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MULTISCALE MODELLING OF ALTERNATIVE PROPELLANTS IN MAGNETICALLY ENHANCED PLASMA THRUSTERS

Abstract

In recent years, the increasing demand for simple and low-cost propulsion for small satellites has given rise to a growing interest in low-power magnetically enhanced plasma thrusters (MEPT). Plasma is produced within a source tube using radiofrequency (RF) ionisation, enhanced by a magnetic field which also accelerates the discharge via the magnetic nozzle effect. A key advantage of MEPTs is that they can operate on a wider range of propellants, more easily stored, and often inexpensive (e.g., iodine) compared to traditional xenon. The REGULUS family of MEPTs—which includes 50, 150 and 500 W systems—has been in development since 2015 at T4i SpA. The first in-orbit demonstration was performed in Q1 2021.

Despite simple hardware, plasma dynamics in an MEPT are highly-complex. Accurate numerical models for design and optimisation are therefore essential. Due to the vast range of collisional and physical length scales between the source tube and plume regions, a multiscale approach is required. This work presents a multiscale numerical suite developed for MEPT design and analysis. First, a 0D Global Model offers rapid preliminary estimation of thruster performance. Then, for detailed design, an electromagnetic wave-fluid model considers the RF power deposition and plasma production within the source tube. A fully kinetic Particle-in-Cell model handles plasma expansion in the magnetic nozzle. The fluid and kinetic models are unified under one common framework, providing a tool for adaptive fluid-kinetic coupling in thruster simulations. To this end, the heavy species drift-diffusion approximation in the fluid model has been replaced with the full momentum and energy equations.

The capabilities of the suite are presented by-way-of investigation into the behaviour of alternative propellants iodine and krypton. In particular, modelling iodine plasma considers challenging additional chemistry and collision types due to atomic and molecular ion formation. The suite has been proven to give accurate insight on spacecraft surface-plume interactions (for system integration purposes), source tube erosion (thruster lifetime), and minimisation of iodine contamination. The effect of each species on thermal energy conversion and detachment in the magnetic nozzle is also discussed. The results are then benchmarked against experimental measurements of REGULUS. The multiscale numerical suite is shown to be a powerful tool in MEPT design, applicable also to Helicon, Electron Cyclotron Resonance (ECR) and RF-ion thrusters. For specific missions, it allows optimal propellant choices to be made without expensive experimental campaigns, the capability to scale thruster size/power, and simulate integration of clustered systems.