Numerical study on the Influences of Magnetic Field on the Discharge Characteristics in Hall Thruster Channel

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Abstract: The magnetic field in Hall thruster channel is an essential factor which can restrain the electron axial conduction, change the conductivity distribution, and affect the thruster performance. In this work, the effects of different magnetic field intensities and configurations on particle number density, potential, electron temperature and ion velocity distribution are investigated by particle-in-cell simulation, and the corresponding discharge current and specific impulse are also numerically simulated.

Keywords: hall thruster, magnetic field intensify, magnetic field configuration

1. Introduction

Hall thruster is a type of propulsion device which can provide micro thrust for the spacecraft. It is widely used in various space propulsion tasks because of its high specific impulse, high precision and high efficiency [1-8]. The electrons emitted from the cathode collides with the working substance (usually xenon) injected from the anode which ionized into plasma, electrons are bound by magnetic field to do the circling Hall drift motion, while the ions are accelerated and ejected out of the channel under the influence of the electric field and produce thrust.

2. Physical Model

The simulation of this work is based on the ATON-type Hall thruster. A typical magnetic field with a zero-point configuration in Hall thruster channel is shown in Fig. 1.

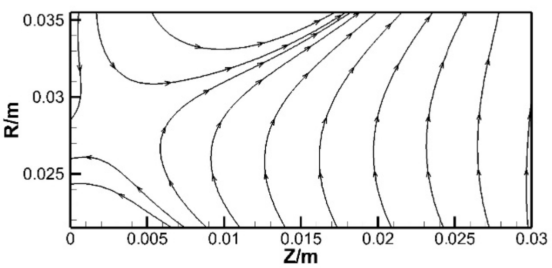
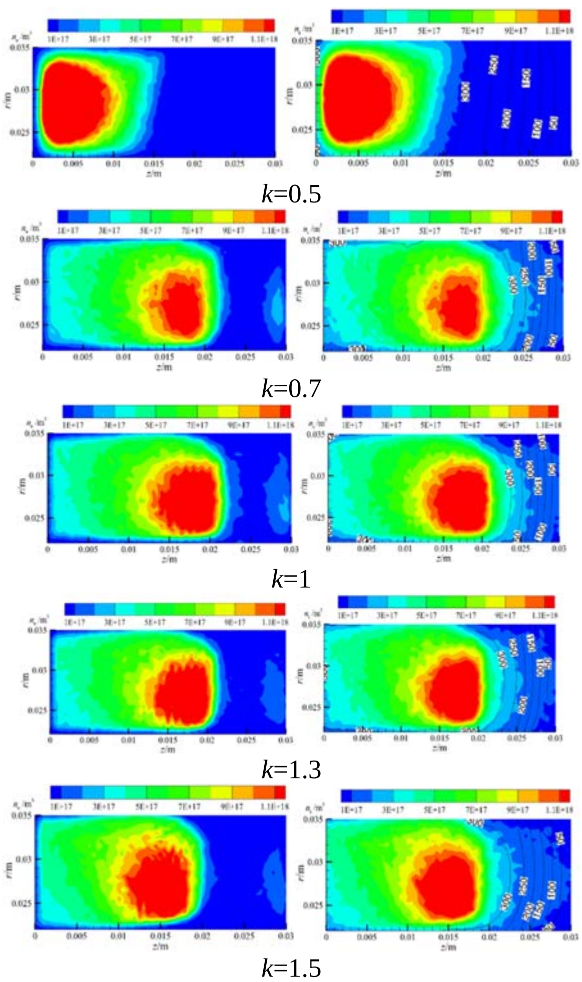


Fig. 1. Magnetic field configuration and simulation area of Hall thruster

3. Effect of Magnetic Field Intensity on Discharge Characteristics

Fig. 2 shows the influences of magnetic field intensity on the channel particle density and potential distribution. It can be seen from Fig.2, when k = 0.5, the ionization takes place at the anode region, acceleration region is elongated, the entire channel of the thruster has a potential drop, but the gradient is relatively small, ion axial acceleration at the outlet area (right area in the simulation zone) is weakened. When k = 0.7, the ionization region moves towards to the exit of the channel, the particle density decreases, the acceleration region is shortened and potential gradient increases. When k = 1, due to the increase of the magnetic field, ionization region is close to the channel outlet, the acceleration region is shorter than before. When k = 1.5, since magnetic field restrains the electron motions, the electron-wall collision frequency is greatly reduced, the ionization region moves toward the anode slightly, and the acceleration region is elongated. It can be seen that different magnetic field intensities can greatly change the ionization region position and potential distribution. In general, a shorter acceleration region helps to reduce particle-wall collisions and improves axial propulsion efficiency.



