DEVELOPMENT OF ION THRUSTER SYSTEM FOR INTERPLANETARY MISSIONS

Hitoshi Kuninaka*
Institute of Space and Astronautical Science
Yoshinodai, Sagamihara, Kanagawa, Japan

Nobuo Hiroe**, Kazuto Kitaoka**, Yoshio Ishikawa+
Nihon University
Narashinodai, Funabashi, Chiba, Japan

Kazutaka Nishiyama**
University of Tokyo
Hongo Bunkyo, Tokyo, Japan

and

Yasuo Horiuchi++
NEC
Ikebe, Midori, Yokohama, Kanagawa, Japan

Abstract

Institute of Space and Astronautical Science has developed the ion thruster system for interplanetary missions. It is characterized to generate simultaneously both plasmas in a plasma source and a neutralizer by a single microwave generator without thermo-emissive electrodes. A thruster head and a neutralizer have been investigated separately. Preliminary test for the system integration was executed.

Introduction

Institute of Space and Astronautical Science in Japan aims at grading up from M-3 to the M-5 launcher, which has a capability to input about 500kg payload in the interplanetary space. It stimulates scientists planning explorations of planets, asteroids and comets. High technologies, for example, the gravity assist, the aerobrake, and high Isp chemical rockets, have been developed to enable high delta-V missions. The electric propulsion, which would compete with them for the space missions, is pressed for the urgent systematization and verification. For the above-mentioned scientific interplanetary probes the electric propulsion would be specified at 500W maximum in electrical power and 20kg maximum in dry weight including redundant system. The flight operation of the interplanetary mission is significantly different from that of the geostationary satellite. A single tracking center is not able to communicate with spacecraft all the time. Telemetry bit rate may not be enough due to long distance from the earth in the order of astronomical unit. The electric propulsion, which will take a longer time to complete a space mission, will be operated automatically without the supervision of a ground station in some duration at least. An onboard computer is required heavy loads for health check, emergency stop and restart of the electric propulsion, etc. It is reasonable to develop the electric propulsion with less control parameters, which never confuse the onboard computer. One of the stumbling blocks to apply the electric propulsion to the space mission is its expensive cost, which is originated from complex system and complicated ground operation. The author insists that the electric propulsion should aim at the simplicity for hardware and operation. It results in light weight, system robustness, and light load to the computer. In order to accomplish the above objectives, the ion thruster system using microwave discharge has been developed in Institute of Space and Astronautical Science.
Microwave Ion Thruster

The microwave discharge is able to generate plasma without electrodes so that it is completely free from electrode erosion and contamination. A part of the thermal electrons is accelerated by the microwave electric field and ionizes collisionally neutral particles. The primary electrons with high energy are originated from the thermal electrons besides thermo-emissive electrons. The microwave power is able to ignite plasma quickly without the preignition sequence. Especially, the needless of the thermo-emissive cathode will solve several malfunctions on the conventional DC discharge ion thruster system. The plasma source is a simple chamber made of soft iron with permanent magnets. In addition a microwave generator can feed power to both plasmas in the plasma source and the neutralizer because it does not require a reference potential. The conventional ion thruster system have seven DC power supplies: those to heater and keeper for the main cathode, discharge, acceleration, deceleration, heater and keeper for the neutralizer. And it integrates three flow controllers to the main chamber, the main cathode and the neutralizer.

On the other hand, the YOSHINO series ion thruster system developed by Institute of Space and Astronautical Science has a microwave generator and two DC power supplies for the ion acceleration and a flow controller as seen in Fig.1. The microwave power and propellant are distributed to both the discharge chambers by fixed dividers. The plasma source integrates a DC cutter in a microwave coaxial cable and an isolator in a propellant feed line in order to isolate DC high potential. The microwave neutralizer is electrically grounded without any DC power supplies. This feature makes the ion thruster system down-size as contrasted with the conventional system. Microwave power input ignites immediately both plasmas in the plasma source and the neutralizer after propellant injection.

The YOSHINO series ion thruster has several types historically. The first generation (model Y-I) generates plasma using the microwave cavity with 2.4GHz microwave\textsuperscript{1}. It has two discharge chambers neighboring on the cavity. Ions are extracted from the large chamber and mixed with electrons from the propellant tank. The microwave discharge is able to generate plasma without electrodes so that it is completely free from electrode erosion and contamination. A part of the thermal electrons is accelerated by the microwave electric field and ionizes collisionally neutral particles. The primary electrons with high energy are originated from the thermal electrons besides thermo-emissive electrons. The microwave power is able to ignite plasma quickly without the preignition sequence. Especially, the needless of the thermo-emissive cathode will solve several malfunctions on the conventional DC discharge ion thruster system. The plasma source is a simple chamber made of soft iron with permanent magnets. In addition a microwave generator can feed power to both plasmas in the plasma source and the neutralizer because it does not require a reference potential. The conventional ion thruster system have seven DC power supplies: those to heater and keeper for the main cathode, discharge, acceleration, deceleration, heater and keeper for the neutralizer. And it integrates three flow controllers to the main chamber, the main cathode and the neutralizer. On the other hand, the YOSHINO series ion thruster system developed by Institute of Space and Astronautical Science has a microwave generator and two DC power supplies for the ion acceleration and a flow controller as seen in Fig.1. The microwave power and propellant are distributed to both the discharge chambers by fixed dividers. The plasma source integrates a DC cutter in a microwave coaxial cable and an isolator in a propellant feed line in order to isolate DC high potential. The microwave neutralizer is electrically grounded without any DC power supplies. This feature makes the ion thruster system down-size as contrasted with the conventional system. Microwave power input ignites immediately both plasmas in the plasma source and the neutralizer after propellant injection.

