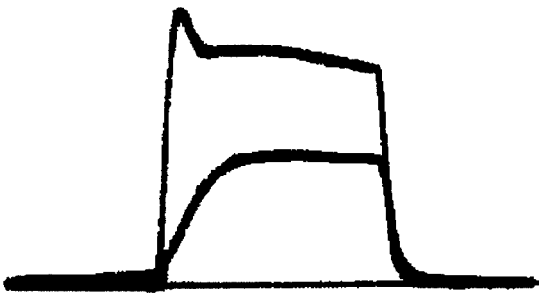


Photo 3. Object Cup Pulse with Enhanced Space Charge Neutralization.

closed. This translated to the object cup where the vacuum went from  $5 \times 10^{-6}$  Torr (opened) to  $9 \times 10^{-6}$  Torr (closed). The results are shown in Photo 3. where the object cup pulse is overlaid on the 920  $\mu\text{A}$  source cup pulse. As can be seen in this photo the intensity rises to 500  $\mu\text{A}$ , where it is sustained for 300  $\mu\text{sec}$ . The rise time is roughly 120  $\mu\text{sec}$  which is comparable to that seen on the low energy faraday cup at the entrance to the MP-7 Tandem accelerator.

## V. FUTURE PLANS

Clearly there is a need for further in-depth studies of the source with pulsed beams. More time needs to be devoted to learning about space charge neutralization and improving transmission. There should be a complete study of emittance measurements for gold at various extraction energies and pulser voltages. These should be made with both the spherical and helical ionizers using harps with greater resolution and some computer assistance.

## VI. ACKNOWLEDGEMENT

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