Abstract—JAXA developed the Advanced Technology On-orbit Test Instrument for space Environment-mini (Atotie-mini) with Kyushu Institute of Technology to measure the potential of H-II Transfer Vehicle. The following issues are reported in this report. Atotie-mini integrated on HTV-4 was launched on August 4 2013. Atotie-mini was automatically activated when HTV-4 arrived at the orbit, and started the potential measurement. Atotie-mini acquired the potential data for approximately one month, which was almost equal to the entire operation time of HTV. During the operation, the HTV potential shows -25V to -40V in sunshine. The measurement results on several operation phase of HTV are reported in detail.

Keywords—HTV, Potential measurement, Plasma interactions.

I. INTRODUCTION

In low earth orbit, H-II transfer vehicle (HTV) and International Space Station (ISS), charges due to ionospheric plasma [1]. It is known that the primary discharge occurs on the surface of spacecraft when the potential of spacecraft against the ambient plasma reaches approximately -100V. In case of ISS, the bus voltage of solar array is more than 100V, therefore, the potential against the ambient plasma potentially exceeds -100V. The ISS equips with the plasma contactor to control the potential. Through the years of operation of ISS, it is known that the ISS potential is not so high to cause the discharge. Currently, ISS does not use the plasma contactor in principle.

In case of HTV, although HTV does not measure the generated voltage of solar array, the output voltage of solar array potentially exceeds 100V with consideration of its capability. It is necessary for us to measure the potential of HTV in flight condition to check the design of HTV against spacecraft charging. In addition, we measure the potential of HTV during docking operation to ISS to check the effect of HTV docking operation to potential of ISS.

We developed the module to measure the potential of HTV [2]. The name of module is Atotie-mini. Atotie-mini is the acronym of Advanced Technology On-orbit Test Instrument for space Environment-mini. Atotie-mini was launched at 4th of August, 2013. We report the Atotie-mini module and the result of operation.

II. ATOTIE-MINI MODULE

A. Introduction of Atotie-mini module

Atotie-mini module is shown in Fig.2-1. Atotie-mini module has two kinds of sensors, the electrotvoltmeter (TREK-3G) and spacecraft charging monitor (SCM). The electrical circuit boards are installed on the control box. The function of Atotie-mini is following.

- Potential measurement against ambient plasma using TREK-3G and SCM.
- Active thermal control using the heater.
- Communication with HTV using passive analog telemetry.

The Atotie-mini controller is assembled on the seat. The size of seat is almost same as the size of solar array panel. Atotie-mini module is attached on the brackets on HTV structure as the replacement of a solar array panel of propulsion module. Fig.2-2 shows Atotie-mini on HTV-4. The probes of TREK-3G and SCM are at +X direction of HTV. The surface material of HTV around the probes are dielectric material, such
as MLI and beta cloth. Because, there is no conductive material near probes, it is possible to measure the potential of HTV against ambient plasma without interaction of plasma sheath of HTV.

Table 2-1 shows the main characteristics of Atotie-mini module. The sensors measures the potential of HTV against ambient plasma ranges from -200V to +200V. To protect the thermal environment, Atotie-mini controller controls the temperature of the electrical circuit boards from -10°C to 45°C. For the passive thermal control, Atotie-mini module almost covered by MLI and Silver Teflon. The surface of MLI and Silver Teflon is not conductive surface for the potential measurement.

### Table 2-1: Main characteristics of Atotie-mini module

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mechanical property</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eigen value</td>
<td>525Hz</td>
</tr>
<tr>
<td></td>
<td>Size</td>
<td>720 x 420 x 97mm</td>
</tr>
<tr>
<td></td>
<td>Mass</td>
<td>4.3kg</td>
</tr>
<tr>
<td>2</td>
<td>Thermal control</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operational temperature range</td>
<td>-20°C to 60°C</td>
</tr>
<tr>
<td></td>
<td>Control temperature range</td>
<td>-10°C to 45°C</td>
</tr>
<tr>
<td></td>
<td>Power consumption</td>
<td>25.2W</td>
</tr>
<tr>
<td>3</td>
<td>Electrical characteristics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TREK-3G Measurement range</td>
<td>-200V to +200V</td>
</tr>
<tr>
<td></td>
<td>SCM Measurement range</td>
<td>-200V to +200V</td>
</tr>
</tbody>
</table>

B. Potential measurement mechanism of TREK-3G

The sketch of TREK-3G probe is illustrated on Fig.2-3. Thin dielectric coating covers the tip of core cable of coaxial cable. Fig.2-4 illustrates the block diagram of the electrical circuit of TREK-3G. TREK-3G measures the potential between the surface of dielectric coating and the structure of HTV. The ground of electrical circuit of TREK-3G is connected to the structure of HTV. TREK-3G controls the potential of center cable of TREK-3G probe against the ground to be equal to the surface potential of dielectric coating. In the low earth orbit, the surface potential of dielectric material is almost equal to the potential of ambient plasma. Therefore, TREK-3G can measure the potential of HTV against ambient plasma.

