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Hall thruster plume divergence angle assessment method based on image processing

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ABSTRACT

A kind of plume divergence angle assessment method in Hall thrusters is proposed based on image processing. The detail assessment method and probable error is described and discussed. Comparing with the probe measurement method, this assessment method has advantages of being fast, simple and properly accurate. These advantages show that it is a competitive method to analyze dynamic characteristics of plume divergences in a low frequency oscillation time scale.

1. Introduction

Hall thrusters are typical electric propulsion equipment in certain near-Earth missions, such as satellite station keeping and orbit transfer. A typical Hall thruster is designed as a symmetric cylindrical structure whose discharge is established through an externally applied crossed electromagnetic field. The neutral propellant is ionized and accelerated to produce thrust. Hall thrusters use high-speed ion flow to form plume at the exit of the thruster. The plume contains high energy plasma, which can not only erode the solar panel of satellites, change the surface potential and threaten the operation of satellites, but also disturb the communication between the satellite and the ground. All these bad influences are factors limiting the application of Hall thrusters. Thus, the plume divergence angle becomes the major indicator of the characteristics of Hall thrusters. Therefore, it has been one of the most important contents to get to know the situation, to measure, and to optimize the plume divergence. For example, Dannenmayer et al. measured the plume to analyze Hall thruster plume characterization [1]. Xu et al. take advantage of probe measurement to research on the characterization of ion-focusing Hall thruster [2]. Diamant use segmented electrode to reduce plume divergence angle [3]. Also, some plasma oscillations such as Rayleigh–Taylor instability, resistive instability and ionization-driven instability are sensitive issues [4–12]. Malik et al. studied the mechanism, characteristics and influencing factors of resistive instability deeply [6,12]. These all indicted that there are of importance when one attempts to characterize the plasma or plume. Such kinds of researches are too many to be mentioned.

Up to now, almost all researches use probes to measure plume divergence angle. Russian researchers mostly put measurement probe in an axial cross profile to measure the distribution of the ion current density in its radial direction in order to work out the plume divergence angle. American researchers mostly let the probe do half-circular motion in the plume region to measure the distribution of the ion current density along the circular arc to measure the plume divergence angle [13,14]. However, all methods mean to obtain the divergence characteristics of the plume in different situations, and to assess in which situation the plume divergence angle will be larger or smaller. Probe measurement is a kind of intrusive measuring method, for which the motion of the probe in the plume region can unavoidably affect the plume in both of the two

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methods. Also, the reliability of probe measurement is reduced and the service life of the probe is shortened when high-speed ions strike the probe. Taking the probe measurement's disadvantages into consideration, we come up with a new plume divergence angle measurement method, which is based on image processing. The major advantage of this method is that it is a kind of non-intrusive measurement, which is easy and simple to handle, and also with a proper accuracy. Moreover, this method can achieve continuous measurement, which might be used to assess some dynamic process of plume divergence angle in a short-term time scale.

2. Experimental set-up and results

Our studies were carried out on a 1 kW Hall thruster with an outer diameter of 70 mm and a discharge channel width of 15 mm, which was mounted on a fixed platform and placed in a 1.5 m $\times$ 4 m vacuum chamber with two diffusion pumps, one rotary pump, and three mechanical booster pumps. A Canon Digital Camera 60D was put on the outside of the germanium glass, which was on the side of the thruster and 50 cm away from the thruster. The axis of the camera lens was vertical to the axis of the thruster, and the camera was placed horizontally at a height that is the same as the thruster center. The diameter of the transparent observation window was 30 cm. The placement of the devices is shown in Fig. 1. The thruster was operated at a discharge voltage of 350 V, and the anode xenon flow rate is 42.8 sccm. We calibrate the magnetic field to form different plume divergence angle. After setting the speed of exposure to be 1/60 s, we take pictures of the discharge plume, shown in Fig. 2(a and b). According to the photoluminescence of plumes, the illumination distribution of the plume can approximately reflect the distribution of the ion density in the plume region. Therefore, if the radial distribution of the pixels' illumination of one cross profile can be obtained, we can use the same definition of the probe measurement to calculate the plume divergence angle.

According to the empirical formula below,

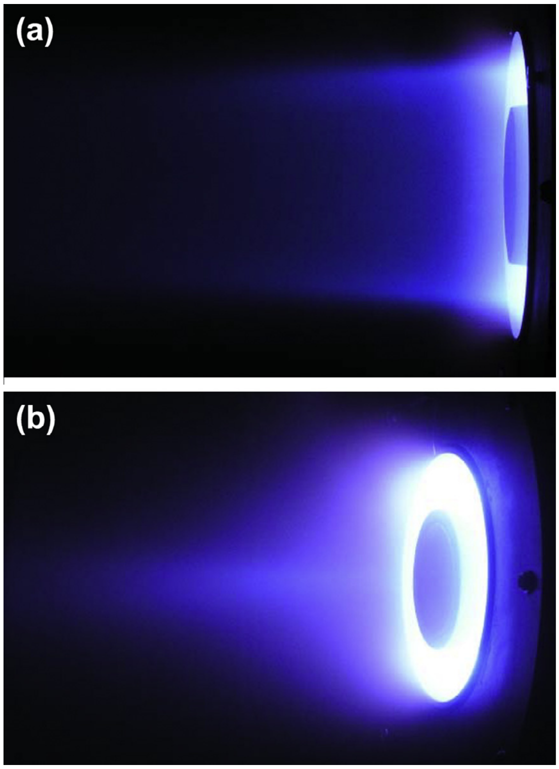

Fig. 2. Photograph of discharge plume (a) Focusing plume and (b) Diverging plume.

$$L = \frac{1}{3}r + \frac{1}{3}g + \frac{1}{3}b \quad (1)$$

we can calculate the illumination of every pixel in the photos of the plume that we take from the side of the thruster, where L is the illumination of the pixel, r is red channel's value, g is green channel's value, and b is blue channel's value.

It should be noticed that the plume is prismatic light source, and the frequency of visible light is 3.846×10^{14} Hz $\sim 7.895 \times 10^{14}$ Hz, which is far greater than the plasma

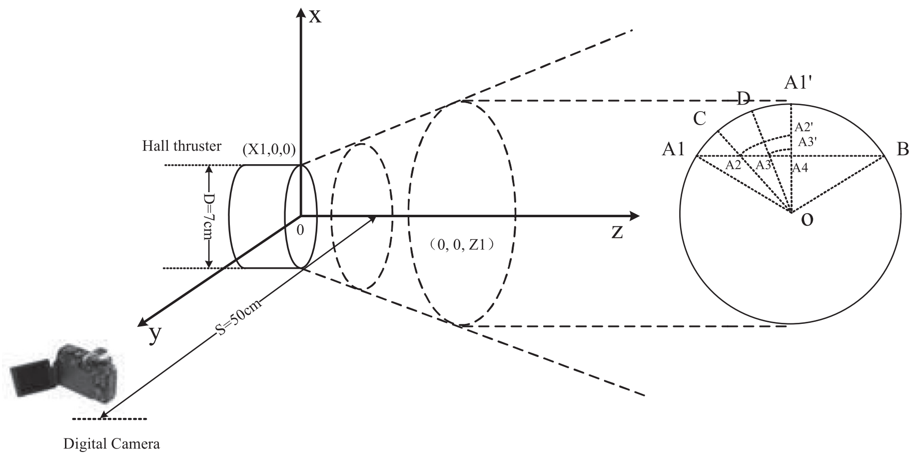

Fig. 1. Experiment device spatial arrangement.