Selecting an Anode Orifice Configuration for Hall Thrusters

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Abstract

Discharge current oscillation in a 20kHz range is a serious problem for Hall thruster performance. In our previous work, a possibility of controlling the oscillation amplitude by increasing the speed of neutral particles incoming to the ionization zone was predicted in our previous work. In this paper, the effects of diameter of anode orifice on the oscillation phenomena and the thrust performance were evaluated experimentally. The experimental results show that the measured amplitude of oscillation becomes smaller as the diameter of anode orifice. However, the larger orifice makes thrust performance lower. The results of numerical analysis of neutral particles show that these tendencies have much to do with neutral properties.

Introduction

Hall thrusters are promising propulsion systems for space missions capable of reduction of mass flow rate of propellant due to high specific impulse 1000-3000s. It has been used chiefly as a thruster for satellite station keeping and orbit correction, more than one hundred times up to date.[1] Moreover, it has possibility of achieving the thrust density identical to the electromagnetic-acceleration-type thrusters under no restriction of space charge limited current rule; the acceleration part is quasi-neutral.

Experiments and numerical analyses on Hall thrusters have been done by numerous workers.[1-13]

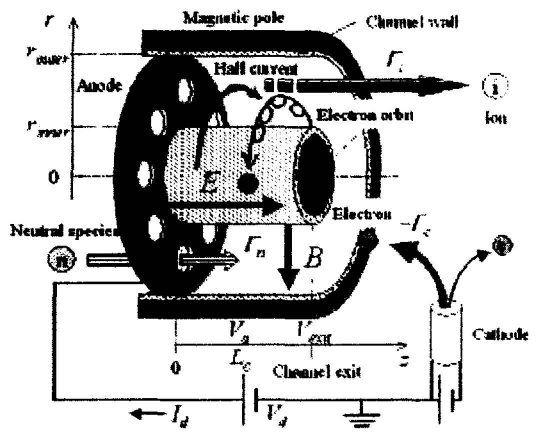


Fig. 1 Schematic of Hall thruster for numerical analysis

However, some serious problems still remain for improvement of Hall thruster performance. A typical problem that should specifically be solved is discharge current oscillation phenomenon observed under standard operational conditions at high-voltage mode of DC regime; it has been regarded as an unavoidable problem of Hall thruster. Since the oscillation affects electron conductivity and anomalous diffusion in acceleration channel, it appears to be a cause of reducing durability and unstable operation etc. In particular, since a long-time stable operation is required in a space mission, it is an urgent item for development of thruster design to probe the physical mechanisms of discharge current oscillation phenomenon.[6-13]