Generally, the spacecraft charges due to ionospheric plasma in the area of low latitude in low earth orbit. When HTV flights on sunlit region, the solar array panels supplies the generated power to HTV. The positive electrodes of solar array circuit collect the electron from ambient plasma. The negative electrodes of solar array circuit and the conductive parts on HTV body collect the ion from ambient plasma. The HTV has the negative potential that equals to the generation voltage of solar array panel to make zero the sum of electron current and ion current. In the dark region, the solar array does not generate the power and instead of that, the battery supplies the power to HTV. Therefore the difference of mobility of electron and ion determines the potential of HTV at several volts.

Because TREK-3G measures the surface potential of dielectric material on the tip of TREK-3G probe against the structure of HTV, TREK-3G measures the potential of ambient plasma against HTV. As the example, when TREK-3G shows +40V, the potential of HTV is -40V against the ambient plasma.
C. Potential measurement mechanism of SCM

SCM is designed based on the Plasma monitor (PLAM) on ISS which is developed by JAXA. SCM especially measures the spacecraft potential [1]. The SCM probe is the conductive plate as shown in Fig.2-5. The size of SCM probe is 150mm by 30mm. Figure 2-6 shows the electrical circuit diagram of SCM. SCM probe is connected to the structure of HTV via 1GΩ. In low earth orbit, the conductive plate exposed to space collects ion or electron from ambient plasma. When the potential of HTV against ambient plasma is negative, SCM probe collects ion, because SCM probe connects to the structure of HTV. Because SCM probe is connected to the structure of HTV via high-value of resistance, the potential of SCM probe has different potential against the structure of HTV. The ion collection from ambient plasma of SCM probe stops, when the potential of SCM probe becomes equal to the potential of ambient plasma. This fact means the potential difference of high-value resistance is equal to the potential of HTV against ambient plasma. Therefore, SCM measures the potential difference of high-value resistance.

It should be considered that SCM needs enough value of plasma current to measure the potential of HTV. When SCM is in the wake side of HTV, the accuracy of SCM becomes low.

III. PLASMA INTERACTION TEST

The requirements for the potential measurement of HTV by TREK-3G and SCM are following.

1. Atotie-mini controller should be electrically bonded to the structure of HTV.
2. Measurement mechanisms of TREK-3G and SCM are correct.

The electrical design, and electrical bonding test guarantee first requirement. However, we have to perform the plasma interaction test to verify the measurement mechanisms. We performed the plasma interaction test in the vacuum chamber which can simulate the plasma environment of low earth orbit. Figure 3-1 illustrates the test configuration.

TREK-3G probe and SCM probe are attached on Atotie-mini controller. Atotie-mini controller is put inside the vacuum chamber as shown in Fig.3-2. In flight configuration of Atotie-mini module, the dielectric materials, such as MLI and Silver Teflon, cover the Atotie-mini module. The Polyimide sheet covers the exposed conductive material to simulate the flight configuration of Atotie-mini.

HTV is electrically floating from space. Therefore, Atotie-mini controller must be insulated from vacuum chamber. The insulating transformer cuts it electrically from the ground system equipment (GSE) and vacuum chamber. The high voltage power source is connected to the floating ground of Atotie-mini and GSE.
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The test environment is shown in Table 3-1. The test is performed under the plasma density of $2 \times 10^{11} \text{m}^{-3}$ and $4 \times 10^{12} \text{m}^{-3}$. As it is shown in Table 2-2, TREK-3G and SCM measures the potential ranges from -200V to 200V. In case of negative bias, -180V is the threshold voltage of discharge on the surface. In case of positive bias, 150V is the threshold voltage of glow discharge. Therefore, the performance of TREK-3G and SCM is measured from -180V to 150V. Figure 3-3, 4 show the characteristics of TREK-3G and SCM. Figure 3-3, 4 show the output voltage is proportional to the bias voltage. This fact means that the measurement mechanisms of TREK-3G and SCM is verified.

IV. FLIGHT EXPERIMENT

Atotie-mini module is equipped with HTV-4. HTV-4 launched at August 4, 2013. Atotie-mini module was automatically activated by stored command when HTV-4 arrived at the orbit. Atotie-mini acquired the potential data for approximately one month, which was almost equal to the entire operation time of HTV. As it is mentioned before, the potential of HTV is determined by the current balance of ion current and electron current from ambient plasma. It means the exposed conductive area on HTV structure influences the potential. It is possible to imagine that the attitude of HTV influences the potential. As an example, assuming RAM side of HTV has large area of exposed conductive material, large value of ion current flows into HTV, therefore, HTV does not have large potential difference against ambient plasma.

