# Experimental studies on the effect of the electric potential inside the water ion thruster

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**Abstract: Water unified propulsion was proposed as a propulsion system for CubeSat. Water unified propulsion composed of a water resistojet for attitude control, and a water ion thruster for orbit transfer and station keeping. In order to enable various missions with increasing its specific impulse, we divided the interior of the discharge chamber electrically and applied the different DC voltage to each part. The specific impulse increased from 400 s to 800 s by applying the positive bias voltage to the antenna, and the specific impulse decreased by applying the negative bias voltage to the magnets.**

## Nomenclature

| | | |
|---|---|---|
| $B$ | = | magnetic field |
| $f_{\mathrm{electron}}$ | = | electron cyclotron frequency |
| e | = | elementary charge |
| $m$ | = | mass of electron |

## I.Introduction

NASA's lunar gateway has the potential to accelerate deep space exploration.[1] According to the plan, supply ships will go to the gateway several times a year. There is also a plan to release CubeSat from the gateway as well as ISS. The gateway is scheduled to be put into an orbit called Near-Rectilinear Halo Orbit, which requires a small ΔV for exploring asteroids and other planets. Releasing CubeSat from the gateway enables the more frequent exploration to the deep space.

Water unified propulsion system is a unique propulsion system which uses water as a propellant and has a possibility to be released from the Gateway because of its safety to the human.[2] The system is a 3U propulsion module with which equipped a water resistojet for attitude control and a water ion thruster for orbit transfer and station keeping. A variety of missions to deep space will be possible by releasing CubeSat with the propulsion system.

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The water ion thruster has a much smaller specific impulse than other conventional ion thrusters, and the increase of its specific impulse is required. The water ion thruster consists of an ion source and a neutralizer. The ion source accelerates positive ions, extracts the ion beam, and obtains the thrust. The neutralizer emits electrons and prevents a satellite charging up electrically. Both have a same microwave discharge chamber.

In this study, we focused on the ion source to improve the specific impulse by changing the electrical potential of the wall. The walls of the discharge chamber inside the ion source are isolated to give the different electrical potentials to each part. As the previous study, the experiment with a 10 cm-class microwave-discharge ion thruster was conduced with dividing and electrically insulating the wall of the discharge chamber.[3] Its specific impulse increased with some surfaces floated. However, there is no example of dividing the interior of the discharge chamber in a small microwave discharge ion thruster with a diameter of several centimeters, and also no experiment changing the voltage actively. The characteristic length of a miniature ion thruster is almost same as expected Debye length, therefore, it can be expected that changing the wall potential affects its plasma and performance greatly. In this study, we experimentally confirmed the effect of applying a DC voltage with measuring the current through each surface, and intended to increase the beam current from the ion source.

## II.Experimental setup

### A. Design of water ion thruster

The ion source and the neutralizer consist of a handle antenna and two ring magnets. Figure 1 shows the schematic of a water ion source. Electrons are trapped in a magnetic field and are heated by Electron cyclotron resonance (ECR). The plasma is generated in a magnetic field where the microwave frequency matches with the electron cyclotron frequency. The electron cyclotron frequency is expressed as Eq. (1) . [4]

$$f_{\mathrm{electron}} = \frac{2\pi m}{eB} \quad (1)$$

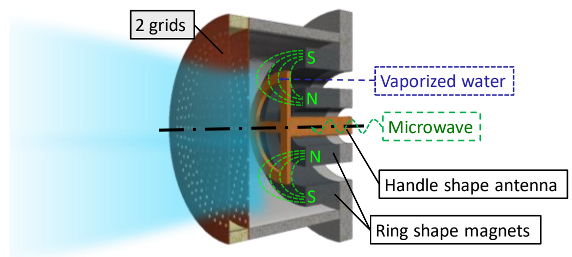


**Figure 1. A schematic of water ion source**

Figure 2 shows the internal magnetic field. The ECR region at 4.25 GHz of the microwave, which is the nominal frequency, is located 0.9 mm away from the antenna.

