KINETIC PLASMA SIMULATION OF ION BEAM EXTRACTION FROM AN ECR ION SOURCE

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Abstract

Designing optimized ECR ion beam sources can be streamlined by the accurate simulation of beam optical properties in order to predict ion extraction behavior. The complexity of these models, however, can make PIC-based simulations time-consuming. In this paper, we first describe a simple kinetic plasma finite element simulation of extraction of a proton beam from a permanent magnet hexapole electron cyclotron resonance (ECR) ion source. Second, we analyze the influence of secondary electrons generated by ion collisions in the residual gas on the space charge of a proton beam of a dual-solenoid ECR ion source. The finite element method (FEM) offers a fast modeling environment, allowing analysis of ion beam behavior under conditions of varying current density, electrode potential, and gas pressure.

INTRODUCTION

The first simulation reported here represents proton extraction from a hexapole ECR ion source similar, but not identical, to an existing 10 GHz source [1], [2] and with a magnet system for higher frequency operation. The v14 SCALA/TOSCA 3d FEM software [3] is used for reasonably fast prediction of ion beam formation with automatically generated secondary charged particles from gas in the ionization chamber. A second model of a dual-solenoid ECR ion source [4] is used to simulate space charge beam compensation with gas secondary electrons.

PART 1: KINETIC PLASMA SIMULATION

The simulation includes space charge interactions of electrons and ions in the ionization chamber of a hexapole ECR ion source with a solenoid magnet lens (Fig. 1), extracting a proton beam from the plasma volume. The simulation predicts a three spoke ion beam cross-section.

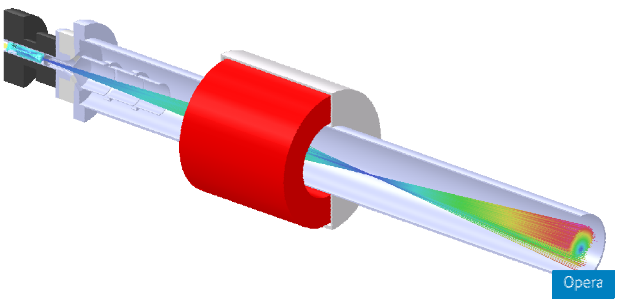

Figure 1: Source geometry with solenoid lens.

The source is composed of a magnet system and ionization chamber. An extractor is held at -10 kV. An einzel lens is also included (Fig. 2).

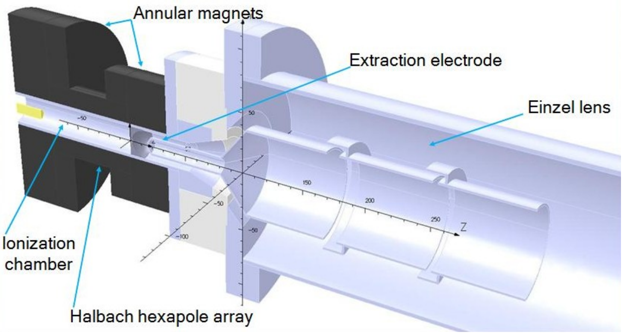

Figure 2: Source and einzel lens.

SIMPLE PLASMA SIMULATION

A small current of ions launched from the ECR surface initializes emission of volume secondary electrons and ions. The plasma fills the magnetic volume in the ionization chamber. Electrons and ions can be given energy and angular distributions, energy and current loss and scattering may be calculated, and surface secondary particles may be added as well.

RESULTS

The minimum B axial magnetic field is simulated with non-linear magnetic materials and has a minimum of about 0.47 T on axis (Fig. 3).

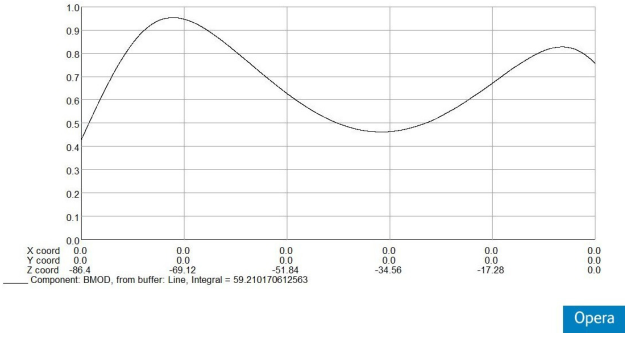

Figure 3: Ionizer on-axis magnetic flux density.

The space charge distribution in the ionization chamber is inhomogeneous due to the magnetic field (Fig. 4).

