Simulating a 5 kW Class Hall Thruster
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Introduction

• A 5 kW class Hall effect thruster has undergone extensive ground testing, but there are currently no corresponding thruster simulations available in the literature.
• Extrapolating upon available limited thruster geometric properties and magnetic field profiles, a preliminary thruster model is created using HPHall.
• HPHall is a hybrid PIC code that models highly mobile electrons as a quasi-1D fluid and heavier species using a particle-in-cell (PIC) method. [2]

Simulation Preprocessing: Magnetic Field

• Using radial magnetic field data taken at the thruster discharge channel centerline, inner diameter, and outer diameter, a magnetic field configuration complying to the following assumptions is generated:
  • Magnetic field variations due to plasma currents and changing electric fields are small compared to the field produced by the electromagnet. [2]
  • The magnetic field is purely solenoidal \( \mathbf{B} \times \mathbf{r} = 0 \). Therefore, a magnetic potential function, \( \phi \), exists, and Laplace’s equation must be satisfied in the plasma region.
  \[ \nabla^2 \phi = 0 \]
  • A magnetic stream function, \( \lambda \), whose gradient is everywhere orthogonal to \( \mathbf{B} \), can be defined.
  \[ \frac{\partial \phi}{\partial r} = -\frac{\partial \lambda}{\partial z} \quad \text{and} \quad \frac{\partial \phi}{\partial z} = \frac{\partial \lambda}{\partial r} \]
  • Once \( \phi \) is known, the magnetic field can be calculated. In this case, a field is created to satisfy available experimental data. However, because the exact magnet locations are not known, the simulated magnetic field topology will differ somewhat from the experimental field.

Simulation Setup

Parameters:
• Thruster run-time: 1ms start up, 4ms on with plasma physics
• Ion & neutral particle step size: \( 5 \times 10^{-8} \) s
• Electron step size: \( 1 \times 10^{-11} \) s
• Background pressure and discharge voltage: experimental inputs

Results

• 20+ cases were simulated, mainly altering the electron mobility coefficients from one case to the next. The results shown here are those for which the highest average thrust was achieved.
• Avg Thrust: 75.61%; Avg Discharge Current: 92.7% achieved; Avg Ion Current: 110.0% achieved

Discussion

• The electron temperature contour exhibits unexpected curvature outside of the channel, indicating that the domain may not be large enough to capture the flow field properties.
• The plasma potential decreases to zero in the near field thruster plume, which is not realistic.
• Since the axial ion velocity is still increasing at the edge of the domain, it is likely that the acceleration region has not been fully simulated.
• The magnetic field lines extend past the thruster walls (Fig. 2), indicating that the upper magnet location requires modification.

Conclusion

• Qualitatively, simulation results agree with experimentally observed behavior.
• Macroscopic quantities including thrust, discharge current, and ion current do not yet agree with expected measured properties.
• Discrepancies in the model may be due to the following:
  • Results are sensitive to the magnetic field topology. [3] The simulation uses a mathematically possible magnetic field topology that has not been compared to the entire experimental field.
  • The simulation domain may not be large enough to capture thrust occurring outside the thruster channel.

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References