SCALING OF A MINIATURIZED CYLINDRICAL HALL THRUSTER

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ABSTRACT

Electric propulsion provides a significantly higher specific impulse that allows mass reduction for spacecraft when used in lieu of chemical propulsion. For micro and nano satellite applications, plasma thrusters should not only be miniaturized in mass and volume, but also capable of operating efficiently at very low power levels of a few watts or less. Research was conducted to determine theoretical limits and practical restrictions on materials and electrodes for miniaturization of cylindrical Hall thrusters (CHT) [1,2]. Analysis of the scaling relationships for plasma properties and thruster performance were derived and the thruster design, including the magnetic circuit, will be presented.

HALL THRUSTERS

The Hall thruster (Figs. 1, 2) is a spacecraft propulsion device that generates thrust by electrostatically accelerating ions in a quasi-neutral plasma. Neutral gas, typically xenon, enters near an anode while electrons are emitted from a cathode. Plasma discharge is sustained by a radial magnetic field and axial electric field that create a closed E x B drift allowing trapped electrons to effectively ionize the neutral gas [5].

SCALEING

The following data was selected from the PPPL 1.5cm pmCHT operating data for scaling initial conditions [7,8].

- Thruster: 1.5cm CHT with permanent magnets.
- Discharge voltage, \( V = 3kV \)
- Discharge current, \( I = 0.2A \)
- Power, \( P = 7W \)
- Channel length, \( L = 15cm \)
- Channel Radius, \( R = 0.7cm \)
- Electric field, \( E = 16kV/cm \)

Using the scaling similarity for electron anode loss and accelerated ion loss, \( \eta_e \eta_i \sim \eta_i \eta_e \), the magnetic field scaling can be derived [10].

MAGNETIC FIELD

The following general scaling relationships can be derived to relate the thruster geometry and plasma characteristics to a common scaling factor [3,9].

Assume constant \( T_e \), \( T_i \), \( n_e \), and \( n_i \).

Mean free path
\[
\lambda = \frac{1}{n_e} \frac{\sqrt{2}}{\pi} \frac{T_i}{m_i} \frac{1}{\sqrt{T_e}}
\]

Electron Density
\[
n_e = \frac{1}{V} \frac{1}{\lambda}
\]

Ionization frequency
\[
\nu_i = \frac{1}{\lambda} \frac{1}{\tau_i}
\]

Total + collision frequency
\[
\nu_{tn} = \frac{1}{\lambda} \left( \frac{1}{\tau_i} + \frac{1}{\tau_n} \right)
\]

Electric Field
\[
E = \frac{V}{L}
\]

Current Density
\[
J = \frac{I}{A}
\]

Power
\[
P = IV = \frac{IV}{L} \frac{L}{1} \frac{1}{\lambda}
\]

Magnetic field (Linear method)
\[
r_m = \frac{1}{\lambda} \frac{L}{B} \frac{B}{1} \frac{1}{\lambda}
\]

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Magnetic field (Anomalous mobility)
\[
\eta_m = \eta_i \eta_e \eta_i \eta_e \sim \eta_i \eta_e \eta_i \eta_e
\]

SIMULATION

A magnetic circuit was modeled consisting of an Alnico5 rare-earth permanent magnet ring and MIL-N-14414C “μmetal” housing. For the scaled channel length of 2 mm and radius of 1 mm, the magnetic field at the exit plane was 1.6kGauss. The permanent magnet was 2 mm in length, 0.2 mm thick, with 1.2 mm inner radius.

REFERENCES

3. V. Khayms, Design of a Miniatuerized Hall Thruster for Microsatellites, MIT (1997).