Development of vacuum arc thruster for nano satellite

IEPC-2013-264

Presented at the 33rd International Electric Propulsion Conference,
The George Washington University • Washington, D.C. • USA
October 6 – 10, 2013

Shingo Fuchikami[1], Masayoshi Nakamoto[2], Kazuhiro Toyoda[3], and Mengu Cho[4]

Kyushu Institute of Technology, Kitakyushu, Fukuoka, Japan

Abstract: A nano-satellite which mounts an attitude control system has little space. Therefore, there are few choices of attitude control methods. The vacuum arc thruster of this research is small and lightweight, thus it is suitable for the attitude control of the nano-satellite, while the possibility of the attitude control system of a nano satellite is extended. This research evaluates the performance of a vacuum arc thruster, a thrust density of which is very small. Therefore, the evaluating device should detect small thrust. This detection is performed from displacement of a thrust target. The performance of the vacuum arc thruster was evaluated by the impulse bit in this research. The impulse bit of this thruster was µNs order. We measured velocity of the fluid. Result of the experiment, flight velocity of the fluid was found to be 12km/s approximately. Moreover, we changed applied voltage and capacitance of the discharge indicating circuit, and we found that the impulse bit changes.

Nomenclature

L	=	string length
x	=	displacement
g	=	gravitational acceleration
m	=	weight of thrust target
$\bar{v}$	=	average velocity of vapor
Δm	=	vapor mass per one shot (called mass shot)

I. Introduction

Thruster mounted on a nano-satellite must be small and light. Propellant of vacuum arc thruster of this study is a solid conductor. This thruster is ignited by the primary discharge generated in a plasma environment. And it is suggested that the direct drive from a solar cell is possible[1]. From the above, this thruster does not require piping, fuel tank, igniter (such as high-voltage pulse generator), and DC/DC converter. Therefore, this vacuum arc thruster is possible to realize a compact and simple structure. Thruster head of vacuum arc thruster is φ6mm x 14mm, and is 2[g] in mass.

A small satellite developed in Kyushu Institute of Technology (called Horyu-2) generated 300V on orbit[2]. High voltage solar array have been used for power generation. Applied voltage for the vacuum arc thruster can use power from this high voltage solar array directly.

CFRP is a composite material of carbon (conductor) and resin (insulator). Under plasma environment, many triple junctions exist at the section of CFRP. The triple junction is deeply concerned with the primary discharge frequency. Therefore, we think that CFRP is suitable for the propellant.

[1] Master 1, Department of Electrical and Electronic Engineering, n349525s@tobata.isc.kyutech.ac.jp
[2] Associate professor, Department of Electrical and Electronic Engineering, toyoda@ele.kyutech.ac.jp
[3] Associate professor, Department of Electrical and Electronic Engineering, toyoda@ele.kyutech.ac.jp
[4] Professor, Department of Applied Science for Integrated System Engineering, cho@ele.kyutech.ac.jp

The impulse bit of the vacuum arc thruster of this research is μN-s order. We developed the equipment which can measure very small thrust. Since injecting material reflected, the flat type thrust target which created before included the error[3]. The cone type thrust target created this time can make this error small. The impulse bit was measured with this cone type thrust target.

II. Principle of Vacuum Arc Thruster

Figure -1 shows the circuit of the vacuum arc thruster of this research. A capacitor is charged by the power supply. An anode is connected to the satellite ground. The anode and cathode is shorted by the primary discharge generated by the triple junction. By the electric charge stored in the capacitor, the primary discharge reaches arc discharge. Metal vapor is jetted from the discharging point of cathode. The reaction of this metal vapor becomes a thrust of a satellite.

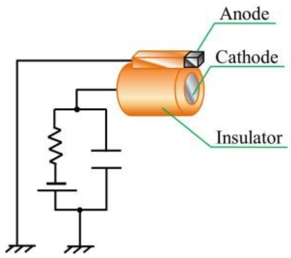

Figure 1. Circuit of a vacuum arc thruster.

