Paper ID: 18299
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SPACE PROPULSION SYMPOSIUM (C4)
Electric Propulsion (4)

Author: Mr. Mario Merino
Universidad Politécnica de Madrid, Spain

MAGNETIC NOZZLE OPTIMIZATION FOR PLASMA SPACE PROPULSION

Abstract

High-specific-impulse plasma thrusters are opening the way to efficient interplanetary travel, economic station-keeping of Earth-orbit satellites, and ambitious space missions. Nevertheless, the erosion and damage of thruster materials in contact with the energetic plasma jet is a major drawback for their widespread use, as this is usually the limiting factor for the thruster durability.

A convergent-divergent magnetic field can be used to confine and harness the hot plasma of these engines in a contactless manner thanks to long-distance magnetic forces, keeping it away from sensitive surfaces and accelerating it into a high-velocity, well-collimated plume. Such a "magnetic nozzle"' (MN) essentially converts the internal energy of the propellant into directed kinetic energy, thereby producing thrust. Illustrative examples of next-generation thrusters with MNs are the Helicon thruster, the applied-field MPD thruster, and the Variable Specific Impulse Magnetoplasma rocket (VASIMIR).

One of the challenges of MNs is the tendency of the plasma to remain attached to strong magnetic fields beyond the acceleration region, and thus return along their lines back towards the thruster, ruining thrust efficiency and endangering sensitive surfaces on the spacecraft. Based on a two-dimensional, two-fluid MN/plasma model and careful numerical simulations thereof, we show that ion demagnetization in medium-strength MNs leads to efficient plasma detachment and to the formation of a free plasma plume. The requirement of sufficiently-strong magnetic fields to properly confine and channel the plasma in the accelerating region is in conflict with the requirement of efficient detachment, and a trade-off optimization analysis becomes necessary to maximize the efficiency of the device, and minimize the amount of coming-back plasma that remains attached to the field.

In this contribution we focus on the optimization, for different plasma conditions at the plasma source, of (1) the shape of the MN, (2) the strength of the magnetic field, and (3) the use of different propellants. Additional insight is sought by analyzing the physics of acceleration and detachment. An interesting aspect of MNs is the possibility of fine-tuning the geometry and intensity of the field in-flight to enable continuous thrust and specific impulse control during the mission. Finally, we analyze candidate applications of MNs, based on their propulsive requirements.