COMSOL Multiphysics® Software Used As a Laplacian Potential Simulator for an Electrospray Propulsion System Extraction Region

S. Gallucci[1], P. Mirbod[1]

[1]Clarkson University, Potsdam, NY, USA

Abstract

Electrospray propulsion is a contemporary type of thruster technology that electrostatically drives particles through an extractor grid without the need of a pump. The basis of this propulsion system is the coalescence of propellant into a Taylor cone and through a charged extraction grid. Analysis of the Taylor cone to extraction grid area, known as the extraction region, aims to define the formation of the thruster plume, to the end of characterizing the beam formation and divergence, as well as particle trajectory tracking. The understanding of particle trajectories within the extraction region is sought, and Laplacian potential, which drives electrostatic forces on particles, was simulated for the iEPS system following a comparison study to validate the efficacy of COMSOL Multiphysics® software as a finite element solver for this system.

In order to develop the components of the motion of the electrospray thruster plume, a study of the extraction region and near-plume region was conducted. The COMSOL AC/DC Module, in conjunction with mathematical modeling, was used to characterize these areas of the plume, observing the Laplacian potential developed between the extraction grid and Taylor cone. The Taylor cone boundary being considered equipotentially 0V allows for a clear observation of the potential development. Redesign of a Gallium emission electrospray system studied by Ward and Seliger [1] was conducted within the COMSOL software, with an emission bead diameter of 1000Å. Electric potential data was juxtaposed with data from the mathematical analysis of the system with the Sphere-on-Orthogonal-Cone (SOC) model within MATLAB® software. Acceptable margins of divergence were found between the SOC potential model and the COMSOL finite element solutions at very fine resolutions. The SOC model as well as the COMSOL software stationary electrostatics underestimated electric potential compared to Ward and Seliger's data from the Herrmannsfeldt program.

Using the comparison between COMSOL modeling and the SOC model as support for further work, the iEPS electrospray thruster system was recreated, and its Laplacian potential was analyzed. Normalized potential with regards to the extraction grid was exported into MATLAB software, and compared to the Gallium emission system; the parabolic trend of the electric potential was noted, but greater divergences from the Gallium system were also seen. While upwards of 90% of the extraction grid potential is seen in the near-grid outer boundary of this system, only 80% is seen in the iEPS system. As the iEPS emission bead is 300000Å in diameter

and utilizes 1/5 of the voltage used in the Gallium extraction system, divergence was expect. However, with certainty measures from the Gallium simulation, it is believed that the iEPS Laplacian potential is being characterized acceptably.

Utilizing results for the electric potential within the extraction region, the time-dependent space charge of the plume will be preliminarily modeled as a conventional particle beam. The paraxial ray model is being explored for future work. Direct numerical simulation of particle motion is feasible with knowledge of the forces induced by the potential field, but the time-dependent space charge must be considered for the final goal of defining particle trajectories.

Reference

[1] J. W. Ward, and R. L. Seliger. Trajectory calculations of the extraction region of a liquid -metal ion source, Journal of Vacuum Science & Technology, vol. 19(4), 1082-1086 (1981).

Figures used in the abstract

Figure 1: Construction of Gallium extraction system studied by Ward and Seliger.

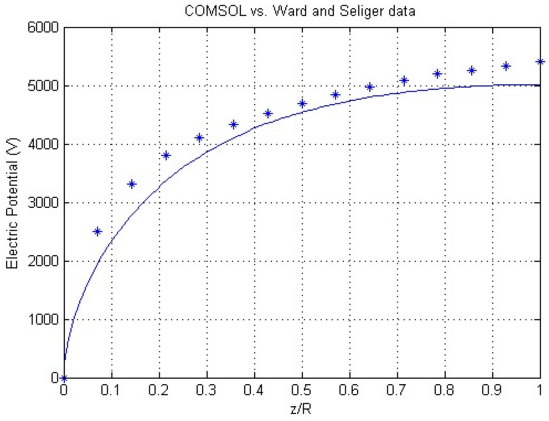

Figure 2: Laplacian potential plotted along a normalized axial displacement; COMSOL software solutions (line) and solution by Herrmannsfeldt (asterisks).

Figure 3

Figure 4