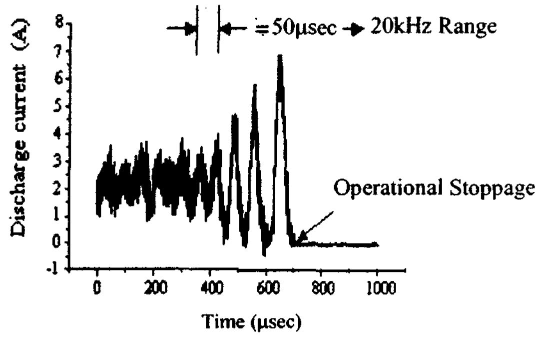


Fig. 2 20kHz-range discharge oscillation and operational stoppage

Therefore, it is important in Hall thruster study to focus its efforts on the large-amplitude and low-frequency discharge current oscillation in 20kHz-range (20kHz-range oscillation) which is speculated as a main cause for deterioration of propulsive efficiency and operational instability among various oscillation phenomena observed in Hall thruster. In our previous work, a possibility of controlling the amplitude of the 20kHz-range oscillation by increasing the speed of neutral incoming to the ionization-zone was predicted.[10, 11] The speed of neutral was increased by heating the propellant in the experimental work.[12] As a result, it is found that the amplitude of the oscillation decreases as the propellant temperature increases. The tendencies were also confirmed numerically using one-dimensional analyses. However, the propellant preheating causes a complicated system. The purpose of the present study is to investigate a possibility of control of the oscillation by optimizing geometric parameters of propellant-inlet part.[13] In this paper, for the purpose of investigating dependencies of the oscillation properties on the size of anode orifice, the amplitudes are measured for different diameters of the orifice. The dependencies are also investigated by numerical analyses. In order to evaluate the effect of geometries of anode orifice on the distributions of neutral properties in the ionized-zone, neutral motions are calculated for different sizes of anode orifice by axi-symmetric analyses using direct simulation Monte Carlo (DSMC) method.[14]

Experiment Apparatus

Hall thruster measurement system

Experimental facility consists of a vacuum system, a propellant supply system, measurement equipments, and a Hall thruster, as shown in Fig. 3.

Experiments are performed in a water-cooled stainless steel vacuum chamber with 1.0m in diameter and with 1.8m in long. Vacuum system consists of Rotary pump, Mechanical-booster pump, jet pump, and diffusion pump. Standard experiment conditions: discharge voltage 200V, magnetic field 0.062T, acceleration channel length 16mm, mass flow late of Xenon 1.36mg/s (=1A-eq=14sccm). Propellant is supplied to the thruster by using a heat-type mass flow meter (control range 0-100sccm, accuracy 2%, time-response 6sec). Discharge current and voltage are measured with two 1 Ω holo resistors arranged parallel in the discharge circuit, and recorded by a high-speed PC-based digital oscilloscope, with a 10MHz maximum sampling rate, the ionization fraction reaches a maximum value (nearly 100% propellant utilization, i.e., the conversion of neutral xenon to ionized xenon).

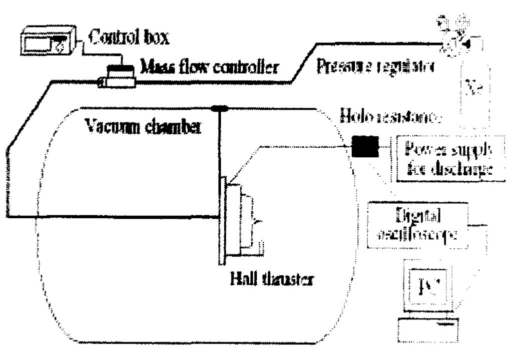


Fig. 3 Schematic of Hall thruster measurement system

Nagoya University Hall Thruster II (NUHT-II)

A schematic of NUHT-II used in this experiment is presented in Fig.2. NUHT-II belongs to a laboratory version of a nominally 0.5kW-class Hall thruster. The acceleration channel consists of two annular ceramic (Boron-Nitride) cylinders with a thickness of 2mm, 72mm in outer diameter, 10 mm in width, and 16mm in maximum length, prevents the plasma current from leaking through the magnetic pole. The length of the acceleration channel is 16mm. The anode is made of copper, and thickness of is 2mm. After propellant is introduced from 24 ports of 3mm in diameter into a plenum chamber behind the anode, it is uniformly injected from anode orifices into the acceleration channel. The constant voltage power-supply was used for the cathode power supply and the power supply for magnetic field generating.

Axial distribution of radial magnetic field used in the experiment is shown in Fig.5. Plotted are the measured values (for different coil currents) at radial middle of acceleration channel of NUHT-II which is so-called Japan-Type Hall Thruster; the special aspect is that the magnetic field lines distribute nearly flat during acceleration. The radial magnetic field in the center of the acceleration channel is able to range from 0.035T to 0.070T by changing the coil current between 2A and 5A wide. The main power for discharge was a direct-current power, 0V-500V in voltage and 0A-5A in current. The cathode is made of filaments structured with Tungsten, attached at every 90 deg., is placed in the position of 30mm back from an acceleration channel exit.