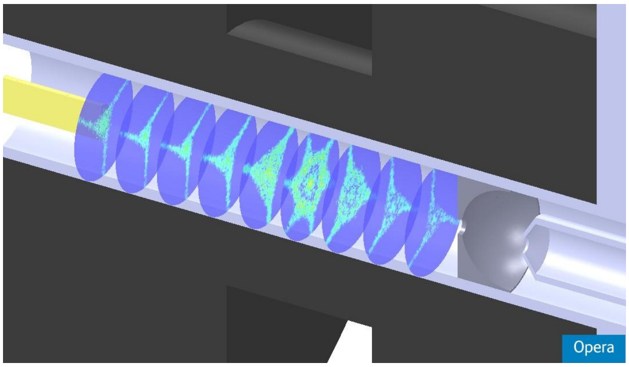

Figure 4: Ionization chamber space charge.

The ionizer plasma is visible by displaying trajectories (Fig. 5).

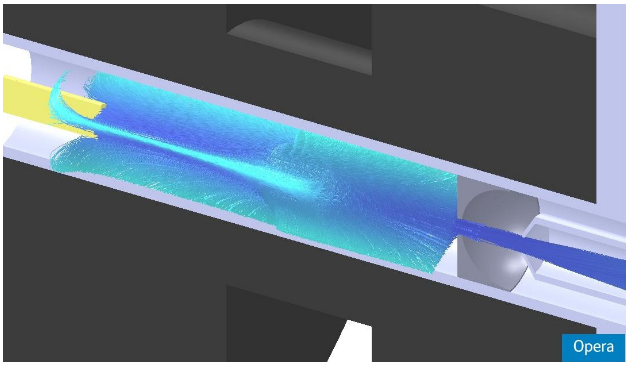

Figure 5: Ionizer plasma.

The extracted ion beam contains three spokes and is embedded in a partial ring halo (Fig. 6). Varying conditions in the ionization chamber can result in variations of the beam profile.

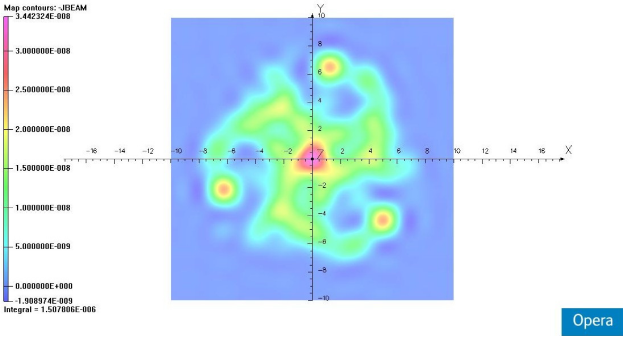

Figure 6: Ion beam profile at Z = 140 mm.

PART 2: BEAM COMPENSATION

The second simulation illustrates the influence of secondary charged particles generated by ion collisions in the drift space residual gas on the space charge in a proton beam. The simulation predicts a decrease in beam divergence with gas secondary electron space charge compensation. The finite element model is composed of two solenoid magnets, a three-electrode accel-decel extraction system and a downstream, partially reflecting termination (Fig. 7).

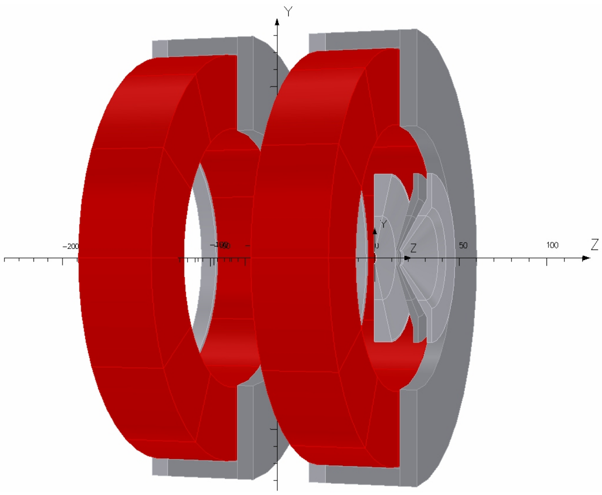

Figure 7: Source geometry with non-linear magnetic materials.

The source is held at 15 kV, the extractor at -4 kV, and the electron suppressor and reflector at -0 V.

BEAM INTERACTIONS

The basic simulation and primary emission method is described elsewhere [4]. Secondary emission from background gas, with user specified energy and angular distributions, is automatically simulated.

Secondary particles are generated from a volume representing the background gas. Volume secondaries are generated at a randomized, user-defined characteristic length along the primary beam trajectories.

RESULTS

The maximum magnetic flux density along the ion source axis is about 0.11 T [Fig. 8].

