EMMITANCE MEASUREMENTS OF A COLD CATHODE INTERNAL ION SOURCE FOR CYCLOTRONS*

E. Forringer, H. G. Blosser, NSCL, USA

Abstract

Studies of the emmitance and phase space density of an internal, cold cathode ion source are underway at the NSCL. The source being studied is of the same style as the one used in the Harper Medical Cyclotron [1], and planned for use in the 250 MeV superconducting cyclotron for advanced cancer therapy under development [2]. Experimental results for $r - p_r$ and $z - p_z$ emmitance will be compared with predictions from the orbit tracking code CYCLONE.

1 DESCRIPTION OF THE SOURCE

The ion source under investigation is a Penning Ion Gauge cold cathode source similar to ones used to produce heavy ions [3].

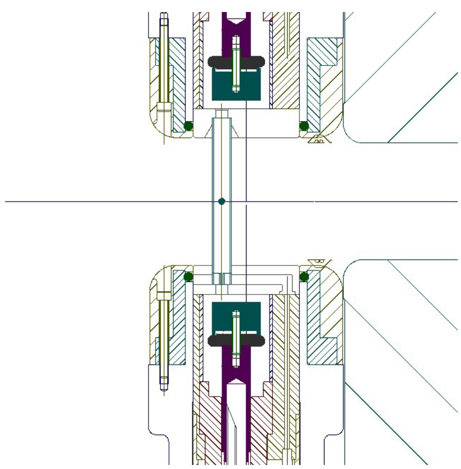

Figure 1: CAD drawing of PIG ion source.

This source, shown in figure 1, uses a tantalum cathode mounted on a water cooled copper tube, and a copper anode with a molybdenum chimney. The chimney is 0.25 in. diameter with an 0.020 in. wall. The source hole is 0.047 in. diameter with an 82 degree countersink. The arc supply produces 1 A at 3 KV. Typical arc characteristics are 250 mA at about 1.5 KV.

2 COMPUTER MODELS

2.1 Electric Fields

In order to predict the phase space characteristics of the extracted beam, we produced a detailed 3D model of the chimney and puller for electrostatic calculations (Fig. 2).

One challenge in modeling a plasma ion source is in determining the shape of the plasma boundary at the source hole. A simple method for representing the plasma boundary has been developed by Schubert at the NSCL [4]. This method involves putting a fictitious "image electrode" at the center of the chimney and assigning it a potential. The V=0 surface is then taken to be the plasma boundary and is used as the starting point for all ions in the tracking code. By using different potentials on the image electrode different plasma boundary shapes can be simulated (Fig. 3). We used Relax 3D, a three dimensional Laplace equation solver, to calculate the fields.

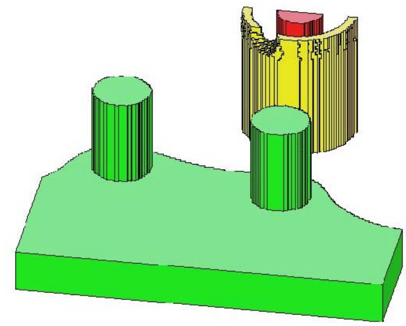

Figure 2: View of the grid used in Relax 3D to determine the electric field near the chimney. Special effort was taken to accurately represent the shape of the source hole.

2.2 Magnetic Field

The so called "airport magnet", a decommissioned bending magnet from the NSCL, was used for these studies. Before modifications were made, the magnet was mapped. Then the magnet geometry was entered into TOSCA (Vector Fields Inc.) to verify that TOSCA would correctly calculate the magnetic field. A comparison of the TOSCA field with the mapped field shows good agreement (Fig. 4).

Several modifications were made to the airport magnet for this project. Those changes were also put into the TOSCA model. The magnetic field used in all our simulations came from TOSCA.

2.3 Particle Tracking

CYCLONE is the standard orbit tracking code used at the NSCL. We used "part one" of cyclone to predict the phase space characteristics of the beam extracted from our ion source. Part one uses time as the independent variable.

250 particles were started on the V=0 surface at the source hole. Each particle was assigned a random initial direction with a starting energy based on estimates of the

* This work supported by the NSF Grant No. PHY-9528844.