The interior of the water ion source was divided into the antenna, the magnets, and the side wall and the screen grid. They were electrically insulated. The bias voltage was applied to the magnets and the antenna.

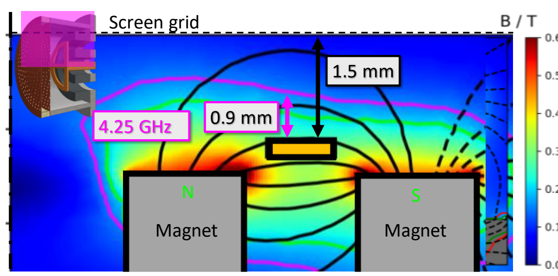


**Figure 2. magnetic field inside the thruster**

### B. Experimental condition

Table 2 shows the experimental conditions. The mass flow rate and the microwave input power were kept constant. The bias voltage was the applied voltage to the antenna and the magnets, and expressed as the difference from the screen grid voltage. Figure 4 shows a schematic of the interior of the ion source. The currents through each surface were measured as shown. The definition of the positive direction of the current was as shown, and the positive value means that the flow of electrons to the wall exceeded that of ions. The current through the side wall and the screen grid is calculated by equation (3).

$$I_{\mathrm{screen\ grid+side\ wall}} = I_{\mathrm{screen}} - I_{\mathrm{antenna}} - I_{\mathrm{magnets}} \quad (3)$$

The screen current was the amount of current that passed through the holes of the screen gird. The experiment was terminated in the case that the plasma disappeared or the plasma was not generated while changing each bias voltage in range of ± 60V. The ion source was operated with a neutralizer operated with xenon. The electrical common of the ion thruster was connected to the vacuum chamber. The propellant was

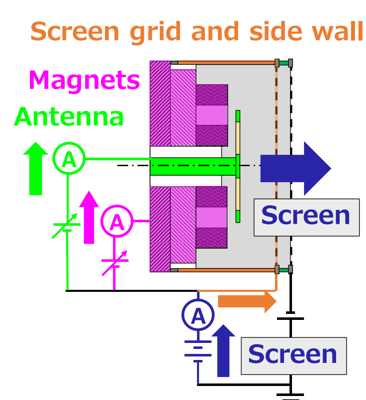


**Figure 3. Electric circuit diagram**

supplied with a constant mass flow rate by the bang-bang control system of the water feeding system shown in Fig. 4. A diagram of the microwave system was shown in Fig. 5, and the antenna current measurement and applying the voltage were performed by branching the line as shown.

**Table 2 Experimental conditions**

| | |
|---|---|
| Mass flow rate /$\mu$gs$^{-1}$ | 30 ±3 |
| Accel voltage /V | -200 |
| Screen voltage /V | 1000 |
| Bias voltage /V | -60 to 60 |
| Microwave frequency /GHz | 4.25 |
| Microwave input power /W | 1.5 ±0.08 |
| Gas | Water |
| Chamber pressure /Pa | $< 5 \times 10^{-2}$ |

s

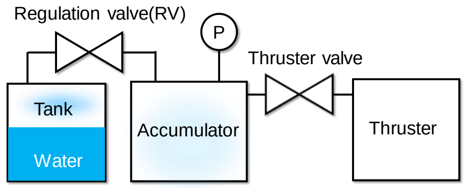


**Figure 4. Water feeding system**

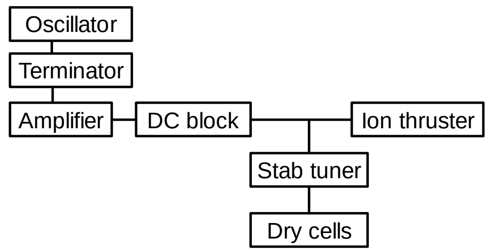


**Figure 5. Microwave schematic**

## III.Results and discussion

### A. Antenna bias voltage experiment

Figure 6 shows the experimental results of changing the antenna bias voltage. When the current through each surface was positive, the electron current exceed that of the ion. When the antenna bias voltage was over 48 V or under -12 V, the plasma was not generated or disappeared by the acceleration. The screen current, the current passing through the holes in the screen grid, was increased to 12.7 mA by applying 38 V. The specific thrust increased to 800 s while neglecting the neutralizer.

