Modeling of Electric Field and Ion Trajectories Inside a Micro-Satellite Electrospray Thruster

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Motivation

The recent trend in satellite design has tended towards smaller, lighter, lower cost designs. Thus, there exists a need for low mass, low volume propulsion systems that can produce high ΔV. The electrospray thrusters in development at the Space Propulsion Laboratory (SPL) are amongst the first of their kind to fulfill this need [1]. Figure 1 shows a schematic of the SPL's thruster. With current technology, the ion trajectories inside the electrospray thrusters are not well understood leading to spatial non-uniformity in the release of ions across the emitter [2]. Current thruster designs incur spatial non-uniformity in the release of ions due to non-optimised tip geometry [3]. This project will solve the forward problem: given a specific tip geometry and an assumed release point distribution, what is the trajectory that an ion will take?

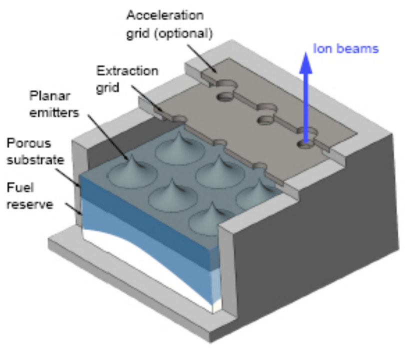

Figure 1: Schematic of the electrospray thruster.

Problem Formulation

This problem can be modeled as a network. The nodes will be produced through a discretization of the space in a 2D cross section of the emitter domain. The inputs to the system will be the electric potential between the emitter tip and extractor grid as well as the ion release point distribution. The outputs will be the potential field inside the thruster domain and the trajectory of the ions. The potential field can be solved using a conservation relation which is simply Laplace's equation: $\nabla^2\phi = 0$ where ϕ is the electric potential. The trajectories of the ions can be solved for using a constitutive relation: $m_i\vec{a} = q\vec{E} = -q_i\vec{\nabla}\phi$ where m_i is the mass of an ion, $\vec{a}$ is the acceleration vector, q_i is the charge of an ion, and $\vec{E}$ is the local electric field. The interactions between ions will be ignored as the magnitude of the effect is negligible when compared to the effect of the extraction grid.

Numerical Techniques

The potential field in the domain was solved using an *LU* algorithm. The *LU* algorithm was chosen due to the matrix being banded allowing the *LU* algorithm to have $O(N^2)$ computational complexity. Iterative algorithms such as GCR were attempted but did not provide any computational boost as the eigenvalues for the matrix had no significant clustering. For each timestep the ion position was calculated using the trapezoidal rule and the change in velocity was calculated with Forward Euler. The changes in velocity showed limited aliasing, indicating that the use of Forward Euler had a very limited impact on accuracy since the local electric field was calculated with a closest-node approximation and governed by the spatial discretization. Adaptive time-stepping was utilized to control the distance traveled per step.

Results

Figure 2 shows the trajectory of an ion that was released at an ideal release point (near the tip) and the trajectory of an ion that was released at a non-ideal release point (away from the tip), simulating the effects of manufacturing surface defects. In the ideal case the ion is able to leave the thruster and produce thrust while in the non-ideal case the ion hits the extractor grid and does not produce thrust. Such a tip design that includes both release points in its statistical distribution among all tips in a thruster would yield decreased thrust efficiency. This tool allows for rapid evaluation of the performance of a given tip geometry. If the tip design can be fully parameterized, this tool can aid in optimizing the tip geometry to solve the inverse problem and maximize output thrust.

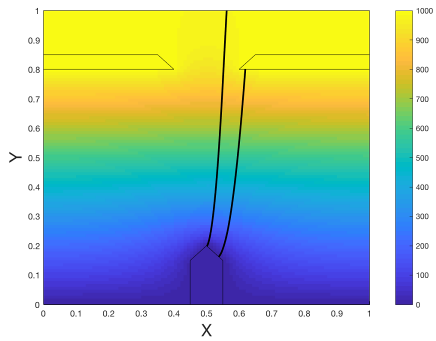

Figure 2: Ion trajectory for ideal release point.

[1] Lozano, P., *Personal Communication*, Sep. 2017.

[2] Guerra-Garica, C., Krejci, D., and Lozano, P., "Spatial uniformity of the current emitted by an array of passively fed electrospray porous emitters," *Journal of Physics D: Applied Physics*, Vol. 49, No. 11.

[3] Krejci, D., Mier-Hicks, F., Thomas, R., Haag, T., and Lozano, P., "Emission Characteristics of Passively Fed Electrospray Microthrusters with Propellant Reservoirs," *Journal of Spacecraft and Rockets*, Vol. 54, No. 2, 2017, pp. 447–458.