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Effect of matching between the magnetic field and channel length on the performance of low sputtering Hall thrusters

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Abstract

Discharge characteristics of a non-wall-loss Hall thruster were studied under different channel lengths using a design based on pushing a magnetic field through a double permanent magnet ring. The effect of different magnetic field intensities and channel lengths on ionization, efficiency, and plume divergence angle were studied. The experimental results show that propellant utilization is improved for optimal matching between the magnetic field and channel length. While matching the magnetic field and channel length, the ionization position of the neutral gas changes. The ion flow is effectively controlled, allowing the thrust force, specific impulse, and efficiency to be improved. Our study shows that the channel length is an important design parameter to consider for improving the performance of non-wall-loss Hall thrusters.

1. Introduction

For the demands of low-orbit flight, the production of small- and medium-sized satellites utilizing low-power Hall thrusters is of increasing interest in a growing number of countries. Low-power Hall thrusters have traditionally been used by orbital spacecraft for station keeping, and numerous other applications of such devices with varying sizes and performance levels have been developed over the past several decades. Compared with high-power (larger than 500 W) Hall thrusters, low-power (below 500 W) Hall thrusters have defects such as short service life, large thermal load, and low efficiency due to large surface-to-volume ratios and severe interactions between plasma and the wall. Conventional Hall thrusters are generally limited to sub-45% anode efficiencies and maximum lifetimes on the order of 1000 h. For example, the French-designed SPT-20 thruster has an operational power of approximately 50 W, a specific impulse of 1000 s, and an efficiency of approximately 15% (Guerrini et al., 1997). The Russian-developed SPT-30 thruster has an operational power of approximately 200 W with an efficiency of up to 32%, and has an estimated operational lifetime of more than 600 h (Jacobson and Jankovsky, 1998). The BHT-200 Hall thruster has an operational power of approximately 200 W with an efficiency of 42% (Cheng and Martinez-Sanchez, 2008; Smirnov et al., 2002; Beal et al., 2002; Hargus and Charles, 2003; Hruby et al., 1999; Matlock et al., 2007). Experimentally determined useful lifetimes of over 1700 h have been observed; however, operational times of 1300–1500 h have led to failure of the thruster's nose-cone, exposing the centerline pole pieces to ion bombardment (Jacobson and Jankovsky, 1998). The CAM200 thruster developed by the Asher Space Research Institute has an operational power of approximately 200 W, with a specific impulse of 1622 s, at an anode efficiency of approximately 49.6% (Kapulkin et al., 2011). The Russian-developed PlaS-40 thruster has an operational power of approximately 200 W, with a thrust of 15 mN, at an anode

