Simulation of Ion Beam Extraction from a Single Aperture Triode Extraction Column: A comparison of the beam transport code PBGUNS with the test stand data

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Introduction

Beam transport codes are invariably utilized to facilitate the design of low-energy, high current ion beam extraction systems. In this paper, we compare the results of simulations of extraction of high-current ion beams from a plasma ion source with experimental data obtained on test stands. The particle beam transport code PBGUNS was used to model single aperture triode extraction system that was originally characterized on well equipped ion source test stands. The behavior of a hydrogen ion beam extracted from a high-current microwave-driven ion source was studied for fixed extraction geometry. The extraction geometry is shown in Fig.1.

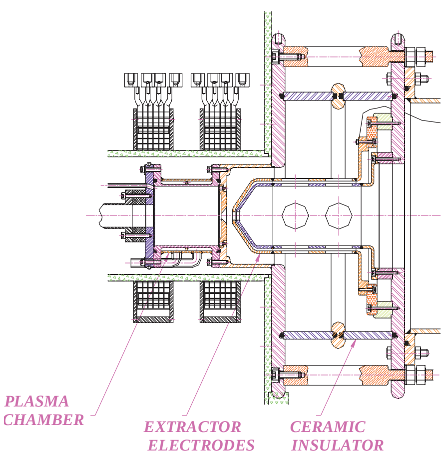

Fig. 1. Schematic of ion source extraction system.

Test stand data

The intent of this study was to determine the optimum geometry for a single aperture three electrode extraction system. The hydrogen ion beam was extracted from a microwave ion source that was designed and developed in-house with a single aperture triode extraction column operating at extraction voltage of 20-40 kV[1]. The ion source was installed on a test stand equipped with water-cooled Fadaray cup of aperture 5 cm that intercept the beam at a distance of 30 cm from the plasma electrode.

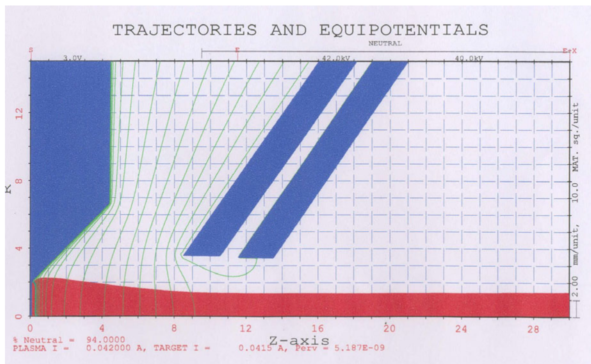

Fig. 2. Trajectory plot of a 42 mA hydrogen beam modeled in PBGUNS. The plasma aperture is biased at 40 kV, the accel electrode -2 kV and the decel electrode is grounded.

The pressure of the background gas in the test stand was kept constant for each measurement. The beam current was checked from the Faraday cup with secondary electron suppression and was also inferred from the acceleration supply drain current.

Simulation

In the initial setup of the extraction problem, the electrode geometry is described by line segments sketched onto a grid. The geometry was defined in axis symmetric terms. The axial magnetic field for the microwave ion source was entered by specifying a series of breakpoints along the beam axis. The program then interpolates between these points to give a distribution. It has been observed that the presence of an axial magnetic field did not appear to affect the beam trajectories in the PBGUNS simulations.

PBGUNS simulation utilizes a self-consistent solver to define the shape of the ion emission surface at the extraction aperture. PBGUNS require initial ion energies of 10-20 eV with the velocity vector oriented in the direction of beam extraction for the simulation to work. Multispecies beams (such as hydrogen) are interactively specified in PBGUNS during the initial setup. Figure 2 shows the beam extraction electrodes, equipotentials, and trajectories obtained from PBGUNS simulations using the actual source geometry and injected current density of 835 A/m^2. An injected particle Maxwellian distribution corresponding to the ion thermal energy of 1.0 eV was used in the simulation. The full beam space charge (f = 0) is effective in the ion source from the emission surface to z = 19 mm where the space charge compensation with f = 0.94 become effective. This calculation gives 42 mA total beam current of 85% of H^+, 10% H_2^+ and 5% H_3^+ beam.

Comparison of simulation results and test stand data

The simulated results are compared to the experimental results in Fig. 3.

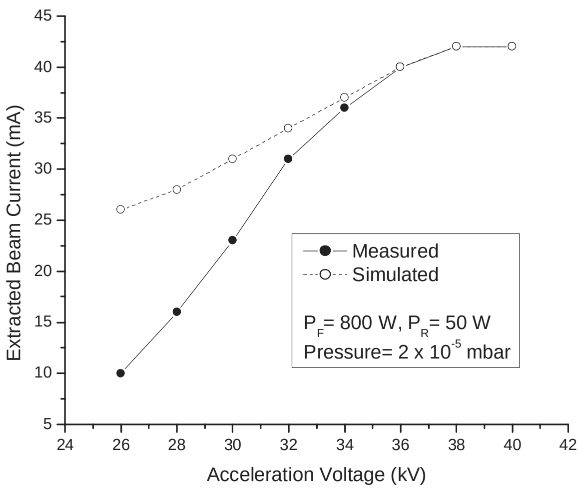

Fig. 3. Measured test stand data and simulation results for a hydrogen ion beam extracted from a microwave ion source.

The extracted ion current in Fig. 2 was found saturated for an acceleration voltage of 36 kV. The simulated results show the maximum ion beam current that can be extracted for a given geometry and the extraction voltages on the electrodes. This mainly depends on the space charge limiting current. The discrepancy at lower voltages is due to the fact that the plasma density at these voltages is lower than the optimum and leads to lower Bohm current. The plasma density can be optimized by varying the microwave power, gas pressure and the applied magnetic field. Near the saturation region the beam current agree reasonably well with the results generated on the test stands.

Conclusion

This study illustrates the value of the simulation code PBGUNS when applied to the design of ion beam extraction systems, as a supplement to the test stand data. The code reproduced the qualitative behavior of the extracted ion beam to the extraction electrode geometry, perveance and beam species. The quantitative results agree reasonably well near the saturation region with the results generated on the test stands.

References

[1] P. Roychowdhury et. al., Proceedings of the Indian Particle Accelerator Conference, (InPac 2009) RRCAT, Indore, India 2009.