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Time-Resolved 3D Characterization of the Plume of a Low-Power Ablative Pulsed Plasma Thruster

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Abstract

Ablative Pulsed plasma thrusters (APPT) are transient electromagnetic space propulsion systems. Their operation consists in the surface flashover of a solid propellant, placed at the beginning of the thruster discharge channel. The plasma accelerates down this channel up to its ejection thanks to the Lorentz force, as a result of the interaction between the generated cross current and the self-induced magnetic field.[1] In contrast to other plasma thrusters, this technology is suitable for low power operation and miniaturization; which constitutes an opportunity for nanosatellites to have on-board propulsion. Since the 60s, multiple research groups have been working worldwide on systematic studies of PPTs; however, the efforts to describe the discharge physical mechanisms in detail have been so far limited.[2,3,4,5] Hence, many challenges still prevail concerning the understanding of the APPT underlying physics and the influence of design parameters on the plasma generation and acceleration, as well as the processes defining the thruster performance and durability. As part of the regional MARTINLARA project, a complete engineering model of a low power APPT is being developed with the eventual goal of embarking it in a CubeSat platform for validation, among other payloads. Along 2021, some breadboard models based on a parallel rail channel configuration have been already operated successfully in a vacuum chamber environment -see Fig. 1.[6,7]

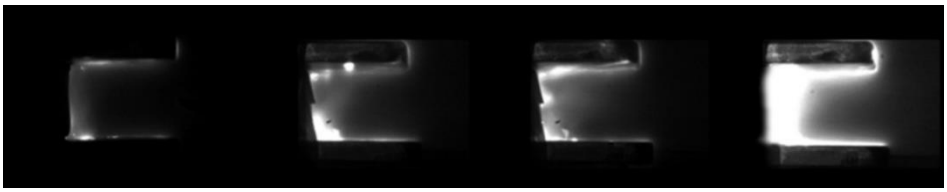

Fig. 1. Reconstruction of a representative APPT discharge sequence using the breadboard model 1 (May, 2021).

The goal of this study is to assert the influence of a series of geometrical and operational factors on the APPT electric discharge characteristics and plasma plume properties with dedicated diagnostics, as well as, to compare this with existing results of similar devices. These parameters are the electrode geometry, propellant exposed area and material, energy per pulse, initial discharge voltage and thruster ageing. To this end, an experimental test campaign is carried out on the prototype varying the electrode dimensions (length, width, and convergence angle) and separation distance, the initial discharge voltage, and the total capacitance of the capacitor bank. The electric parameters of the discharge (voltage and direct current measurements) are sampled at high rate (100 MHz), allowing the analysis of the different discharge phases. An ad-hoc diagnostic was developed for this work; a set of metallic grids placed inside the plume at chosen distances enables the characterization of the spatial and temporal distribution of ion current density and floating potential. A single grid is composed of series of filaments in both the up-down direction and the left-right direction, allowing to explore the complete plume cross section. The independent recording of the properties above is allowed by the electrical insulation between each of the filaments of the grid.

This experimental campaign provides a rigorous time and space characterization of the dynamics of a low power APPT discharge under 5 J, though a parametric study around the design nominal point. These results represent a further step in the testing of this topology carried out along the past years, aimed preliminary to validate ignition, to ensure repeatability and to elucidate the discharge basis, and to address the velocity distribution of the exhaust plasma and the plume divergence.[7,8] To conclude, this analysis has been developed with the main objective of achieving a better understanding of the involved physics and, ultimately, an optimization of the prototype. In addition, these experimental data are necessary for validating a plasma simulation model currently being developed in the frame of this research line.

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