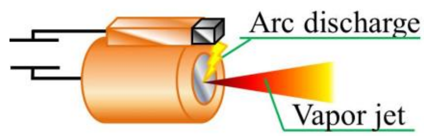

Figure 2. Jet of the thruster

Some triple junction exists on the discharge point of the thruster of this study. In a plasma environment, such as low earth orbit, an electric field is concentrated at the triple junction. The electric field is increased, and the accelerated electrons will be emitted from the propellant surface. While moving to the anode, the electrons will hit the propellant surface. The struck propellant surface generates plasma. Between the anode and the cathode is short-circuit by this plasma. As a result, the arc discharge occurs. Figure -3 shows the waveform of the arc discharge was generated by utilizing this principle. Red line shows voltage of capacitance, and blue one shows current of discharge.

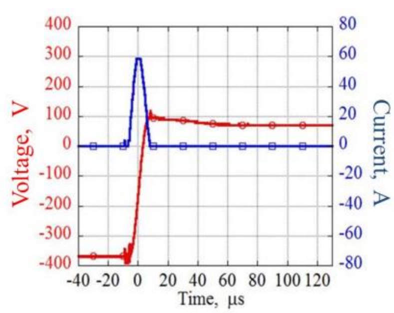

Figure 3. Arc discharge

A. Measurement of the vapor velocity

We measured the vapor velocity is jetted from a cathode. Experiment configuration is shown in Fig.4. We used an igniter in this experiment. It was because the experiment is performed in a short time and active.

We used a Quadrupole Mass Spectrometer (QMS) to detect the vapor material. We measured a distance from the cathode to QMS. And we measured a time of flight of the jet vapor. Velocity of vapor was calculated from value of distance and time.

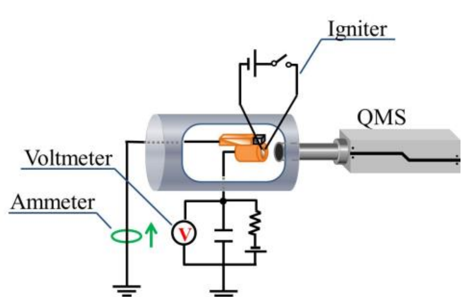

Figure 4. Experiment configuration

We calculated the velocity distribution of the jet vapor, and it is shown in Fig.5. Furthermore, in order to calculate the average velocity of jet vapor, weighted velocity distribution was calculated. It is shown in Fig.6.

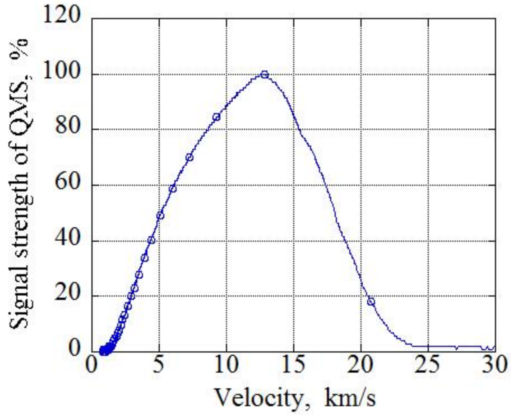

Figure 5. Velocity distribution

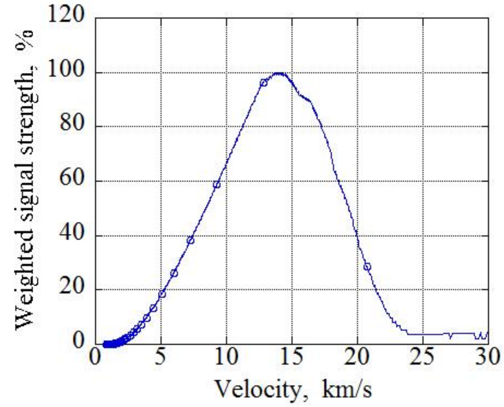

Figure 6. Weighted velocity distribution

Integral value of the weighted velocity distribution divided by the integral value of the velocity distribution is the average velocity of vapor.

