HIGH BRIGHTNESS POTASSIUM ION GUN FOR THE HIF NEUTRALIZED TRANSPORT EXPERIMENT (NTX) *

S. Eylon, E. Henestroza, P. K. Roy, and S.S. Yu
Lawrence Berkeley National Laboratory, Berkeley, CA 94530, USA, and the Heavy Ion Fusion, Virtual National Laboratory

Abstract
The NTX experiment at the Heavy Ion Fusion Virtual National Laboratory is exploring the performance of neutralized final focus systems for high perveance heavy ion beams. To focus a high intensity beam to a small spot requires a high brightness beam. In the NTX experiment, a potassium ion beam of up to 400 keV and 80 mA is generated in a Pierce type diode. At the diode exit, an aperture with variable size provides the capability to vary the beam perveance and to significantly reduce the beam emittance. We shall report on the gun characterization including current density profile, phase space distributions and the control of electrons generated by the beam scraping at the aperture. Comparison with particle simulations using the EGUN code will be presented.

INTRODUCTION

The Neutralized Transport Experiment (NTX) [1-2] at Lawrence Berkeley National Laboratory is designed to study the effects of plasma neutralization for a strongly space-charge-dominated ion beam, using a 400 KeV beam of singly charged potassium ions. The experiments require variable beam current, by one order of magnitude, up to 75mA. In addition, a very high brightness source is required. One way to generate high brightness beams is to remove the edge of the beam after it is generated in the diode; but scraping the beam also generates secondary electrons that must be controlled to prevent them from perturbing the beam. We have designed a beam scraper system that includes an electron trap for the control of secondary electrons. Beam aperturing appears to be a natural match to the requirements.

The control of electrons is our first concern in this experiment, as stray electrons can introduce nonlinear space charge forces, which could lead to increase of beam emittance [3], and disruption of beam propagation. The proposed technique is to confine the electrons generated by the aperturing process to its place of birth by adjacent electron traps. These electron traps have negative potentials sufficiently large to confine the electrons even in the presence of the positive potential (a couple of kilovolts in NTX) from the self-field of the ion beam.

DESIGN

Design of the ion gun, together with the beam aperture and electron trapping device is shown in Fig. 1. The K+ beam at 400 kV and 75mA is extracted from a 2.54 cm diameter alumino-silicate source [4] across a diode with a 12 cm gap. Downstream of the exit cathode plate is a beam aperturing plate with holes of variable diameter, sandwiched between two metal tubes of 5cm length, and 6.2 cm inner diameter. The EGUN calculation in Fig. 2 shows the nominal design of –3kV on each of the metal tubes (beam scraper system), providing adequate electron trapping in the presence of the ion beam.

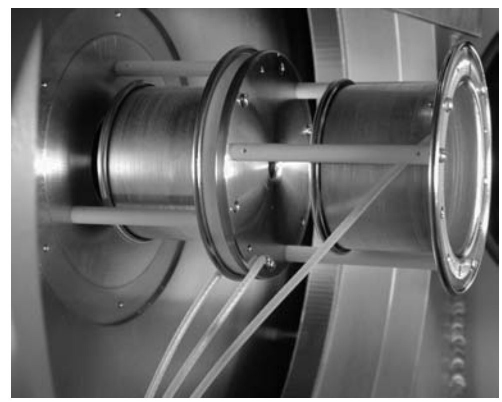

Figure 1: Beam scraper system.

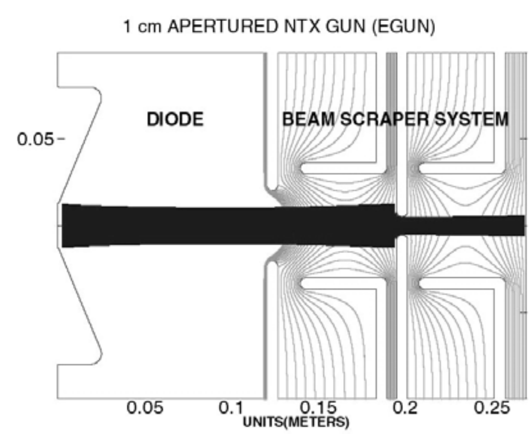

Figure 2: EGUN simulation of diode and beam aperture setup.

The primary diagnostics for this experiment consist of a Faraday cup to measure the total beam current exiting the aperture plate, and a slit/ slit-cup arrangement to measure the line-integrated beam profile (with slit cup only) and emittance (with slit and slit cup). The Faraday cup and the slit cup each consists of a collector and a guard

*Supported by the Office of Energy Research, US DOE, at LBNL & LLNL,contract numbers DE-AC03-76SF00098 and W-7405-Eng-48.

ring/grid with bias voltages that are controlled to collect beam ions only. In addition, we can also monitor the currents flowing through the aperture plate and each of the two electron traps.

EXPERIMENT

The experiment is first performed without an aperture plate. The peak current at 400 kV is 77mA, which is in agreement within the uncertainty of the measurement with the EGUN code prediction of 73 mA. The measured current follows the Child-Langmuir three-half power law as the voltage was varied over a factor of 3 in range and is shown in Fig. 3. The measured beam profile and emittance show a variation from uniformity due to known imperfections in beam optics. An aperture of 2 cm diameter was then introduced with the nominal electron trap voltages applied. The measured current is 55% of the total, again consistent with the EGUN prediction. The measured profile of the aperture beam is much more uniform, and the emittance is a factor of 2 lower (translating to an overall increase of brightness by a factor of 2).

