Vacuum Arc thruster development for Horyu-4 satellite

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Abstract: Article describe Vacuum Arc thruster (VAT), which was developed and manufactured in Kyushu Institute of Technology, Japan. Purposed to use this thruster on-board micro and nano satellites for attitude control, orbital station keeping or momentum wheels. Firstly, thruster will be present on-board student satellite project- Horyu-4, which will be launch in 2015 by H2A rocket. Satellite size 49.3 cm x 48.7 cm x 49.0 cm, and weight about 10 kg. Main mission of this project is discharge experiments. Thruster head mass is around 15 gram and size ϕ13 mm x 21 mm length. Thruster's anode manufactured from aluminum, cathode is Carbon Fiber Reinforced Plastic (CFRP). This thruster has specific impulse 1200 s,the impulse bit is 2μNs at 0.45 J and per one discharge can produce angular velocity 50μdeg/s/discharge. Velocity detect on-board by high-resolution gyro sensor. Power VAT receives directly from High voltage solar array(300 V). Efficiency of thruster is 2.6 %.

I. Introduction

Solution of many problems associated with Space expanding space electric propulsion systems, executive bodies which are electric engines.
Electric propulsions (EP) are a class of devices in which the driving force is obtained by converting electric energy into kinetic energy are emitted from the mass of the working body.
EP opened a new perspective direction in space propulsion engineering. They differ from cosmic engines operating on chemical fuel, higher efficiency. One of the popular for small microsatellite is electric propulsion from ablation thrusters class, which is uses electric energy to evaporate solid propellant and produce arcs in plasma. the important advantages of this thrusters is small size, small weight, long lifetime, small level of power consumption, no ignition system, no gas system for propellant.
We purpose Vacuum Arc Thruster as a propulsion for microsatellite maneuvers. In VAT uses the principle of acceleration of charged particles static electric field, which is used to create electricity. The sources of this energy can be different: nuclear power plant spacecraft, photoelectric converter, the thermoelectric converter or thermionic converter, solar arrays.

The division of energy sources and the working substance in electric propulsion-can determines the range of applicability of electro jet propulsion systems for spacecraft with large temporal activity functioning.
This Vacuum Arc thruster will be work on-board microsatellite Horyu-4.

II. Horyu-4

Satellite Horyu-4 was designed and manufacturing in Kyushu Institute of Technology and will be launch by H2A rocket in 2015.Name of this satellite is Arc Event Generator and Investigation Satellite (AEGIS), Horyu-4. Now, in this project take part 43 persons from the Laboratory of Spacecraft Environment Interaction Engineering (LaSEINE) are involved in the project. This number includes professors, research staff, contractor, and students.HORYU-IV mission statement is to acquire on orbit data of discharge phenomena occurring on high voltage solar array to deepen understanding of satellite charging, to contribute to the reliability improvement of current space systems, and to positively contribute to the realization of future high power space systems. Discharge experiment is Acquire current waveform and picture of discharges occurring on solar arrays. The mission aims at verifying whether what has been observed during gorund-based experiment is the same as what is occurring in space. For instance, there are no walls in space, and this might influence the results. High voltage solar array (HVSA), as a source of electric power for sub-systems on-board, generate high voltage to bias dedicated solar cells at -300V for on-orbit evaluation of discharge mitigation methods (film-covered or coated solar cells). And Vacuum Arc Thruster demonstrate trigger-less thruster technology that uses HVSA (300V or more) for ignition instead of a booster circuit

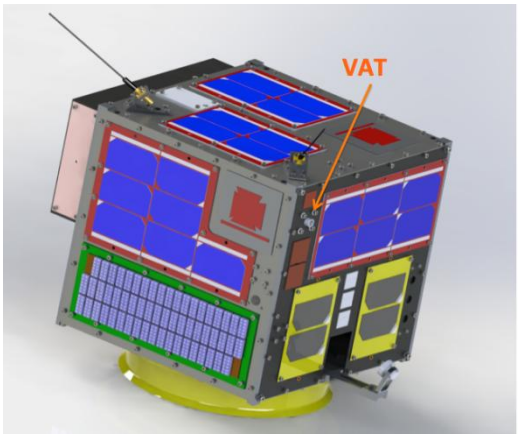

Figure 1. Horyu-IV satellite

HORYU-IV is a cubic-shaped nano-satellite with dimensions of 490mm × 490mm × 495mm, including antennas and mirror holder, with an approximative mass of 10kg. The size of the satellite main external structure is 331mm × 285mm × 331mm, without antennas and mirror holder. Orbit altitude 575 km and inclination 31 deg.Together with main mission on-board will be operate Double Langmuir probe, Electron-emitting film, Secret ink, Photoelectrons current measurement, Camera, Oscilloscope. Discharge experiments will be provide by On-board

oscilloscope (OBO) and Arc Vision Camera (AVC). First one will be operate with HVSA`s current probe and measure VAT`s discharge current too. AVC will photography the solar arrays before and after the discharge spark, and will photography VAT`s discharges.