The YOSHINO series ion thruster has several types historically. The first generation (model Y-I) generates plasma using the microwave cavity with 2.4GHz microwave\textsuperscript{1}. It has two discharge chambers neighboring on the cavity. Ions are extracted from the large chamber and mixed with electrons from the propellant tank. The microwave discharge is able to generate plasma without electrodes so that it is completely free from electrode erosion and contamination. A part of the thermal electrons is accelerated by the microwave electric field and ionizes collisionally neutral particles. The primary electrons with high energy are originated from the thermal electrons besides thermo-emissive electrons. The microwave power is able to ignite plasma quickly without the preignition sequence. Especially, the needless of the thermo-emissive cathode will solve several malfunctions on the conventional DC discharge ion thruster system. The plasma source is a simple chamber made of soft iron with permanent magnets. In addition a microwave generator can feed power to both plasmas in the plasma source and the neutralizer because it does not require a reference potential. The conventional ion thruster system have seven DC power supplies: those to heater and keeper for the main cathode, discharge, acceleration, deceleration, heater and keeper for the neutralizer. And it integrates three flow controllers to the main chamber, the main cathode and the neutralizer. On the other hand, the YOSHINO series ion thruster system developed by Institute of Space and Astronautical Science has a microwave generator and two DC power supplies for the ion acceleration and a flow controller as seen in Fig.1. The microwave power and propellant are distributed to both the discharge chambers by fixed dividers. The plasma source integrates a DC cutter in a microwave coaxial cable and an isolator in a propellant feed line in order to isolate DC high potential. The microwave neutralizer is electrically grounded without any DC power supplies. This feature makes the ion thruster system down-size as contrasted with the conventional system. Microwave power input ignites immediately both plasmas in the plasma source and the neutralizer after propellant injection.

The historical changes of the YOSHINO series is summarized in Table 1 including the Y-IV. Microwave power propagates in a plasma and causes the Electron Cyclotron Resonance (ECR) discharge near the magnets. The magnets not only confines the plasma but also generates the ECR magnetic field. The 5.9GHz microwave reduces the plasma cut-off effect so as to access the ECR zone. The ion production performance was drastically improved as seen in Fig.2, of which the vertical axis is expressed by logarithm. In the contrast to the Y-II, which has a microwave launcher on the side wall, the Y-III model is launched it from the rear wall through a gradual expanding wave guide to reduce microwave reflection\textsuperscript{3}. The neutralizer with the microwave discharge has been investigated independently to the thruster head, described in Ref.4.
Propellant Utilization Efficiency, %

Table 1

<table>
<thead>
<tr>
<th>Model Item</th>
<th>Y-I</th>
<th>Y-II</th>
<th>Y-III</th>
<th>Y-IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma Discharge</td>
<td>Cavity</td>
<td>ECR</td>
<td>ECR</td>
<td>ECR</td>
</tr>
<tr>
<td>Microwave Generator</td>
<td>Magnetron</td>
<td>TWT</td>
<td>TWT</td>
<td>Semi-con.</td>
</tr>
<tr>
<td>Frequency</td>
<td>2.4GHz</td>
<td>5.9GHz</td>
<td>5.9GHz</td>
<td>4.2GHz</td>
</tr>
<tr>
<td>Transmission Line</td>
<td>Wave Guide</td>
<td>Wave Guide</td>
<td>Wave Guide</td>
<td>Coaxial</td>
</tr>
<tr>
<td>Neutrilizer</td>
<td>Discharge</td>
<td>Thermo-Emissive Cathode</td>
<td>Thermo-Emissive Cathode</td>
<td>Dis-Charge</td>
</tr>
<tr>
<td>Cooling</td>
<td>Air Cooling</td>
<td>Water Cooling</td>
<td>Water Cooling</td>
<td>Radiation</td>
</tr>
</tbody>
</table>

Integration Test

The Y-IV model is redesigned on the basis of the Y-III in order to conduct the integration test, which has the following objectives: 1) to integrate the thruster by gathering subsystem developed individually, 2) to acquire data of the thrust performance in the system level, and 3) to get preliminary data for the endurance test. Figure 3 shows the cut view of the discharge chamber made of soft iron. It has no components to note but three rings of Samarium-Cobalt permanent magnet. The discharge chamber in 120mm internal diameter is fed microwave power through a circular wave guide from its rear wall. The Y-IV plasma source is set facing its outer wall to the hexagonal cryogenic panels in the vacuum chamber as seen in Fig. 4. Its microwave amplifier is replaced from the electromagnetic tube to the semiconductor. Figure 5 represents the diagram of the microwave
Fig. 5  Diagram of microwave power generator.

Fig. 6  Operation profile of Y-4.
generator system. The microwave divider distributes the amplified microwave power to both the plasma source and the neutralizer. The plasma source is isolated electrically by the DC cutter in the coaxial transmission line. The preliminary operation have just been performed as seen in Fig.6. The microwave power injection ignites both the plasmas in the plasma source and the neutralizer simultaneously. And in quick succession the acceleration voltage apply executes ion acceleration and beam neutralization so that the signal of beam current is measured in consistent with the acceleration voltage in time.

**Summary**

The microwave ion thruster system YOSHINO series has several advantages in contrast to the conventional DC discharge system. It makes the subsystems of the power supply and the propellant supply down-size drastically so that system weight, system robustness and computer load would be improved. Based on the historical achievements the thruster operation was demonstrated in the system integration test.

**Reference**