Average velocity of vapor when capacitance is changed is shown in Fig.7. Specific impulse was approximately 1200 seconds.

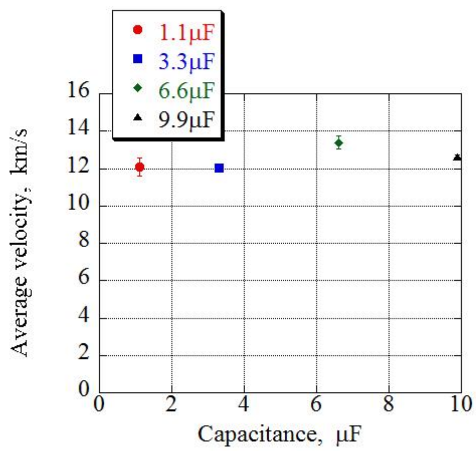

Figure 7. Average velocity of each capacitance (-300V applied)

B. Selection of Propellant

We tried some materials for propellant of vacuum arc thruster. The thruster was compared to vapor velocity of each propellant material. The tested material was aluminum, tungsten, and Carbon Fiber Reinforced Plastic (CFRP).

Figure 8.1. Aluminum sample

Figure 8.2. Tungsten sample

Figure 8.3. CFRP sample

The average velocity of vapor for each propellant is shown in Fig.9. A horizontal axis is the voltage applied to the capacitor, and a vertical axis is the average velocity of vapor. Even if it changed the material of the propellant, average velocity of vapor was almost unchanged.

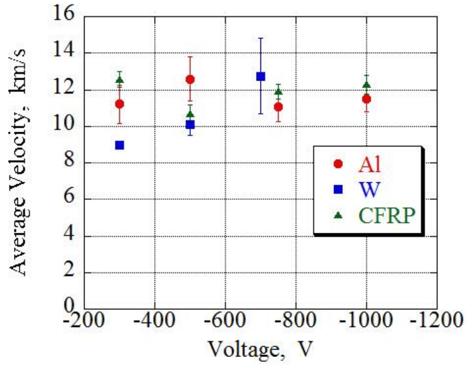

Figure 9. Average velocity of each propellant

There are many triple junctions in a cross section of CFRP. Therefore, the thruster can generate a primary discharge without an igniter. We think that CFRP is useful as a material of the propellant.

C. Measurement of impulse bit

The scale of arc discharge is determined by the amount of electric charges stored in the capacitor. Capacitance and applied voltage were changed and the impulse bit was measured.

Specification of the thrust target is shown in Fig.10 and Table.1. We measured displacement of the thrust target when metal vapor is injected. The impulse bit was calculated from the Eq.1.