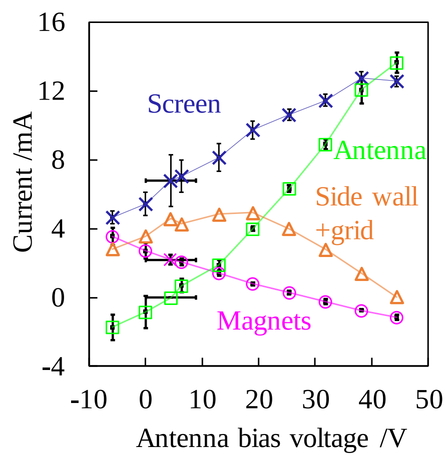


**Figure 6. Currents in each antenna bias voltage. Screen means the current through the screen grid holes. Side wall+grid means the current flowing towards side walls or screen grid hole edges.**

The electron loss to the antenna became large and the plasma could not be maintained over 48 V of the bias voltage, and the increase of the screen current and the decrease of the neutral particle density in the discharge chamber also affected the limit of the operation. The reason why it became impossible to operate under -12 V would be the increase of the loss of electrons on the magnet surface as a result of decreasing the plasma potential and increasing the relative voltage of the magnet to the plasma. When the antenna bias is 38 V, the side wall + screen grid current and the magnet current are almost zero. This suggested that a similar result might be obtained even when the voltage is applied only to the antenna with the other surfaces floated. It would achieve the performance improvement without the additional power supply for biasing the wall.

### B. Magnets bias voltage experiment

Figure 7 shows the experimental results of changing the magnet potential. When the current through each surface was positive, the electron current exceed that of the ion. When the magnet bias voltage was over 18 V or under -66 V, plasma was not generated or disappeared during acceleration. The electron loss to the magnets decreased with the bias voltage decreasing, but the screen current does not increase as the case of the antenna and the performance improvement was not achieved.

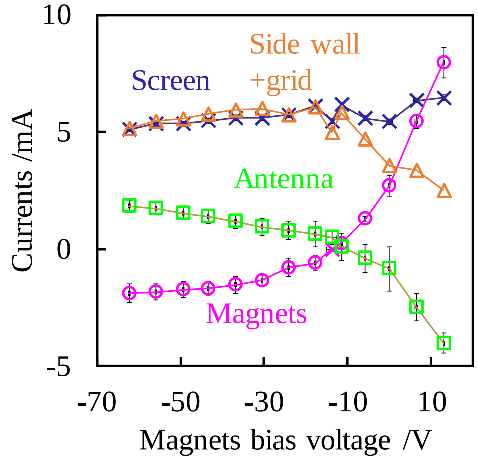


**Figure 7. Currents in each magnets bias voltage. Screen means the current flowing through the screen grid holes. Side wall+grid means the current flowing towards side walls or screen grid hole edges.**

## IV.Conclusion

In the water ion thruster, the interior of the discharge chamber was divided into the magnets, the antenna, the side wall and the screen grid. The different electrical potentials were applied to each part. With applying the bias voltage to the antenna, the screen current increased to 12.7 mA at 38 V of the antenna bias voltage. This was an increase in specific impulse to 800 s while neglecting the neutralizer. In the case of the magnets, although the loss of electrons to the magnet was reduced by applying a negative magnet bias potential, the screen current was not increased by applying the magnet bias potential as the case of the antenna.


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