Development of a Stable and Efficient Electron Cyclotron Resonance Thruster with Magnetic Nozzle

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Résumé :

Plasma thrusters are the subject of growing interest as a means for small satellite propulsion. Miniaturizations of mature technologies as well as innovative concepts have been proposed such as the electron-cyclotron resonance thruster with magnetic nozzle (ECRT). This thruster appears as a potentially disruptive technology because it is gridless, neutralizerless, and only requires one power supply. This work consists in the development of an ECRT with magnetic nozzle and its accompanying experimental test bench, able to accurately demonstrate high thruster efficiency during prolonged steady state operation. Previous studies on the ECRT were limited by a significant lack of accuracy on key measurements, due to the specific setup and technology needed for this thruster. The experimental procedure and the setup are thus heavily upgraded to improve the accuracy of experimental data. However, peculiarities of the magnetic nozzle complicate the interpretation of the ion current density measurements, thus our analysis of performance is mainly based on thrust balance measurements. Besides, thruster performance is shown to significantly increase when decreasing vacuum tank pressure down to 10^{-7} mbar Xenon, and facility effects are investigated by testing the thruster both at ONERA (France) and at JLU (Germany). Well aware of these experimental difficulties, we study the efficiency of the thruster as a function of neutral gas injection, magnetic field topology, and boundary conditions of the magnetic nozzle. In addition, we address erosion issues in two ways: first by a change of materials, and second by a change of coupling structure (coaxial, or circular waveguide). Waveguide coupling yields insufficient ion energies for space propulsion requirements but manufacturing the coaxial coupling structure with graphite appears to substantially mitigate erosion. These results enable to design and test a ~ 30 W and a ~ 200 W thruster consistently yielding state-of-the-art efficiencies as compared to other thruster types while having sufficient estimated lifetime. In order to shed light on the experimental outcomes, a new modelling approach is developed based on the study of electron trajectories and a Fokker-Planck heating model calculating the formation of the electron energy distribution function in the thruster.

Mots clés : plasma thruster, electron-cyclotron resonance, magnetic nozzle, satellite micro-propulsion

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Composition du jury :

Directeur de thèse :	Jean-Marcel Rax, Ecole Polytechnique, Palaiseau
Encadrant :	Denis Packan, ONERA, Palaiseau
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