III. Vacuum Arc Thruster

VAT principle consists in generating a vacuum arc thanks to the load accumulated into the condenser. Then, upon vacuum arc creation, metallic vapor is ejected from the cathode and this reaction is used as the thrust force. For charging the condenser, HVSA is used, which makes VAT a direct drive system (300 V directly apply from HVSA system) that does not require booster circuit. Moreover, the cathode used as propellant is made of carbon fiber reinforced plastic (CFRP). Thanks to the interaction of the CFRP surface with the surrounding plasma, very small discharges can be generated to trigger vacuum arcs. The structure of the thruster head that includes the cathode, anode, and insulator parts is described on Figure 2.

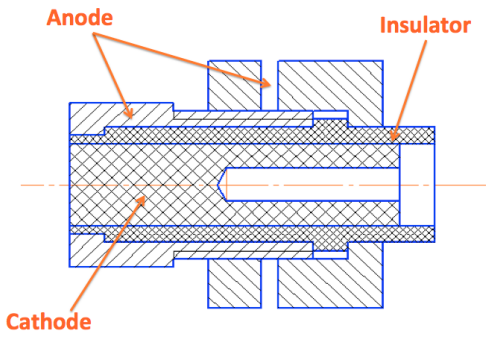

Figure 2. Vacuum Arc Thruster

Specially for this thruster and for HVSA system on-board satellite was designed electric circuit. On the Figure 3, green line of circuit is charging line directly connected to HVSA, and a red line is discharge circuit with 10 microF main discharge capacitor connected to Cathode and Anode of VAT. On the cathode use current probe to measure discharge parameters on-board by OBO (On-board oscilloscope).

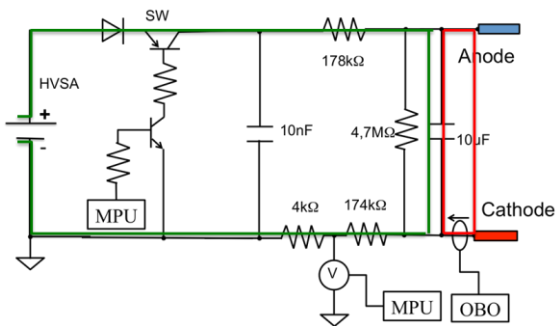

Figure 3. Electric circuit for Horyu-4 VAT

III.I. VAT's cathode material

To choose the thruster propellant was measure average velocity of particles, which evaporate and accelerate from propellant in electric field. purposed to measure this dates for three different propellant: Aluminum, Tungsten and Carbon Fiber Reinforced Plastic (CFRP).CFRP is a composite material made of carbon fiber (conductor) and resin (dielectric). Results presented in comparing on the Figure 4.

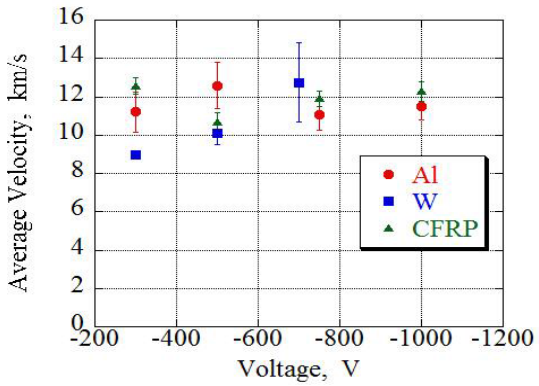

Figure 4. Average velocity for thruster propellants

A considerable number of triple junction points (the region called a triple junction is the boundary of the conductor, the dielectric, and plasma)was registered for the material CFRP, which was followed by working body for VAT.

III.II. Experiments with VAT

In geometry with CFRP like the propellant for VAT, polyimide insulator and Aluminum anode, was make simple model of thruster for testing (Figure 5).

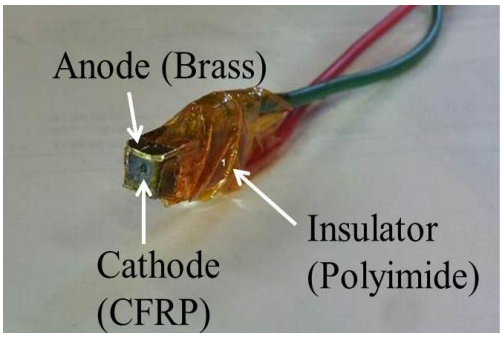

Figure 5. Simple model of VAT

Thruster was install in LEO vacuum chamber, to calculate arc numbers in condition closed to space. Real satellite propulsion model doesn't use igniter, so we have to know discharge frequency. Pressure in chamber was 10-3 Pa, and for electron cyclotron plasma source, that simulate plasma in chamber we had: electron temperature 1.7 eV, electron density 2.5E11 m-3, gas Xenon. Thruster, with circuit and the main discharge capacitance (10 microF), installed on the special stand inside vacuum chamber.From outside discharge moment and arc numbers detected

by camera, and current waveforms by oscilloscope. Scheme of experiment presented on the Figure 6.

