Dissertation Abstract

Title: Investigation of Performance and Plasma Dynamics of the Pulsed Plasma Thruster ADD SIMP-LEX (パルス型プラズマスラスタ「ADD SIMP-LEX」の性能とプラズマ力学に関する研究)

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With an increasing number of satellites being launched into space, the demand for cheaper, but highly efficient propulsion systems, is growing. This is particularly motivated by economic reasons as both budget to be invested to implement and develop a certain system and its corresponding lifetime are major drivers for relevant industries.

Within the Stuttgart Small Satellite Program, several electric propulsion systems are being developed and investigated to serve for technology demonstration and for application as main propulsion on-board small satellite missions. One of these developments is a pulsed magnetoplasmadynamic thruster (PPT). The PPT engineering model ADD SIMP-LEX was previously set up and optimized at the Institute of Space Systems (IRS) of the University of Stuttgart, Germany, and this dissertation continues that research.

Chapter 1 includes a review of pulsed plasma thrusters that shows a strong dependency of the thrust efficiency on discharge voltage and capacitance. The effects, however, seem to be ubiquitous for all different thruster designs including variations in, for example, propellant or electrode geometry. Understanding the physical phenomena that lead to these dependencies can yield valuable information for further development of such pulsed plasma thrusters with special regard towards the satellite mission that is envisaged. This work proposes an explanation of the phenomenon.

In Chapter 2, the thrust performance was investigated as a function of voltage and capacitance in order to verify the dependency for the pulsed plasma thruster used within this study. Therefore, both electric and mechanical values were measured. The results show a significant gain in performance with an increase of capacitance and an exponential rise for higher voltages.

The plasma front velocity was seen as being crucial in thrust creation. That is, in Chapter 3, optical and magnetic diagnostics were applied to study this value for the different energy levels of the thruster. The applied techniques showed a good quantitative agreement. The results show a non-linear dependency on the discharge voltage with slightly higher values for a higher capacitance.

In Chapter 4, additional information about plasma composition, excitation temperature and electron density in the plume were derived by emission spectroscopy. The physical phenomena during the discharge were further studied by optical means. This showed that the electrothermal contribution to the thrust is suffering from a strong divergence, that the discharge arc changes its position for a variation in voltage and capacitance, and that the distribution of charged and neutral particles can be derived by their emission.

Within Chapter 5, the experimental data were implemented into a modified slug model in order to yield further information on the inefficiencies in the acceleration process. For that reason, the computation process and the fundamental equations were adapted and improved to reflect better the physics observed in experiment. The ratio of electromagnetically accelerated mass to the total ablated mass shot, and, hence, the balance between electrothermal and electromagnetic contribution to the overall impulse was derived from the computational results. Further, the propellant utilization efficiency for the different thruster configurations was computed. The results indicate a non-linear behavior for the fraction of charged mass, and significant changes in the acceleration processes for variation in energy. A limit in increase in thrust efficiency performance with a higher voltage was determined by means of these different values.

Chapter 6 presents a summary of the findings as well as recommendations for satellite applications and future pulsed plasma thruster developments based on the experimental and analytical data and additional information about performance and specifications of thruster systems existing.