We distinguish the event as Table 4-1 to detail check the potential profile of HTV. Figure 4-1 shows the HTV Yaw Angle Definition in Rendezvous Phase. Space Station Remote Manipulator System (SSRMS) operation phase is the capturing sequence to ISS. In this phase, HTV is connected to ISS via 5kΩ resistance on robot arm. In the ISS attached phase, HTV is connected to ISS. The bonding resistance between ISS and HTV is enough low to ignore the potential difference between them.
A. **LVLH**

Figure 4.2 shows the potential profile at LVLH, flight phase. As it is mentioned above, TREK-3G and SCM measures the potential of ambient plasma, TREK-3G and SCM show the positive voltage when HTV changes negative against ambient plasma. For example, assuming sensors show 10V, it means HTV changes -10V against ambient plasma.

The solar array current (Green dot) indicates the position of HTV in the orbit. In case of 0A, HTV is in the dark region. Figure 4.1 shows the potential of HTV is approximately 5V at the dark region. The HTV potential is approximately 30V in the sunlit region. Contrary to our expected potential, the potential of HTV is low. The exposed conductive area of HTV is larger than that we expected. We need to investigate the potential of HTV based on the charging simulation.

In case of LVLH, +X side of HTV is flight direction as it is shown in Fig. 4.1. In case of this attitude, Atotie-mini module is in the wake side of HTV. As it is mentioned in Table 4.1, SCM shows smaller value than TREK-3G in the sunlit region.

B. **Yaw+90’**

Figure 4.3 shows the potential profile at Yaw+90’, flight condition. TREK-3G shows approximately 40V in the sunlit region. SCM shows smaller value than TREK-3G as mentioned in Table 4.1. TREK-3G at Yaw+90’ shows higher value than the value at LVLH. This fact indicates that the conductive area on RAM side at Yaw+90’ is decreased compared with LVLH.

C. **Yaw+180’**

Figure 4.4 shows the potential profile at Yaw+180’, flight condition. The potential varies from 10V to 40V in the sunlit region. In the dark region, the potential is below 10V.

D. **SSRMS operation**

Figure 4.5 shows the potential profile in SSRMS operation. The potential varies from 10V to 40V in the sunlit region. We cannot distinguish the effect of SSRMS operation to potential of HTV.

E. **ISS attached phase**

Figure 4.6 shows the potential profile at ISS attached phase. The measurement result of FPMU is shown in Fig.4.6. TREK-3G and SCM shows similar value with FPMU. This fact shows that Atotie-mini module measures the potential of HTV. During the ISS attached phase, the potential of HTV is below 20V. As we expected, HTV has same potential as ISS.

V. SUMMARY AND FUTURE WORK

We developed Atotie-mini module to measure the potential of HTV during operation. Contrary to our expected HTV potential, the potential of HTV is not high. In the attitude of Yaw+90’, flight phase, the potential of HTV is the highest during operation.

As the future work, we will investigate the reason of lower charging potential of HTV. At first, we will develop the charging model based on MUSCAT. We will correlate the charging model based on the flight measurement data.

Furthermore, we will launch advanced model of Atotie-mini module, called KASPER module. The KASPER module measures the potential of HTV, plasma current at KASPER module and debris impact. The KASPER module will be integrated to HTV-5.

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REFERENCES


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<tr>
<th>Operation Phase</th>
<th>Attitude</th>
<th>Expected HTV potential</th>
<th>Comment for sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flight</td>
<td>LVLH</td>
<td>&gt; At early time of sunlit region, the potential is approximately -100V because of the generation voltage of solar array circuit.</td>
<td>Sensors toward wake side of HTV. SCM shows smaller value than TREK-3G</td>
</tr>
<tr>
<td></td>
<td>Yaw+90°</td>
<td>&gt; In sunlit region, basically, the potential varies under -90V based on the controlled voltage.</td>
<td>Same as LVLH</td>
</tr>
<tr>
<td></td>
<td>Yaw+180°</td>
<td>&gt; In dark region, potential is several V.</td>
<td>Same as LVLH</td>
</tr>
<tr>
<td>SSRMS operation</td>
<td></td>
<td>The potential is middle of ISS potential and HTV potential during flight condition, because HTV attaches ISS via 5kΩ resistance.</td>
<td></td>
</tr>
<tr>
<td>ISS attached</td>
<td></td>
<td>Same potential as ISS</td>
<td>Sensors toward in ram side</td>
</tr>
</tbody>
</table>

![Fig.4-1 HTV Yaw Angle Definition in Rendezvous Phase](Image)
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Fig. 4-2 HTV potential profile at LVLH, flight phase

Fig. 4-3 HTV potential profile at Yaw+90', flight phase
Fig. 4-4 HTV potential profile at Yaw+180°, flight phase

Capture
SSRMS manuever start
SSRMS Position verification complete
CBM Berthing/Install complete

Fig. 4-5 HTV potential profile at SSRMS operation
Fig. 4-6 HTV potential profile at ISS attached phase