STUDY AND DIAGNOSTICS OF THE EFFECT OF LENGTH VARIATION IN HALL THRUSTERS

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Abstract

Some preliminary results are described, concerning the behavior of a laboratory model Hall thruster when the channel length is varied. The effective channel length variation is accomplished by changing the position of the anode in the channel. Volt versus current characteristics and thrust were measured and analysed for two effective channel lengths. At relatively low propellant mass flow rate values a better thruster efficiency was obtained with the longer channel, while at a larger mass flow rate the efficiency was higher with the shorter channel. The difference in ionization probability between the two channels is suggested as the main cause of these observed results.

1. Introduction

As is well known, Hall thrusters have been a subject of intensive investigations in the former Soviet Union, where they were developed to achieve high performance, namely specific impulse in the range of 1000-3000s and efficiency larger than 50%, while retaining a relatively high thrust density (compared to ion thrusters). Flight models have an operating lifetime of a few thousand hours and tens of them have been flown and operated successfully on board satellites for more than two decades. Larger thrusters, operating at a power of up to 25kW are at various stages of development [1]. Nevertheless, the physical processes involved in the operation of this type of thrusters are not fully understood. These include near wall processes, current and voltage oscillations at various frequencies under some operating conditions, and additional aspects of the ionization and acceleration processes and the coupling between them. Better understanding of these issues is necessary in order to be able to properly scale Hall thrusters to work under various operating conditions, and could lead to improvements in their performance, and to reduced wall erosion and plume divergence.

In order to investigate the performance of Hall thrusters and study the physical processes, a laboratory model thruster [2] was constructed in the Propulsion Physics Laboratory. The design of this thruster is modular and flexible to allow changes in the geometry of the accelerating channel and the magnetic configuration. Some design considerations could be derived from the large literature published over the years about Hall thrusters. Since this thruster was conceived as a research tool and due to the modest size of our test facility, operation

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at sub-kilowatt level was preferred and, as a result, the channel diameter was chosen to be about 7cm [3-6] (in practice the diameter is 72mm). A magnetic circuit producing a field distribution which is minimal near the anode and achieves a maximum near the channel exit [1,3,6,7] was designed and optimized, using a finite-element magnetostatic software package [2]. Due to its modular construction, the magnetic circuit configuration can be easily changed by replacing parts with others of different dimensions, or using spacers to move the poles relative to the anode or to each others. In addition, the effective length of the channel can be modified by changing the position of the anode in the channel [2] (see Fig. 1).

The thruster operation experiments take place in the vacuum test facility at Soreq, consisting of a 1.2 x 2 meter vacuum chamber and a diffusion pump system, having a Xenon pumping speed of about 6000 liter/s [2]. A commercial gas mass flow control and measurement system is used to control and measure the propellant flow to the thruster. The main flow and the flow through the cathode can be varied independently. Separate regulated laboratory power supplies are used for the main discharge and for the magnet coils. Thrust is measured using a pendulum type thrust stand, which make use of a high sensitivity inclinometer as an angle detector. In a comprehensive set of calibration tests this thrust stand exhibited very good linearity, 0.5mN resolution, and about 1% reproducibility. The thermally induced shift of the thrust stand zero is less than 2mN after the first hour of thruster operation. The thrust stand and its calibration are described in more details in [2]. Additional diagnostics include
DC and AC voltage and current measurements and Langmuir probes for measuring plume properties. Optical and thermal measurement techniques are in development or under study.

Initially, thruster operation experiments were performed at a fixed thruster configuration, using Xenon as propellant [2]. The thruster was operated in a broad range of mass flow rate, discharge voltage and magnetic coils current values. Discharge current and thrust were measured at the various operating points, from which the discharge characteristics, specific impulse and efficiency were deduced. These measurements are described in details in [2]. The discharge characteristics were similar in nature to those of state-of-the-art Hall type thrusters [1]. Generally speaking, the thrust, specific impulse and efficiency were found to increase with the discharge voltage and/or the mass flow rate.

In the present paper we describe some results of measurements comparing the laboratory model Hall thruster operation with two different effective channel lengths, L=40mm and L=30mm, where the effective channel length is taken from the front of the anode to the channel exit. One aspect of thruster operation which can be affected by the variation of the channel length is the ionization efficiency. Due to the extended path the propellant atoms have to travel, their probability of being ionized in the longer channel can be expected to be higher. On the other hand, length dependent losses, such as ion losses to the walls, are expected to be smaller in the shorter channel. In the measurements done so far, the thruster was operated at three mass flow rate values and at various discharge voltages. The results of these measurements are summarized and discussed in section 2. The I-V characteristics obtained with the two channel lengths are compared in subsection 2.1, while a comparison of thrust, specific impulse and efficiency, is presented in subsection 2.2.

