Vacuum 136 (2017) 77–81

Contents lists available at ScienceDirect

Vacuum

journal homepage: www.elsevier.com/locate/vacuum

Effect of discharge parameters on pulse current during hall thruster start-up

Wenbo Li, Yongjie Ding, Liqiu Wei*, Liang Han, Daren Yu

Plasma Propulsion Lab, Institute of Advanced Power, Harbin Institute of Technology, Harbin, 150001, PR China

ARTICLE INFO

Article history:
Received 29 September 2016
Received in revised form
12 November 2016
Accepted 12 November 2016
Available online 18 November 2016

Keywords:
Hall thruster
Pulse current
Start-up
Discharge parameters

ABSTRACT

The high amplitude pulse current during Hall thruster start-up is an important source of electromagnetic interference, which impacts the safety and reliability of the propulsion system. The characteristics of the pulse current, including the pulse current's integrated area, peak value, and transient time, are studied experimentally and theoretically under different Hall thruster discharge parameters. Results show that the pulse current's integrated area is determined by the atom density in the channel before Hall thruster start-up; the effects of coil current on the peak value and transient time of the pulse current are negligible. As the discharge voltage and mass flow rate increase, the pulse current peak value increases, the pulse current duration is inversely proportional to the discharge voltage and directly proportional to the mass flow rate.

1. Introduction

Developed in 1970 [1,2], Hall thrusters are widely used in satellite station-keeping and orbit transfer due to their combination of outstanding performance on the efficiency(up to 60%), specific impulse(in the order of 10^3 s) and reliability [3]. The start-up of a Hall thruster is the first and most important step in its operation. The start-up process in a Hall thruster is a gas breakdown process utilizing an orthogonal electromagnetic field, which usually generates tens to hundreds of amperes of pulse current in several tens of microseconds [4,5]. A high amplitude pulse current during Hall thruster start-up is an important source of electromagnetic interference, which impacts the safety and reliability of the propulsion system, and therefore, it is worth paying attention to study in Hall thruster research.

In the last decades, many studies about Hall thruster start-up have been carried out by researchers worldwide. For example, Oghienko et al. [6] found that Hall thrusters are not ignited successfully at low mass flow rates and discharge voltages or under large magnetic field strengths through experimental and theoretical analyses. Vial et al. [7] found the peak value of start-up pulse current was several dozen times as large as the nominal discharge current and the low frequency oscillation of the breathing-mode appeared in the discharge current after the start-up process. Two inrush currents were observed by Arkhipov et al. [4] during the start-up process of Hall thrusters. They found that the first inrush current was related to the discharge of the filter capacitor and the second inrush current resulted from the large number of Xe atoms ionized in the discharge channel. A high-speed CCD camera was used by Ellison and Raitses [8] to study the process of Hall thruster start-up, which showed that the duration of the ionization process from the start-up to the nominal period lasted about 50 μs The Hall thruster start-up process lasts only tens of microseconds and the plasma parameters in the discharge channel are difficult to measure. Therefore, numerical simulation is a useful means to study the Hall thruster start-up process for researchers. A two-dimensional axisymmetric model was established by Taccogna et al. [9] to study the ignition process of Hall thrusters. Liu et al. [5] modified Taccogna's original model by considering the near field plume and the resultant evolution of the discharge current's peak value during ignition was reproduced. Santos and Ahedo [10] pointed out that the larger pulse current peak value during Hall thruster start-up was related to gas impurities present in its ceramic wall. In the recent study, we discussed the peak current on the power supply side. It is considered that the peak current of power supply is triggered by the voltage drop on the thruster side in start-up process [11]. Though the formation mechanism of the peak current on the power supply side is clarified, the characteristics of the pulse current on the thruster side remains unclear.

Through the present studies, we find that the pulse current in

* Corresponding author.
E-mail addresses: weiliqiu@gmail.com, weiliqiu@hit.edu.cn (L. Wei).

http://dx.doi.org/10.1016/j.vacuum.2016.11.026
0042-207X/

Hall thruster start-up is several dozen times as large as the nominal discharge current, which is an inevitable source of electromagnetic interference and may also shock the entire circuit of power supply system. Moreover, the pulse current is closely related to discharge parameters, such as the magnetic coil current, discharge voltage, and mass flow rate. Therefore, in order to enhance the overall reliability of the propulsion system, studying the pulse current characteristics under different discharge parameters and selecting the appropriate discharge parameters of Hall thruster start-up are important topics for the application of Hall thrusters.

The general organization of this paper is as follows. The experimental setup and plan is given in Section 2. Section 3 discusses the influence of magnetic coil current, discharge voltage, and mass flow rate on pulse current characteristics, such as the pulse current's peak value, integrated area, and transient duration, during the Hall thruster start-up process. The conclusion of this work are drawn in Section 4.