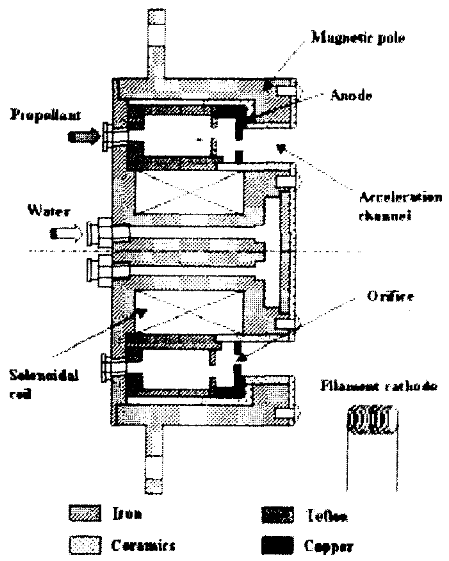


Fig. 4 Schematic of NUHT-II

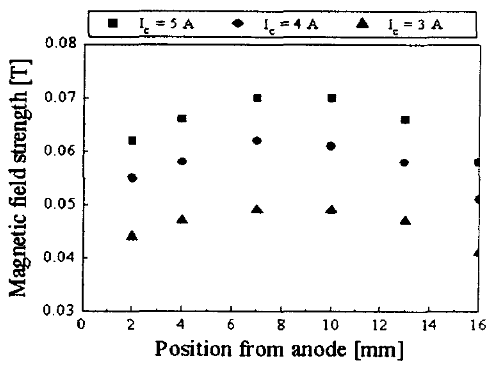


Fig.5 Axial distribution of radial magnetic field in NUHT-II

Measurement Analysis of Discharge Current Oscillation

Evaluations of amplitudes of discharge current oscillation are performed by the following methods. The experiment data of discharge current is measured with Oscilloscope, and moved to PC. Oscillatory wave forms are obtained by cutting high-frequency oscillation automatically with a low path filter. The both-ends amplitudes are calculated by subtracting the bottom current from the top value.

Measurements and Analyses of Thrust Performance

Figure 6 shows the schematic of thrust measurement system. The Hall thruster is mounted on a thrust stand. A displacement of the thrust stand by the generated thrust is detected by an eddy-current-type gap sensor. Using calibration data conducted with a weight, the thrust is calculated.

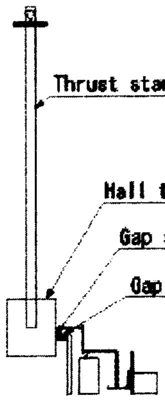


Fig. 6 Schematic of thrust measurement

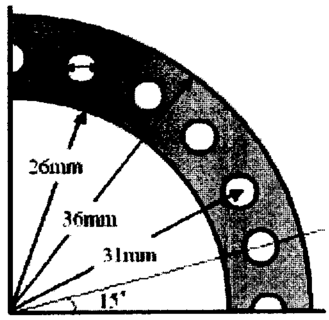


Fig. 7 Schematic of anode orifice

Results and Discussions

Dependency of Amplitude on Diameter of Anode Orifice

For the purpose of controlling the amplitude of 20Hz-range discharge oscillation, the dependency of the amplitude on diameter of anode orifice is investigated. The amplitudes are measured for different diameters of anode orifice (see Fig.6). Figure 7 shows the amplitude at the discharge voltage of 200V and the mass flow rate of 1.36mg/sec. From Fig.7, it is found

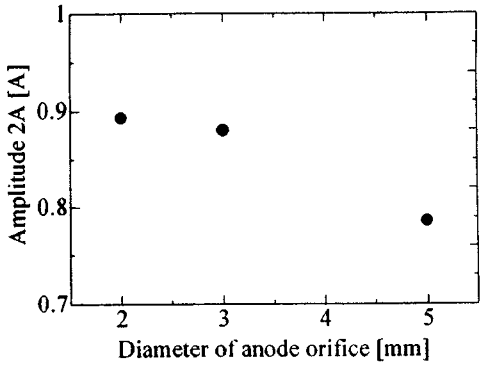


Fig. 8 Dependency of amplitude on diameter of anode orifice

that the amplitude decreases as the diameter of anode orifice increases. This fact indicates a feasibility of controlling the 20-kHz range oscillation by optimizing the geometric parameters of inlet part.