2. Measurements of thruster operation with two effective channel lengths

2.1 I-V characteristics

Fig. 2 compares between the I-V characteristics of the two channel length cases, for three values of the mass flow rate, 1.2, 1.7 and 2.4mg/s. Each point in this figure represents the measured minimum discharge current versus the coils current, at the specified discharge voltage and mass flow rate. As can be seen, at low mass flow rates the discharge current is larger for the longer channel, while at the larger mass flow rate the discharge current is larger for the shorter channel. A possible explanation for this behavior is as follows. At large mass flow rates the ionization efficiency is high with both channel lengths. The thruster resistance is then determined by the length of the channel. As the mass flow rate is reduced, the ionization efficiency of the shorter channel drops, while that of the longer channel remains relatively high, resulting in a larger ion (and electron) flux.
Figure 2: I-V characteristics, obtained with two effective channel lengths, L=30mm and L=40mm, at three values of the mass flow rate, 1.2, 1.7 and 2.4mg/s.

2.2 Thrust, specific impulse and efficiency

If, as suggested above, a better ionization efficiency is obtained at low mass flow rates with the longer channel, then one could expect to see at these mass flow rates a relative improvement in thruster performance with the longer channel compared to the shorter one. This type of behavior is demonstrated in Figs. 3-5. Fig. 3 compares between measured thrust values versus discharge voltage, obtained with the two effective channel lengths, L=40mm and L=30mm, for the three values of the mass flow rate, 1.2, 1.7 and 2.4mg/s. Figs. 4 and 5 compare between the corresponding specific impulses and efficiencies. As can be seen, at 1.2mg/s the thrust, specific impulse and efficiency obtained with the longer channel are higher for all discharge voltage values. The same result holds for 1.7mg/s, although the differences are somewhat smaller, while for 2.4mg/s a better performance is obtained with the shorter channel for most discharge voltage values. At the large mass flow rate, the ionization efficiency can be expected to be high for both channel lengths. The lower thruster efficiency with the longer channel at the large mass flow rate could well be a result of increased wall losses, or any other length dependent loss mechanism which we cannot as yet identify. The possibility of this behavior being a result of increased secondary ionization in the longer channel, although not excluded, is not supported by the measured I-V characteristics (see Fig. 2).
Figure 3: Measured thrust, $T$, versus discharge voltage, obtained with the two effective channel lengths, $L=30\,\text{mm}$ and $L=40\,\text{mm}$, at three values of the mass flow rate, 1.2, 1.7 and 2.4 mg/s.

Figure 4: The specific impulse, $I_{sp}$, versus discharge voltage, obtained with the two effective channel lengths, $L=30\,\text{mm}$ and $L=40\,\text{mm}$, at three values of the mass flow rate, 1.2, 1.7 and 2.4 mg/s.
Figure 5: Thruster efficiency, $\eta$, versus discharge voltage, obtained with the two effective channel lengths, $L=30\text{mm}$ and $L=40\text{mm}$, at three values of the mass flow rate, 1.2, 1.7 and 2.4mg/s.

4. Conclusions

In this paper some measurements of Hall thruster operation at various conditions, with two different channel lengths, were presented. The effective channel length of the laboratory model thruster, constructed at Soreq, is varied by changing the position of the anode in the channel. It was found that the channel length variation affected both the I-V characteristics and the thruster performance. At low mass flow rates, higher thrust, specific impulse and efficiency were obtained with the longer channel, while at a larger mass flow rate a better performance was obtained with the shorter channel. Differences in ionization efficiency and length dependent losses, between the two channel lengths, were suggested as possible causes of these results. Nevertheless, more measurements, under additional variations of channel geometry and at additional operating conditions, are needed in order to substantiate these results and conclusions, while theoretical modelling will be useful in examining the relations between the physical processes and the resulting thruster performance and electrical behavior under such variations. In any case, the above results raise the possibility of optimizing the performance of Hall thrusters of a given diameter to operate at different operating conditions by modifying the channel length.

Other aspects of Hall thrusters operation could in principle be affected too by a channel length variation. An example is the thruster stability and its relation to discharge oscillations.
As is well known, the purpose of the magnetic field in Hall thrusters is to impede the flow of electrons towards the anode. Typically, the increase of the magnetic field strength causes a decrease in the axial electron current and hence the total discharge current. However, above a certain point an increase in the discharge current is observed, which is accompanied by strong voltage and current oscillations [1,2]. Assuming that these oscillations are dominated by the so-called “transit ionization oscillations” [8], which are excited when the axial electron current is too low to sustain a steady-state rate of ionization, it is possible that a steady-state ionization could be sustained at a lower axial electron current (stronger magnetic field) in the longer channel due to the higher ionization probability and, as a result, thruster operation will be more stale in this case. This issue is currently being investigated.

References


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