THE PROBLEM OF POWER PROCESSING AND TELEMETRY CONTROL UNIT DESIGN FOR STATIONARY PLASMA THRUSTER

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Abstract

The results of an investigation of optimal power processing and control unit structures and parameters are presented. The criterion selected for the optimization were minimum discharge current and voltage oscillations. The influence of electromagnet current to the character and amplitude of discharge current and discharge voltage oscillations of the SPT-100 thruster were obtained. The electromagnet was connected to a separate electromagnet power supply. The electromagnet current was independent from the discharge current. The optimal values of the electromagnet current for this structures and parameters of the power processing and control unit are obtained.

Introduction

The stationary plasma thruster (SPT) has a long history of successful flight application in the former Soviet Union and Russian space flight program. A 1.4 kilowatt variant, the SPT-100, is currently being considered for integration with US satellites. This thruster has been evaluated in Russia [1] and in the US [2], demonstrating 1600 seconds of specific impulse, at an efficiency of 0.5. The SPT-100 is presently being developed by consortium led by Space Systems / Loral (SS/L) for flight qualification [3]. As part of this qualification program, this thruster has undergone a cyclic lifetest at the NASA Jet Propulsion Laboratory [4]. Further, an extensive program is underway to evaluate integration issues [5].

A choice of the Power Processing and Control Unit (PPCU) structure and parameters for SPT is not a trivial problem. Here it is to take necessary into consideration the possibility of an electric propulsion thruster and PPCU interaction. The designers of the SPT usually have

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many problems connected with the high level of the discharge current and voltage oscillations. There are many articles [1, 2, 7 - 10] where such oscillations are described and some reasons for these oscillations are given. The results of an investigation of magnetic field characteristics, accelerating channel geometry and wall contamination influence upon thruster performance and oscillation intensity are presented in [8]. The influence the electromagnet current and discharge power supply output filter parameters to the discharge voltage and current oscillations are represented in [9]. Some classification of the oscillations in closed drift thrusters, such as the stationary plasma thruster and the anode layer thruster and some explanations for these oscillations are represented in [10].

As a rule, in these investigations the discharge power supply was a voltage regulated power supply connected to the thruster's anode and the electromagnet, setting up a magnet field in the accelerating channel that is proportional to the discharge current [1, 2]. That scheme of connection has an advantage of being more simple a structure of the PPCU as it gives us a possibility to exclude a separate power supply for the electromagnet. However, the including of the electromagnet in the discharge circuit causes the origin of feedback between the magnet field in the SPT acceleration channel and the parameters of the discharge. And such feedback is as a rule positive and causes considerable oscillations of the discharge current. The peak-to-peak amplitude of these oscillations usually reaches 100...200% from nominal value [1, 2]. The frequency of these oscillations depends on the discharge power supply output filter parameters, the parameters of electromagnet, the parameters of the discharge in the SPT accelerating channel and usually is the range of 25...50 kHz.

1. The main conditions of the investigation SPT-100 discharge current and voltage oscillation

The scheme of the interface SPT-100 and PPCU where the separated discharge power supply and the electromagnet power supply are used for the investigation the electromagnet current influence on the character and value of the discharge voltage and current oscillation. This scheme is shown in Figure 1. In the capacity as the electromagnet power supply was used the controlled supply of current with value of the controlled output current in the range 1...6 A.

In SPT-100 testing to date, several different power supplies have been used [1 - 6]. These include the unit which was developed at the "Fakel" Enterprise in Kalinigrad (Russia),
flight-type units developed by SS/L, a research unit developed at NASA LeRC, and simple laboratory DC power supplies with ballast resistor. In each instance, the voltage and current waveforms published for the main thruster discharge differ. A potential cause of these differences is the individual power supply controls and output filter topologies, which appear to significantly influence the operation of the thruster.

In the capacity as the discharge power supply was used the controlled laboratory discharge power supply which was as supply of voltage with the value of controlled output voltage with the value of controlled output voltage in the range 0...600 V DC. The simple RC output filter \( R = 12 \, \text{Ohm}, \, C = 2.2 \, \text{uF} \) was used between the output of this power supply and SPT-100 on the first stage of these investigations.