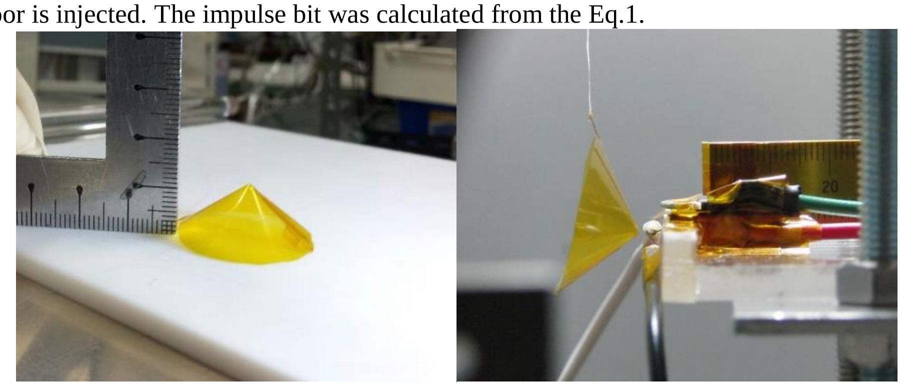

Figure 10. Cone type thrust target

Table 1. Specification of cone type thrust target

Material	Weight, mg	Height, mm	Diameter, mm
Polyimide	20	12.5	25

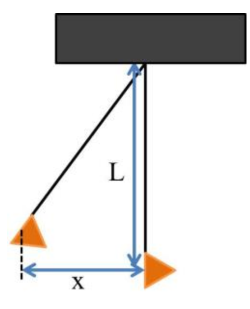

Figure 11. Impulse bit measurement parameter

$$I_{bit} = F \cdot \Delta t = m\sqrt{2g(L - \sqrt{L^2 - x^2})} \qquad (1)$$

A photograph of a moment of arc discharge is shown in Fig.12. And the impulse bit of the vacuum arc thruster is shown in Fig.13 and Fig.14.

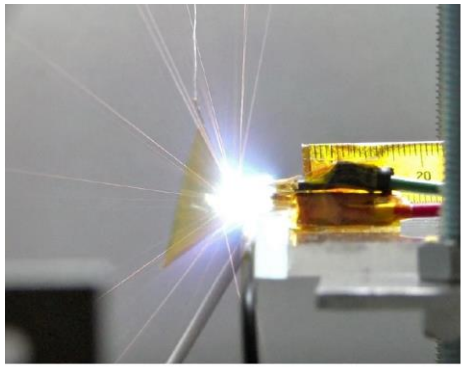

Figure 12. Arc discharge during impulse bit measurement

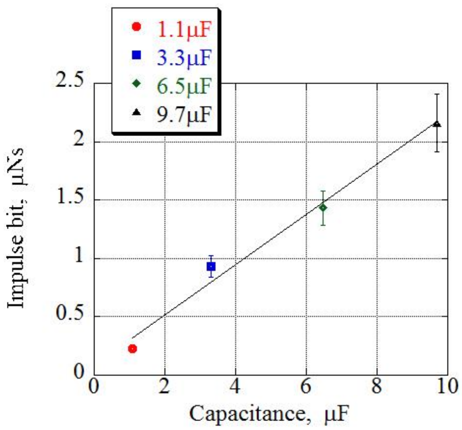

Figure 13. Impulse bit – Capacitance (-300V applied)

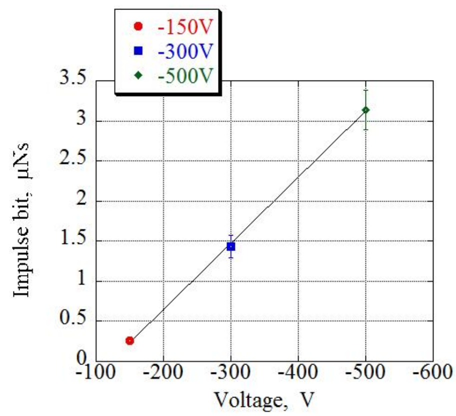

Figure 14. Impulse bit – Voltage (6. 6μFCapacitance)

When the capacitance or applied voltage was increased, the impulse bit increased.

D. Test of prototype

We have created a prototype of thruster head of vacuum arc thruster. The specification of this thruster head is shown in Fig.16 and Table.2.

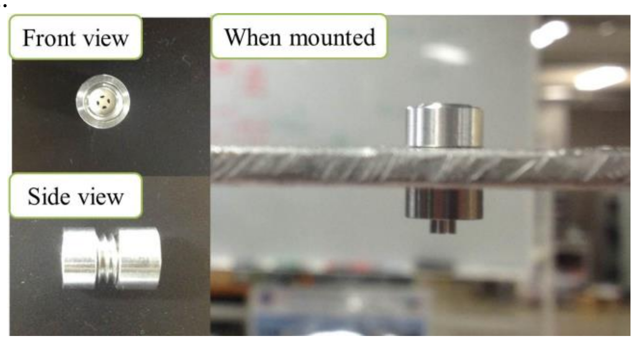

Figure 16. Thruster head of vacuum arc thruster

Table 2. Specification of thruster head

Material	Propellant	Weight, g	Size, mm
Aluminum	CFRP	2	φ6 x 14

In this experiment, plasma environment was made in the chamber. There is no igniter for generate the discharge. Triple junction of propellant generates the primary discharge instead of the igniter.

