Particle-in-Cell Simulations of the VENUS Transport System

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The superconducting Electron Cyclotron Resonance (ECR) ion source VENUS[1] has been designed for the dual purpose of providing ion beams to the 88-Inch Cyclotron at Lawrence Berkeley National Laboratory and serving as the prototype source for the proposed Rare Isotope Accelerator (RIA) project. For both projects the goal is the production of high current beams, with the former requiring these high current beams to be composed of highly charged ions and the latter medium charged ions. In order to better understand the performance of the beam transport system and to aid as a guide in the future design of the transport system for RIA, a concentrated simulation effort was initiated in parallel with the commissioning and testing of the VENUS source.

There are a number of complicating factors that necessitate simulation to improve understanding of the VENUS transport system. The formation of the beams takes place in a region of high magnetic field (up to 3 Tesla) which falls to zero over the first 40cm of beam travel. This fringing field induces both a rotation of the beam about its longitudinal axis and transverse emittance growth. Both of these effects are highly dependent on the charge-to-mass ratio of the transported ions, and a typical beam may be composed of upwards of thirty species. Further, transport is performed with a relatively large beam diameter to reduce space charge effects along the system. As a result, a large-gapped analyzing dipole with a complex pole face geometry was designed whose field must be treated three-dimensionally.

In the past year two particle-in-cell codes, Impact[2] and Warp[3], have been enhanced so that each is now capable of simulating the VENUS beam transport system from the extraction region, through a solenoid lens and the analyzing magnet, and on to the diagnostic region. Developing the codes in parallel allowed for benchmarking of the codes against one another prior to a systematic simulation effort. Tests between the codes show very good agreement, and comparisons of the simulations with experimental data are now underway. One of the more simple beams that can be produced by VENUS is an oxygen beam, which is mainly composed of the eight ionization states of oxygen and hydrogen. Figure 1 shows simulation results of through the first 25cm of the beam line using an experimentally measured beam current spectrum for a 1.3 mA oxygen beam. The varied gyromagnetic wavelengths for the different ions are evident in the figure.

Simulations performed elsewhere have been found to require significant space charge neutralization in order to match experimental results[4]. As an initial test of the importance of space charge along the VENUS beam transport system, two sets of simulations were performed: in the first one the space charge was turned off completely from immediately after the extraction region (z=0.25m) to the analysis region (z=3.5m), and in the second one no space charge neutralization along this length was used.

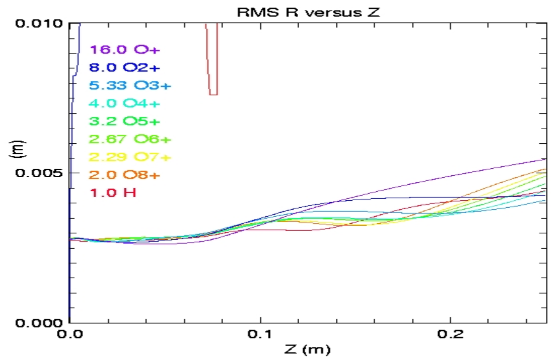

Figure 1: Simulation of the extraction of oxygen/hydrogen beam from VENUS. Radial rms size is plotted as a function of longitudinal distance for each species present.

The same experimental beam currents used in the calculation shown in Figure 1 were used for this test. This current is relatively low for VENUS, therefore it was expected that little difference in the beam should be present by altering the space charge compensation. But as can be seen in Figure 2, what was found is that the inclusion of space charge tends to move the waists downstream 20-30cm, and it is only through the inclusion of these space charge forces that the simulation waists can approach the experimentally measured data.

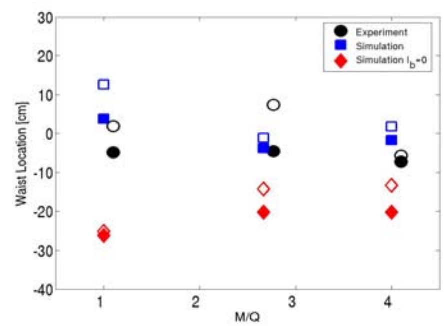

Figure 2: Waist location relative to emittance scanners is plotted versus mass-to-charge ratio. Filled symbols represent horizontal waists and hollow vertical. The experimental results have been offset slightly for clarity.

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