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Performance Modeling of a Thrust Vectoring Device for Hall Effect Thrusters

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The ability to control the thrust vector direction on electric propulsion devices opens new possibilities for mission optimization. The addition of an external magnetic steering system and the nonsymmetric localized injection of propellant have been proposed to deviate the ion beam of a PPS®1350 Hall effect thruster. A two-dimensional hybrid model has been used to evaluate the preliminary design. Simulated results suggest the ion beam angular distributions may be varied in the range of 10 deg by changing the current in the external steering coils. However, a magnetic topography with field lines directly connected from the outer steering pole to the anode leads to a reduction of the Hall effect thruster performance. The erosion of the walls increases drastically as a function of the magnetic lens orientation (6 mm for 1000 h of thruster operation for high coil currents in the external coils). A localized axial injection of atoms has a positive effect on the steering angle of the ion beam (a few degrees), but exhibits additional erosion of approximately 10–15%. Qualitative comparisons with experimental results confirm the simulated trends.

Nomenclature

$B_{o,x}$, $B_{o,r}$ = axial, radial components of the magnetic field in the centerline in the exhaust plane
D = position of the injector
E = ion energy
$E_\perp$ = electric field component perpendicular to the magnetic field
E_{th} = sputtering energy threshold
e = electron charge constant
g = constant gravity on Earth
I_d, I_i = discharge, ion current
I_{ion} = ion beam divergence
I_{sp} = specific impulse
J_{in}, J_{out}, J_{back} = internal, external, back coil current density
L = channel length
$\dot{m}$ = xenon anode mass flow
m_i = ion mass
m_w = mean mass of the wall material
n = plasma density
P = fraction of neutrals released into the channel through the ceramic wall
P_w = injected power
R = erosion rate
T = thrust
V_d = discharge voltage
v = ion mean velocity
Y = sputtering yield
α = angle between the axial axis and the ion velocity
$\alpha_{\dot{m}}$ = mean angle of the ion beam divergence
β = magnetic field line orientation
Γ_i, $\Gamma_{i,\perp}$, $\Gamma_{e,\perp}$ = ion flux, ion, electron cross-magnetic field flux
ε = electron mean energy
η, η_u, η_c, η_E = thruster anode, propellant, current, beam energy efficiency
$\mu_\perp$ = cross-magnetic field electron mobility
ρ_w = mass density of the wall material
ϕ = azimuthal direction
χ = number of times the current crosses the magnetic field lines
$\nabla_\perp$ = cross-magnetic field gradient

I. Introduction

HALL effect thrusters (HETs) are suitable for satellite station-keeping onboard commercial satellites and for orbit transfers of space exploration probes. Control of the thrust vector direction can be advantageous to optimize mission performance during orbital maneuvers and to overcome the displacement of the center of gravity during the mission [1]. Variation in the location of the center of gravity is mainly induced by propellant consumption and thermal deformation. A summary of thrust steering device (TSD) requirements has been detailed in [2]. Gimbal mechanisms have been proposed to change the orientation of the thruster during the HET lifetime [3]. Nevertheless, the integration of mechanical systems generates penalties (weight, complexity, integration, and test). Recent attempts to replace existing mechanisms with electrostatic or electromagnetic systems may simplify the integration and testing, and possibly decrease cost and weight as well.

In an HET, an arrangement of magnetic or electromagnetic coils leads to the establishment of a magnetic field used to confine the electrons, which allows the ionization of neutral flux by high-energy electrons. In conventional HETs, such as the PPS®1350, magnetic field lines are approximately equipotential because the electron

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