High voltage solar cell can generate 300V. All propulsion system (thruster head, condenser, high voltage solar array, protective resistance) was placed in a vacuum chamber with no connection to external units. And we checked that the thruster is discharged.

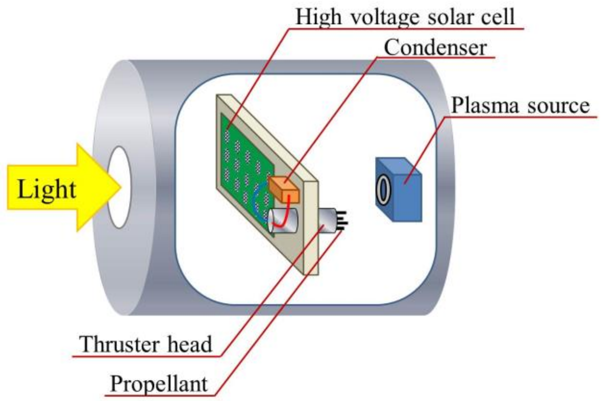

Fig 17. Conceptual diagram of thruster system

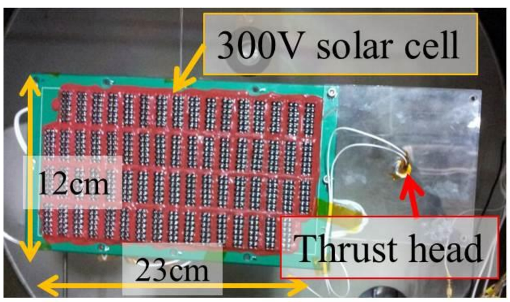

Fig 18. Thruster system

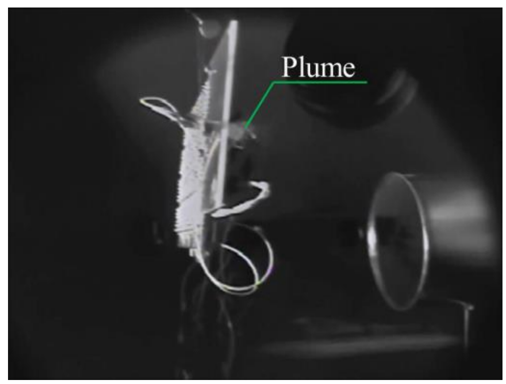

Fig 19. Arc discharge

III. Conclusion

The vacuum arc thruster was developed for nano-satellites. The plasma vapor velocity and impulse bit were measured. CFRP was suitable for propellant, because primary discharge occurred easily in plasma environment. Scale of arc discharge was increased by increasing the applied voltage and capacitance. As arc discharge is lager, impulse bit increase. We have created a small thruster head. The thruster was checked that it works in plasma environment.

References

[1]Masayoshi, N. Shingo, F. Kazuhiro, T. and Mengu, C. “300V direct drive vacuum arc thruster for nano-satellite”, 51st AIAA Aerospace Sciences Meeting, AIAA 2013-0812

[2]Shunsuke, I. Tatsuya, Y. Hirokazu, M. Minoru, I. Kazuhiro, T. and Mengu, C. “On-Orbit Data Analysis of high Voltage Technology Demonstration Satellite HORYU-II”, 51st AIAA Aerospace Sciences Meeting, AIAA 2013-0813

[3]Shingo, F. Masayoshi, N. Kazuhiro, T. and Mengu, C.”Development of Vacuum Arc Thruster for Nano-Satellite in Low Earth Orbit Plasma”, 29th ISTS