(a) (b)

Fig. 2. Spatial distribution of electron density, ion density and equipotential lines with different k. (a) electron density; (b) ion density and equipotential lines

4. Influences of magnetic field configuration on discharge characteristics of Hall thruster

The position of the magnetic field and the location of the zero-point of magnetic field can significantly affect the characteristics of the ionization region and the acceleration region of the plasma. Fig. 3 shows three types of thruster channel magnetic field with different configurations and radial magnetic field intensity distribution. The zero-points of magnetic field intensity are located near the anode, near inner wall and at the inner axis of the channel, respectively, and all three types of the magnetic field configuration have the same intensity at the exit of the channel.

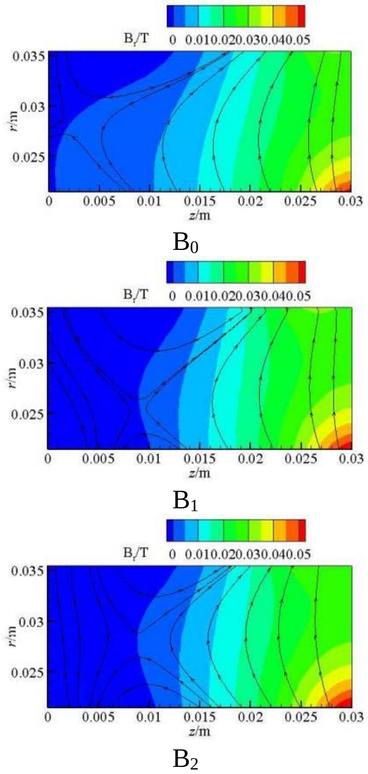


Fig. 3. Magnetic field configuration and radial magnetic field intensity

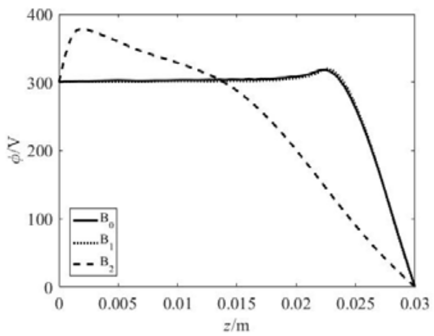


Fig. 4. Axial distribution of potential with different magnetic field configuration

Fig. 4 shows the axial distributions of the potential in the channel with different magnetic field configurations. We can see from Fig. 4, when the magnetic field configurations are B_0 and B_1, the potential distributions are the same and the potential drop are mainly concentrated in the channel exit, which means the acceleration region can be shortened. When the magnetic field configuration is B_2, the ionization mainly takes place near the anode, the potential drop near the anode is higher and the channel potential decreases gradually. The rest simulation results are listed in the next section.

5. Discussion

In this work, a two-dimensional physics model of Hall thruster is established to numerically simulate the effects of magnetic field intensity and configuration on plasma discharge characteristics. The simulation results demonstrate that, as the magnetic field configuration remains constant and the magnetic intensity factor $k < 0.7$, when the maximal magnetic field intensity of the central axis is less than 200 Gauss, the ionization region is near the anode and the acceleration region grows. In the condition that the magnetic intensity factor $k > 0.7$, with the increase of the magnetic field intensity, the electron temperature, ionization rate and electron-wall collision frequency decreases gradually, the ion radial velocity increases, the radial potential drops and the radial velocity increases at the discharge channel exit, and the thrust value reach maximum when $k = 1.3$, thrust-to-power ratio increases with higher magnetic field intensity. When the magnetic intensity factor $k > 1.3$, ion radial velocity and wall corrosion increase, but discharge efficiency reduces. While the location of the zero-point of magnetic field region moves towards to the discharge channel exit, the magnetic field configuration perpendicular to the wall restrain electrons, the acceleration region increase, the discharge current decreases sharply, and the thruster cannot sustain steady operation. When zero-point of magnetic field region nears to the inner wall of the channel, the discharge current increases obviously, the distribution of radial electric potential becomes uneven at the exit of the channel, ion radial velocity increase, and the wall corrosion increases.

6. References

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