Plasma Lensing in a Magnetically Shielded Hall Thruster

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The erosion of ceramic channel insulators in Hall thrusters has been the most dominant cause of end-of-life since the first Hall thrusters first flew in 1971 [1]. As early as the 1960's, during the conceptual development and initial laboratory testing, erosion was identified as a potential failure mode. To combat this, the magnetic field lines were designed to be convex towards the anode direction with increasing strength towards the wall [2]. As the curved magnetic field lines are the equipotential surfaces in the plasma, the ions are focused towards the peak electron density at the center of the channel. This was effective in reducing the erosion in laboratory models and focused off axis electrons away from the walls and reducing the thermal loading. Magnetic geometries similar to this were used in production thrusters for 40 years before the advent of magnetic shielding.

Magnetic shielding is an extension of this concept where the field lines are tangential to the insulator at the front of the thruster, and push the potential peak further outside the channel. First published Mikellides et al., 2010, the concept of magnetic shielding was discovered after a 10,000 hour test of a BPT-4000 thruster effectively stopped eroding after 6,000 hours of operation [3]. The erosion was found to be tangential to the field lines along the outer boron nitride rings, and when stopped, was the first extended lifetime test with no measurable erosion. Since this test, magnetic shielding of Hall thrusters has been demonstrated to drastically reduce the rate of erosion on the boron-nitride insulator to less than 1/1000th of its unshielded counterpart [4][5]. The degree of this reduction is sufficient to remove erosion as the primary cause of end-of-life. However, the switch to a magnetically shielded configuration significantly increases plume divergence contributing to a decrease in thrust. JPL tests on a magnetically shielded thruster showed decreases in thrust due to plume divergence was 9.6%, while the efficiency due to mass utilization, plume divergence, and multiply charged ions decreased by 8.5% [5].

To investigate methods to mitigate the increase in plume divergence, a magnetically shielded hall thruster has been built by the SPACE Lab (Space Propulsion and Advanced Concepts Engineering Lab) at the University of Washington. The thruster nominally operates at 100 W on Krypton and has a standard annular geometry. Accepted scaling laws do not give good performance for unshielded annular thrusters in this power range due to the increase of the wall area to channel volume ratio [6]. The associated losses normally would dictate a move to a cylindrical thruster geometry, however with the addition of magnetic shielding the wall losses are significantly decreased.

The mitigation of plume divergence losses was one of the 3 key aims of plasma lensing in unshielded thrusters [7]. Along with the previously discussed magnetic insulation of the ions from the wall, and the increase of ionization efficiency due to the magnetic mirroring of trapped electrons, plasma lensing developed into a method to focus the ion beam. The focus of the plume to a preferably distant point along the thruster center-line decreased plume divergence, increasing thruster efficiency. The implementation of adjustable plasma lensing on this thruster is a variable inset central pole. Changing the inset of the central pole changes the angle of the magnetic field and the location of the peak field. The current in the inner and outer magnetic coils are used to balance the strength and magnitude of the field with the new separation. FEMM simulations of the field changes at the extremes of inset are shown in figure 1.

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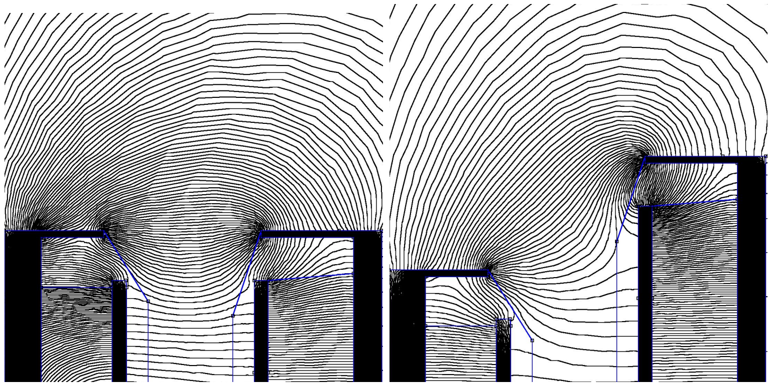

Fig. 1 UPDATED VERSIONS COMING a) Simulated Magnetic field with no inset of the central pole (Axis of rotation off left side of image) b) Simulated Magnetic field with maximum inset of the central pole.

The thruster design is complete and the first model is currently beginning manufacture at the University of Washington. Due to the magnetically shielded geometry, boron-nitride is no longer required as the insulation due to less stringent requirements for wear rate. The standard setup for the thruster will utilize graphite walls, although these are easily interchangeable for materials testing further into the thruster test life. Additional modularity of the design allows for interchange between different center mounted cathodes including the novel cathode currently under development at SPACE Lab. A CAD drawing of the thruster without pole inset and with the maximum value of the inset are shown in figure 2.

Upon completion of the thruster it will undergo testing to characterize the magnetic field and compare it to simulations completed using FEMM. Over a range of center pole insets, the thruster performance will be characterized. Thrust measurements will be taken using an inverted pendulum thrust stand capable of a wide range of steady thrust measurement from 100μN - 100 mN in the SPACE Lab Space Test Facility (STF) [8]. The plume divergence half angle and 90% angle will be determined with a fast Faraday probe array taking both time resolved and swept measurements. The Faraday probe array can also be used to characterize spatially resolved instabilities during thruster operation. Finally the thruster will be optimized for performance and plume divergence and these configurations will be compared across a range of throttling from both propellant flow rate and discharge voltage.

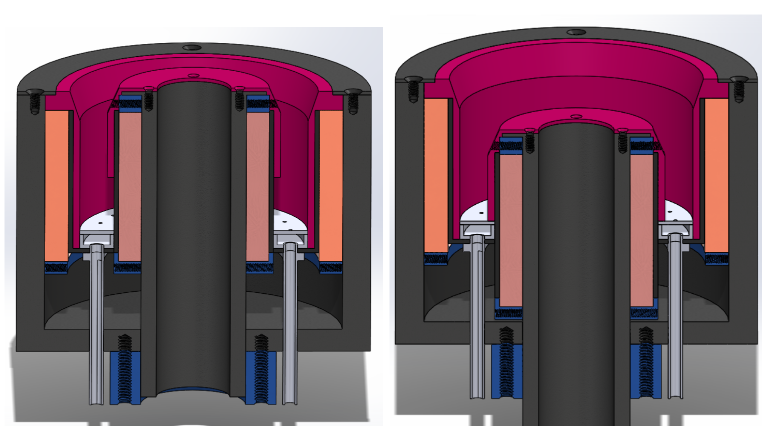

Fig. 2 UPDATED VERSIONS COMING FOR ALL IMAGES ON THIS PAPER a) CAD of the thruster with no inset of the central pole. b) CAD of the thruster with maximum inset of the central pole.

Alternate Titles

Plume Divergence Minimization in the Krypton Viper Magnetically Shielded Hall Thruster
Plasma Lensing in a Magnetically Shielded Hall Thruster

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