During these investigations RCLC-filter also was used between the discharge power supply output and SPT. The parameters of this filter \( R, \, C_1, \, L, \, C_2 \) can be changed separately. It was possibility to disconnect this filter from the discharge circuit.

2. The investigation of the electromagnet current influence to the discharge current and voltage oscillations

The electromagnet current was changed in the range 2.5...4.5 A DC during the investigation of the electromagnet current influence to the discharge current and voltage oscillations. The values of the peak-to-peak oscillations of the discharge current and discharge voltage were recorded. The data was obtained for different values of discharge voltage (250, 300, 350) V DC, different values of the mass flow rate (nominal, nom+10%, nom-10%) and different topology and parameters of the discharge power supply output filter.

The experimental investigations showed the strong a magnet current influence on the SPT-100 parameters including the value and character of the discharge current oscillations. The typical discharge current and voltage oscillations are shown in Fig. 2. In that case when the value of the electromagnet current \( I_m \) approximately is equal to the value of the discharge current \( I_d \) the considerable oscillations of the discharge current is observed. The level of the such oscillations reaches the value 150...200% from the nominal discharge current value. Such oscillations are shown in Fig. 2.a and they are corresponded to the oscillations for the case of the serial connection the electromagnet and the discharge circuit [1, 2, 7]. The character of these oscillations is changed as is shown in Fig. 2,b when the value of the electromagnet
current is decreased to the value 3.5...3.7 A DC. In this case the character of the discharge current oscillations such as described in [2]. The further decrease of the electromagnet current causes the step-form change of the both character and amplitude of the discharge current oscillations as is shown in Fig. 2.c. That change of the character and amplitude of discharge current oscillations was obtained for different levels of the discharge voltage $V_d=250...350$ V DC and different levels of the mass flow rate $+10...-10\%$ from value of the nominal level of the mass flow rate.

The dependence the discharge current total amplitude of oscillations $I_{p-p}$ from the magnet current value are shown in Fig. 3. This dependence was also obtained for different values of the discharge voltage $V_d$ and the mass flow rate $m$. As it is shown in Fig. 3 there is the some optimal level of the electromagnet current when the amplitude peak-to-peak of the discharge current oscillations is minimum. The change of the thruster’s operation conditions in particular the change of the discharge voltage and the mass flow rate doesn’t change of the obtained dependence character. Such change of the operation conditions causes only some displacement the range of the electromagnet current optimal values.

Conclusions

The experimental data which are obtained in this work and analysis of these results give us the possibility to do such conclusion:

- the optimal structure of the PPCU for SPT-100 mast have a separate power supply for electromagnet. the electromagnet current must not depend from the discharge current;

- the character and amplitude of the discharge current oscillations depend from the level of the electromagnet current;

- the optimal value of the electromagnet current exists and ensures the minimal level of the discharge current oscillations. this optimal point can be changed if the parameters of the thruster (the discharge voltage and current, the mass flow rate) will be changed;

- the discharge current oscillations in SPT-100 have two ranges: low-frequency (30...300) kHz and high-frequency (4...12) MHz, the increasing (decreasing) of the electromagnet current causes the decreasing (increasing) of the low-frequency oscillations amplitude and increasing (decreasing) of the high-frequency oscillations.
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References


Fig. 1 Electrical schematic of the stationary plasma thruster and the power processing unit interface.

1. Magnetic pole piece
2. Electrode
3. Insulator
4. Discharge chamber
5. Anode
6. Ignitor electrode
7. Heater
8. Hollow cathode

Fig. 2. Oscilloscope traces of the voltage and current waveform. Upper traces: U, V; Lower traces: I. a) DC, b) Power, c) DC, d) Power. Voltage: 100 V/div., Current: 5 A/div.

Fig. 3. Dependence of the discharge current total amplitude oscillations from the magnet current value.