Dependency of Thrust Performance on Diameter of Anode Orifice

Figure 9 shows the measured thrusts and average discharge current at different diameters ϕ of anode orifice at the discharge voltage of 200V and the mass flow rate of 1.36mg/sec. As shown in Fig.9, an increase in the thrust is observed with decreasing as the diameter of anode orifice increases. The thrust at ϕ =5mm, 17mN decreases by 10% compared with the value at ϕ =2mm, 17mN. Figure 10 shows the

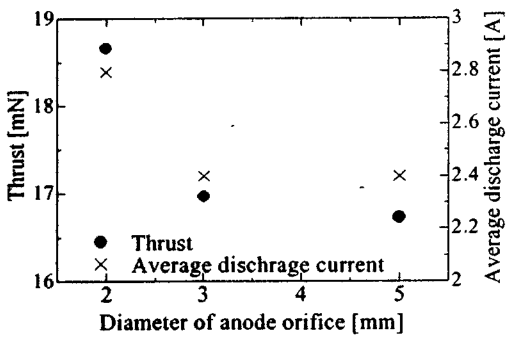


Fig. 9 Dependencies of thrust and discharge current on diameter of anode orifice

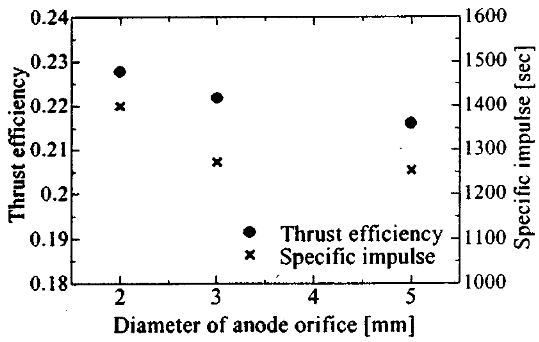


Fig. 10 Dependencies of specific impulse and thrust efficiency on diameter of anode orifice

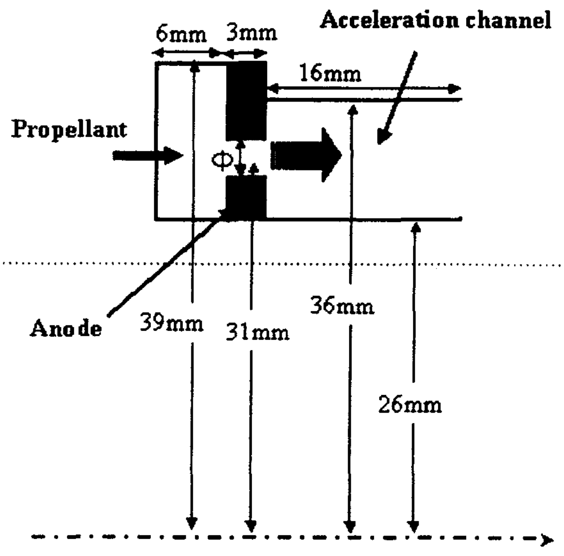
calculated specific impulses and thrust efficiencies calculated from the measured thrusts by the following equations. Since the mass flow rate is fixed in the present experiment, the specific impulse shows the same tendency as the thrust.

As shown in Fig.9, the average discharge current decreases for the large anode orifice. However, the thrust efficiency also decreases as the diameter of anode orifice increases due to the increase of thrust. The thrust efficiency at ϕ =5mm decreases by 5% compared with the value at ϕ =2mm.

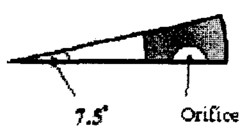
These results suggest that the larger anode orifice lowers the thrust performance. Therefore, from the viewpoint of performance of Hall thruster, it is not suitable to increase the diameter of anode orifice.