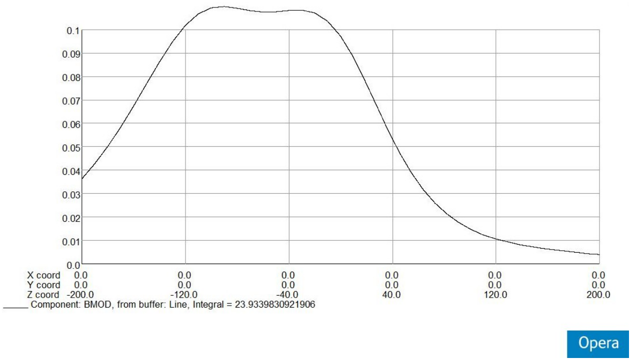

Figure 8: On-axis magnetic flux density.

The gas secondary electrons are highly magnetized and are confined near the ion beam by both the magnetic field and the ion beam space charge [Fig. 9].

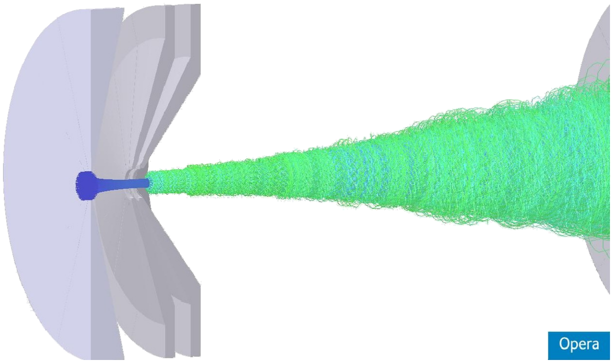

Figure 9: Magnetized secondary electrons.

The ion beam envelope divergence is reduced with space charge compensation (Figs. 10 and 11).

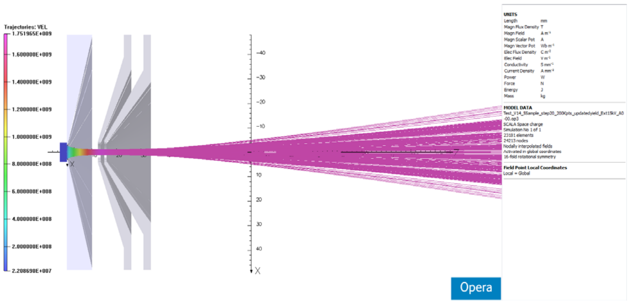

Figure 10: Ion beam without compensation.

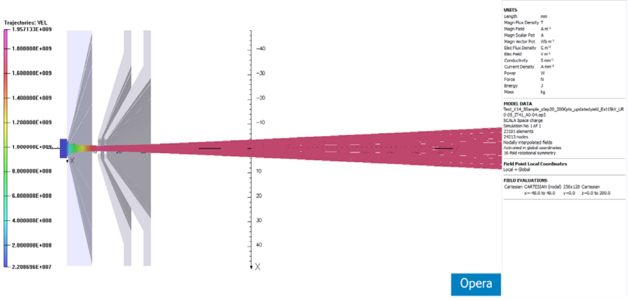

Figure 11: Ion beam with compensation.

The ion beam axial electric potential is reduced with space charge compensation as expected (Figs. 12 and 13).

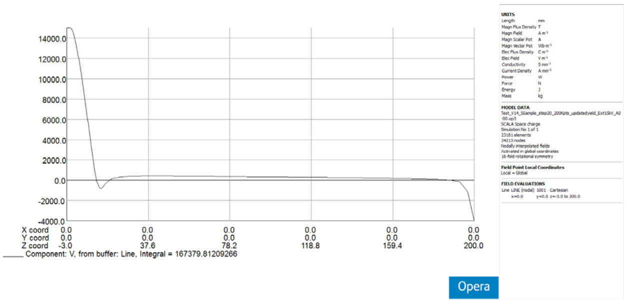

Figure 12: Ion beam axial voltage without compensation.

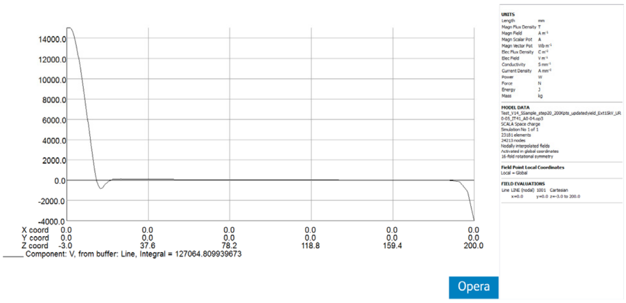

Figure 13: Ion beam voltage with compensation.

CONCLUSIONS

The new version of SCALA/TOSCA, v14, permits simulation of extraction of a structured ion beam from a hexapole ECR ion source as well as simulation of ion beam neutralization by trapped gas secondary electrons. The simulations run in tens of minutes to a few hours on standard computer platforms without the need of particle-in-cell methods. This provides a fast means of simulating beam optics in the design stage for optimal ion extraction.

REFERENCES

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