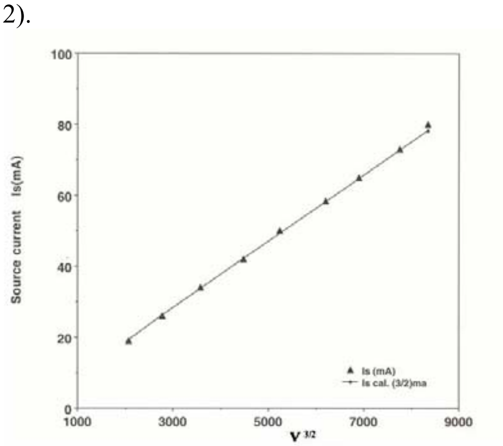

Figure 3: Extracted current from NTX follows Child-Langmuir Law.

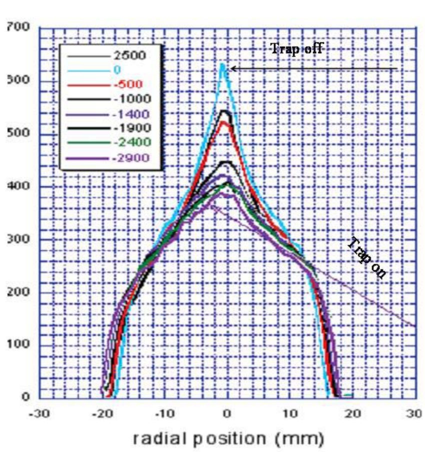

Figure 4: Beam Profile as function of trap voltage.

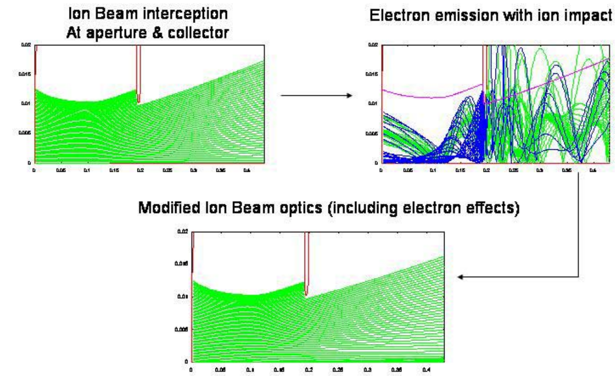

Figure 5: Beam aperturing experiments are modeled by an iterative calculation with EGUN.

To understand the effect of electrons generated by the beam on the aperture and the diagnostic plates, we vary the bias voltage on the electron trap. The total current measured in the Faraday cup increases as the magnitude of the negative bias is reduced. We also measured the change in beam profile as the bias voltage is varied. We notice that as the bias voltage moves towards zero, the on-axis current is greatly enhanced. Associated with the on-axis enhancement is a slight reduction in the overall radial dimension of the beam (Figure 4).

These observations are consistent with a picture where electrons are trapped within the beam as the electron trap voltage is reduced. To quantitatively evaluate these effects, we performed a series of simulations, using PIC codes as well as ray-tracing codes. The predicted current and beam profiles are shown in Fig 5.

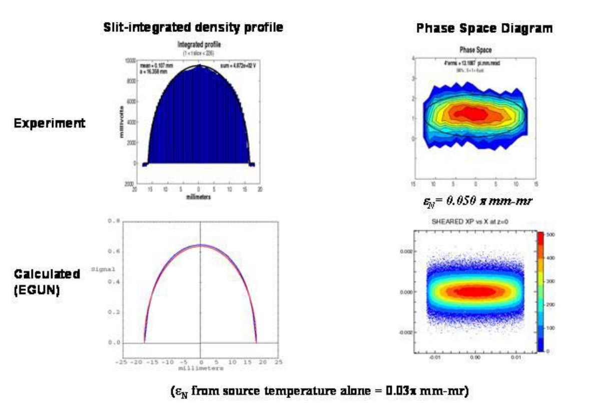

Figure 6: A High Brightness apertured beam (300kV, 25 mA, 2 cm aperture)

With the qualitative agreement of code and experiment, the following picture emerges: when the negative bias on the electron trap is sufficiently high, the electrons born on the aperture plate and the diagnostic plates are locally trapped. Their effect on the ion beam is minimal. However, as the negative bias is reduced, the electrons are finally able to break through the electrostatic barrier, and will accumulate around the beam axis (the bottom of the potential well). The region of electron population increases with reducing bias voltage. These on-axis electrons cancel the space-charge effect of the ions, causing the overall ion beam envelope to decrease, and the on-axis ion density to increase. The total current through the aperture also increases as a result.

REFERENCES

[1] S. S. Yu et al., "Focusing and Neutralization of Intense Ion Beams", Proc. PAC '03, TOAA001.
[2] E. Henestroza et al., "Neutralized Transport of High Intensity Beams", Proc. PAC '03 , WPPG014.
[3] C. Lejeune et al., "Applied charged particle optics", edt. by A. Septier (1980), pt 13A, 159.
[4] D. Baca et al., "Fabrication of Large Diameter Alumino-Silicate K^+ Sources, Proc. PAC '03 FPAB005.