CP600, *Cyclotrons and Their Applications 2001, Sixteenth International Conference,* edited by F. Marti

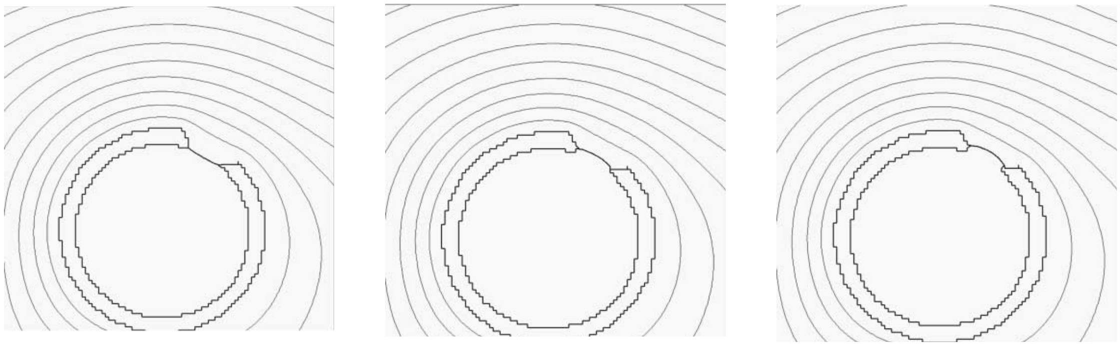

Figure 3: In each image, the dark line represents zero potential. The dark line that goes across the source exit hole is taken to be the “plasma boundary,” the starting point for each ion. The three different plasma boundaries were produced using different values for the image electrode.

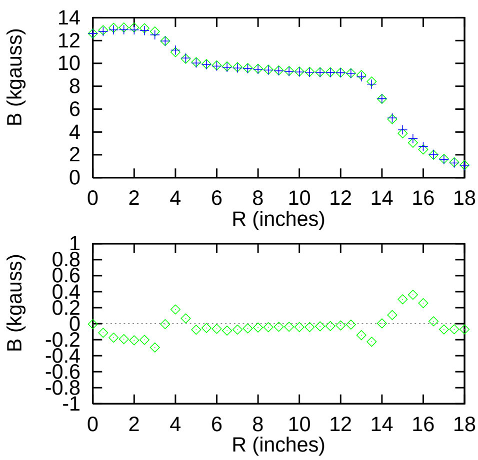

Figure 4: Graph one shows the azimuthally averaged field (Kgauss) as measured (diamonds) and calculated with TOSCA (pluses). Graph two shows the difference between TOSCA and measured fields.

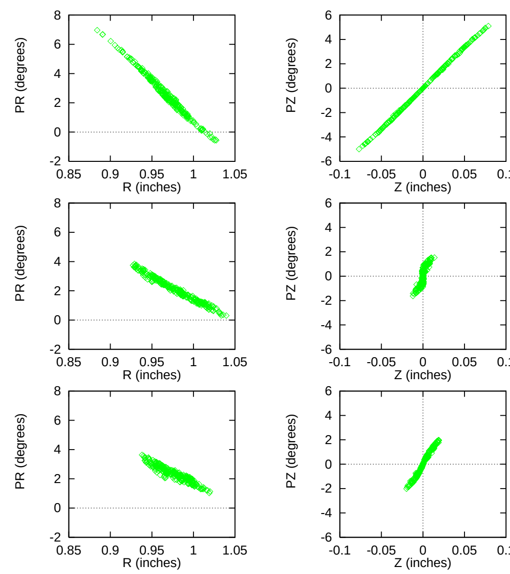

Figure 5: $r - p_r$ and $z - p_z$ phase space diagrams for the three different plasma boundaries shown in figure 3. A and B are the $r - p_r$ and $z - p_z$ for a concave plasma boundary. C and D are for a slightly convex plasma boundary, and E and F are for a very convex plasma boundary.

temperature of the plasma. After acceleration, the final r, p_r, z, and p_z, were recorded.

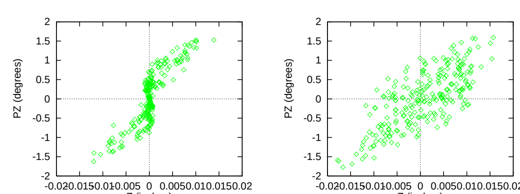

Figure 6: $z - p_z$ phase space plots for two different starting energies for the ions. The larger the starting energy, the larger the phase space area.