Numerical Analyses of Neutral Particles

In order to investigate the dependencies of the measured oscillation amplitude and thrust performance on the diameter of anode orifice, numerical analyses of neutral particle for anode orifices with different diameters are performed by DSMC.[13, 14] The analyses are done for the configuration including the inlet part shown in Fig.11.



(a) Section of configuration cut by axial plane



(b) Section of configuration cut by radial plane

Fig. 11 Configuration used for neutral particle analysis

Numerical Procedure Neutral particles which flow into the thruster are calculated by DSMC. The analyses are performed in the 3-dimensional configuration, which consists of a plenum chamber, an acceleration channel and an anode with different orifice diameter, ϕ , as shown in Fig.11. The mass flow rate, $\dot{m}$ (=1.36mg/sec) and the geometric parameters except the orifice diameter are fixed as close as possible to the experiment.

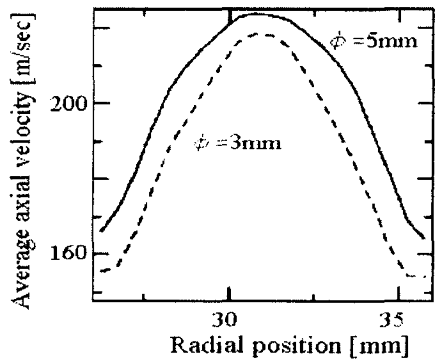


Fig. 12 Radial distributions of axial velocity at different diameters of anode orifice(z=4mm)

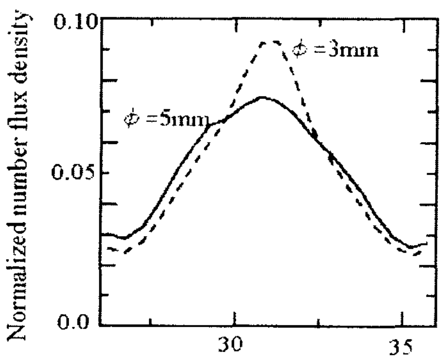


Fig. 13 Radial distributions of number flux density at different diameters of anode orifice(z=4mm)

Axial Velocity and Number Flux in Ionization-Zone From the past numerical works, it is pointed out that there are strong relation between the velocity of neutral particle and the amplitude of discharge oscillation.[10, 11] The works also show that the increase of axial velocity makes the amplitude smaller. Therefore, in the present analyses, radial distributions of neutral axial velocity in the ionization zone are investigated for different diameters of anode orifice. From the experimental data in the past, the point 4mm downstream of the anode surface is employed as the point of ionization-zone.[9, 10] Figure 12 shows radial distributions of axial velocity of neutral particles for different diameters of anode orifice. As shown in Fig.12, the distribution of axial velocity increases in the case of the larger orifice. This indicates that the increase of orifice diameter causes the decrease of the oscillation amplitude.

Radial distributions of neutral flux for different orifice diameters are shown in Fig.13. From Fig.13, it is found that the neutral flux becomes broader as the orifice diameter increases. The broader distribution of the neutral flux causes the increase of ion losses to the walls of acceleration channel. The increase of ion losses results in the decrease of thrust performance. The mechanism appears to be an important fact to explain the tendency of the measured thrust performance.

Conclusions

In this paper, the effects of diameter of anode orifice on the oscillation phenomena and the thrust performance were evaluated experimentally. The effects were investigated with the results of simulation neutral particles. The experimental results are summarized as follows:

1) As the diameter of anode orifice increases, the measured amplitude of oscillation becomes smaller.

2) As the diameter of anode orifice increases, the measured thrust performance and average current become lower.

The simulation results of neutral particles imply as follows:

1) The increase of axial neutral velocity makes the amplitude smaller.

2) The spread of neutral flux to the channel wall causes the decrease of thrust performance.

The investigation on the effect of diameter of anode orifice is summarized above and it is evident that more work about anode geometry using different approaches is necessary.

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