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efficiency of approximately 30%, and its expected lifetime is greater than 4000 h (Potapenko et al., 2015; Potapenko and Gopanchuk, 2013). To improve the service life of low-power thrusters, magnetic shielding (MS) technology developed by JPL and CNRS, as well as wall-less technology, has been applied to low-power thrusters, such as the MaSMi-40 and MaSMi-60 (Conversano et al., 2015, 2014, 2013; Conversano, 2015), and the wall-less Hall thruster (Mazouffre et al., 2014a, 2014b; Vaudolon et al., 2015). MS prevents the magnetic field lines from crossing the walls in the acceleration region. MS field topology forms parallel lines near the walls—also referred to as "grazing lines"—which extend to the anode region where the electrons are cold, allowing a high plasma potential in front of the walls. The combination of a special magnetic field configuration and a bell-mouthed wall can prevent the bombardment of the wall by high-energy ions, thus improving the service life of the thruster. However, due to the deposition of high-energy ions on the wall and the heat produced by the magnetic excitation coil, an X-shaped radiator was adopted for the MaSMi-40 for heat dissipation. The X-shaped radiator, with a total space-viewing surface area of ~1000 cm^2, was adopted for the thruster shell, guaranteeing a longer service life and stable work by the thruster (Kapulkin et al., 2011). Recently, the CNRS proposed that the anode be placed in wall-less hall thrusters at the channel outlet, so that the whole ionization region is within the plume area. Furthermore, MS technology has been applied to wall-less Hall thrusters, improving thruster performance because the anode is at a tangent to the magnetic line. The wall-less Hall thruster pushes the whole ionized region into the plume area, where there is no channel restraint for the neutral gas, and the ionization rate is kept low for large plume divergence angles. A central copper heat drain is employed to transfer heat towards a radiator placed behind the thruster, increasing the discharge time. According to existing research into low power MS and wall-less thrusters, magnetic shielding technology meets the requirements of long service life—especially since the high thermal load of the thruster is unavoidable due to power deposition on the wall from both coil heat and plasma, requiring a heat pipe or radiator for heat dissipation. To solve this problem, we pushed down the magnetic field using a double permanent magnet ring. The simulation results show that pushing down the magnetic field using a double magnet ring can change the ratio between the magnetic field intensity at the channel outlet and the maximum magnetic field intensity, thereby further influencing the ionization and acceleration process and thruster performance. According to the simulation results, matching the magnetic field established by a double permanent magnet ring to the channel length could realize a non-wall energy loss. However, the performance of a thruster increases at first, and then decreases with the extrapolation of the magnetic field. To verify the technology for pushing down the magnetic field with a double permanent magnet ring, a Hall thruster with a double permanent magnet ring was designed for an experimental study. The size and position of the double permanent magnet ring was kept constant, to allow the effect of matching the magnetic field and channel length on the discharge characteristics of the thruster to be observed. The difference in the ionization and energy deposition of a thruster with matching between different magnetic field intensities and channel lengths was analyzed to determine the factors restricting performance improvement in low-power thrusters.

2. Characteristics of non wall loss Hall thrusters

The NWLHT-200 Hall thruster with 200 W of power excited by a double permanent magnetic ring was designed and processed in previous studies (Ding et al., 2016). The specific structure and magnetic field configuration is shown in Fig. 1. The NWLHT-200 Hall thruster has the following characteristics: 1, the magnetic field is only generated by the inner and outer permanent magnetic rings; 2, except for a gas distributor/anode made of non-magnetic stainless steel, the metal structures of the whole thruster are manufactured from titanium, with no other magnetically conductive materials and no magnetic screen; 3, an anode and gas distributor integral structure is adopted, with the front end face of the anode placed at the separatrix position; 4, the length of the channel can be easily modified while the mean diameter and width are unchanged, by means of various sets of ceramic rings. 5, the discharge channel is a straight channel without a bell-mouthed shape; 6, the thruster shell has a hollow surface. A ceramic in the discharge chamber was directly exposed for radiation to the environment, which effectively reduced the ceramic temperature.

As shown in Fig. 2, the magnetic field intensity corresponding to the position of the outer cover is 75% of the maximum magnetic field. Therefore, adjusting the length

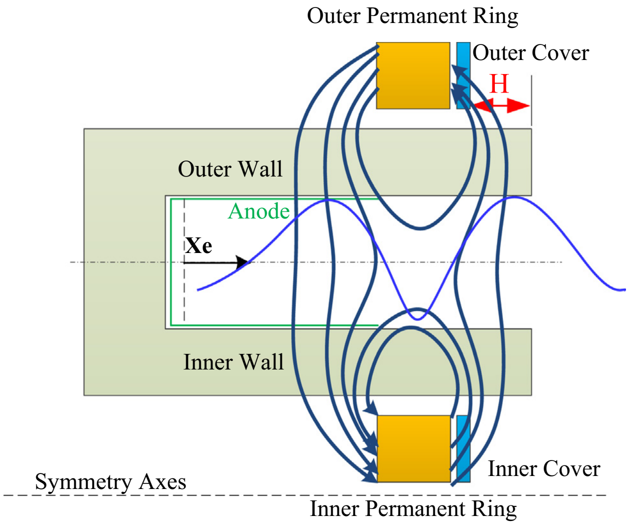

Fig. 1. Schematic diagram of the structure and magnetic field configuration of the NWLHT-200 Hall thruster.

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