2.4 *Predictions from the Calculations*

Plasma Boundary The shape of the plasma boundary had a large effect on the shape of the phase space of the extracted beam (Fig 5). We do not have a theoretical model to predict the actual plasma boundary shape. We should be able to determine the plasma boundary shape experimentally by comparing the measured phase space to these numerical predictions.

Temperature of the Plasma Each ion was started with a randomly generated initial direction, and a fixed initial energy. The total emmitance of the beam after acceleration is dependent on the initial energy of the ions as shown in figure 6.

3 EXPERIMENTAL APPARATUS

For this experiment we are using 50 KV DC extraction. The high voltage electrode shown in figure 7 holds the puller and the probes.

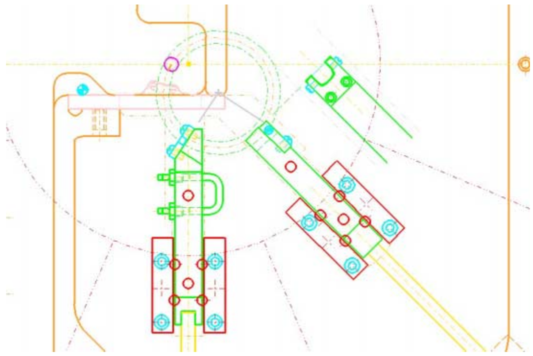

Figure 7: CAD drawing of the chimney, puller, and probes.

There are two interchangeable sets of probes, one set for $r - p_r$ and one for $z - p_z$. The first probe, which intercepts the beam just after it has been accelerated through the puller, is a movable 0.010 inch slit that blocks most of the beam. The second probe is a movable 0.005 inch tungsten wire that scans the beam after it has passed through the slit. Together, the probes measure the angular spread of the beam at each slit position.

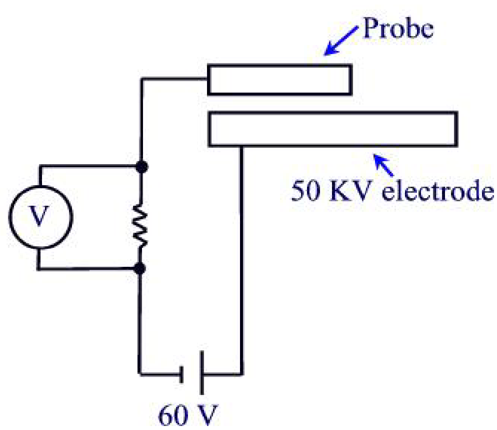

Figure 8: Electrical circuit used to measure the beam current that hits each of the probes. The entire circuit floats at 50 KV.

The probes are isolated from the rest of the high voltage electrode and biased with 60 volts. Digital multimeters are used to measure the beam current on the slit and the wire. Figure 8 is a diagram of the circuit used to measure these currents.

3.1 Status of the Experement

At this time all the components of the experimental setup have been build and tested individually. However, we are currently unable to run the source in the airport magnet because of insufficient vacuum. We are in the process of leak checking and are considering adding a diffusion pump to improve pumping speed.

4 CONCLUSION

Using Relax 3D and CYCLONE, we have produced testable predictions for the size and shape of the phase space of the extracted beam from a PIG ion source. The shape of the plasma boundary and the temperature of the plasma are two free parameters in these calculations. When experimental results become available we will be able to infer the plasma conditions at the starting point. This information will be important in future cyclotron design projects by giving reliable information about the initial conditions of the beam from such sources.

5 REFERENCES

[1] H. G. Blosser, "Superconducting Cyclotron Facility for Neutron Therapy." Tenth International Conference on Cyclotrons and Their Applications, 1984.

[2] M. Schillo et al., "Compact Superconducting 250 MeV Proton Cyclotron for the PSI PROSCAN Proton Therapy Project." Cyclotrons and Their Applications, 2001.

[3] J. R. J. Bennett, "A Review of PIG Sources for Multiply Charged Heavy Ions." IEEE Nuc. Sci. April 1972 NS-19 #2.

[4] J. R. Schubert, "Extending the Feasibility Boundary of the Isochronous Cyclotron." Dissertation p. 23, Michigan State University 1997.