2. Experimental setup and plan

Our studies are carried out on a 1.35 kW ATON-type Hall thruster in a 1.5 × 4 m vacuum chamber with two diffusion pumps of 40000 L/s, one rotary pump, and three mechanical booster pumps. The back pressure of the vacuum is 3*10-4 pa for xenon before operation and 7*10-3 pa in working state. The normal operation is the anode flow rate of 42.8 sccm and discharge voltage of 350 V. A hollow cathode placed in the top of the thruster with flow rate of 3 sccm. The diameter of the inner insulator of the experimental thruster is 70 mm and that of the outer insulator is 100 mm. The length of the discharge channel is 50 mm. A self-heated hollow cathode was used to provide electrons and neutralize ejected ions. The start-up pulse current is related to the atom density in the discharge channel before the thruster is ignited. Therefore, a ZJ27-Φ15.5-type ionization gauge was used to measure the pressure distribution before Hall thruster start-up to estimate the atom density. The ionization gauge is connected to a glass tube. The measuring set is driven by a stepping motor. Similar device and method of measurement can be seen in the Ref.11. The pulse current was measured with a Yokogawa DL850 ScopeCorder at the anode terminal. The measuring scheme diagram is shown in Fig. 1.

Hall thruster start-up is a typical gas breakdown process. During Hall thruster start-up, coil currents affect trajectory of the electrons ejected from the cathode that reach the discharge channel. An electron's energy is affected by the discharge voltage and atom density within the channel before start-up, which can be changed by the mass flow rate, these factors are related to the pulse current during start-up. Therefore, the experiment was planed to study the characters of pulse current by change the different coil currents (3.0–4.0 A), discharge voltages (200–350 V), and mass flow rates (20–50sccm).

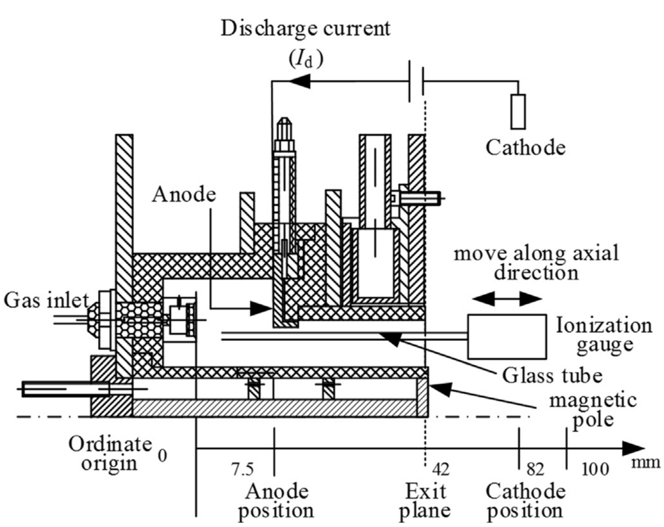

Fig. 1. Schematic diagram of the measurement setup (not to scale).

3. Experimental results and discussion

The experimental results are shown in Fig. 2. It can be seen from Fig. 2(a), that the variation of coil currents within certain limits has no significant effect on pulse current peak value or duration. It can be seen from Fig. 2(b) that pulse current peak value during Hall thruster start-up increases and pulse current duration decreases with increasing discharge voltage. Fig. 2(c) shows that as the mass flow rate increases, the pulse current peak value and duration increase.

Before the start-up of a Hall thruster, the channel is filled with Xe atoms. The initial atom density determines the number of atoms that can be ionized at start-up and the number of ionized atoms during start-up is closely related to the amount of pulse current charge. The total number of atoms can be calculated by the state equation of ideal gas, the amount of charge Q generated during thruster start-up process also can be calculated [11].

The charge Q_I is obtained by integrating the pulse current, represented as follows:

$$Q_I = \int_{t_2}^{t_1} I(t)dt \tag{1}$$

where t_1 is the initial time of thruster ignition, t_2 is the nominal time of pulse current during start-up, $I(t)$ is the pulse current peak value, and dt is the pulse current duration.

A charge obtained by the pulse current integral corresponds to the area under a pulse current curve during thruster ignition in Fig. 2, reflecting a corresponding variation of the pulse current. Comparison of a charge obtained by pulse current integral and a charge obtained by calculating the pressure in the channel before ignition is shown in Fig. 3. It can be observed that a charge obtained by calculating the pressure in channel before ignition is larger than a charge obtained by a pulse current integral. Since the atoms cannot be completely ionized at the start-up process, the parameters α used to represent the degree of ionization during the start-up process, which may be associated with the discharge voltage or mass flow rate, and the α will show a higher condition under higher discharge voltage and larger mass flow rate. The range of α is consistent with the actual degree of ionization of atoms during the thruster ignition process, it changes in the vicinity of 0.5–0.8. It can also be observed that the number of atoms and discharge current electrons have the same order of magnitude increase, this result agrees with experiment. That is, Fig. 3 shows that as the mass flow rate increases, the pulse current peak value increases.

According to the working principle of a Hall thruster, the radial magnetic field generated by the magnetic coil will constrain the axial movement of electrons, which contributes to more atoms ionized by electrons. Due to the limitation of Hall thruster size, the magnetic field only has an effect on the electrons, not ions. The discharge current consists of ion and electron currents, and the electron current is a very small proportion of the discharge current. During the Hall thruster operation, compared to ions, electrons is more easier magnetized by magnetic field. Thus, the influence of the coil current on the pulse current during start-up can be