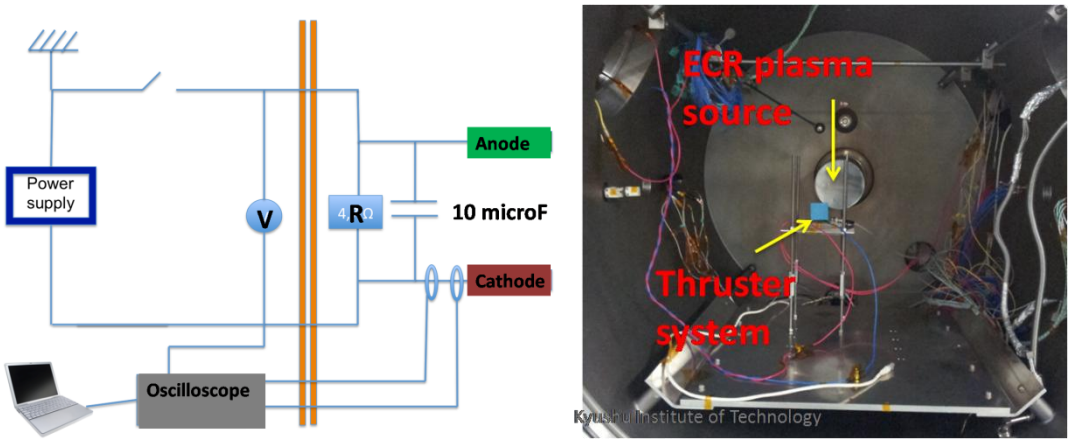

Figure 6. Scheme of VAT testing in LEO chamber

Was detected that each discharge has a length in 5 microsec and every discharge we have to waiting around 20 minutes. Its mean, that discharge frequency is 0.83mHz. Discharge current was measure two times with 300 V and 400 V apply. Detected discharge for both situation (Figure 7).

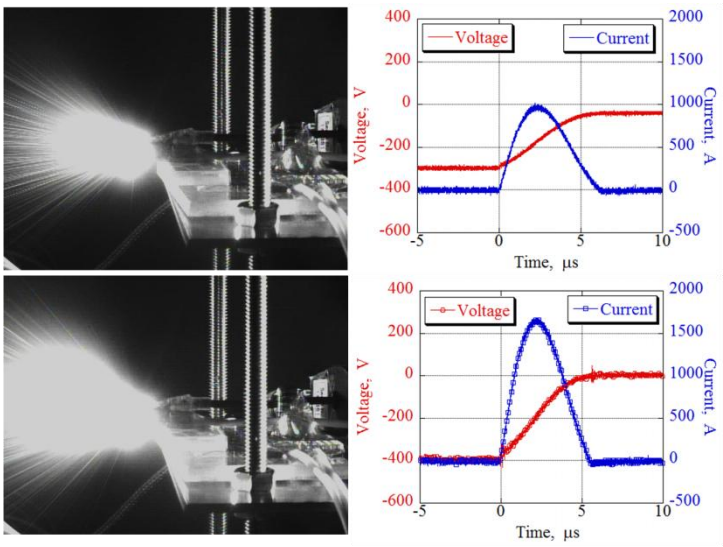

Figure 7. Discharge testing of VAT

To measure Impulse bit of thruster system, he was installed in general purpose chamber (vacuum 3E-3 Pa, without plasma source). Use ignition system, to receive discharges dates as soon as possible and provide measurements for different level of applied voltages. For measurements used special target, manufactured from polyimide, and suspended by string under the thruster. Target located vey close to the thruster surface. Target mass is 20 microgram. By the geometry between target and thruster body before and after discharge was calculated impulse bit (Figure 8).

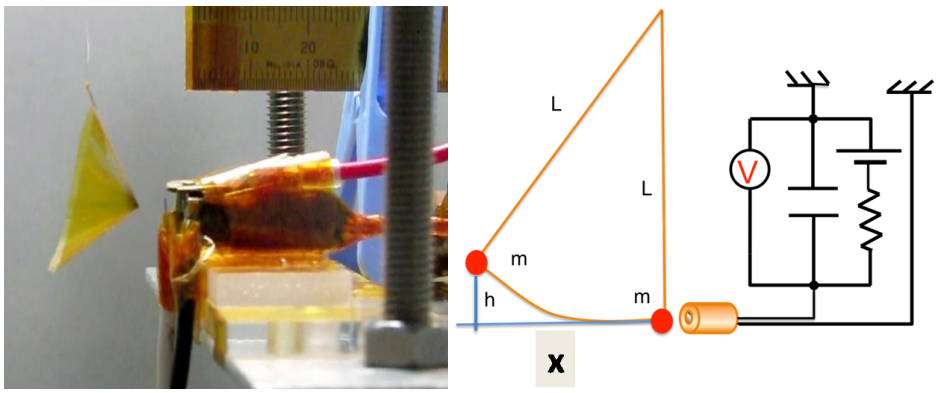

Figure 8. Impulse bit measurements

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

where is F-thrust of VAT; Δt – discharge time, m- target mass, L- distance from target to filaments fixing place, x- displacement.
Changing parameter was applied voltage, which changed from 150 volts to 350 volts. Results presented on Figure 9.

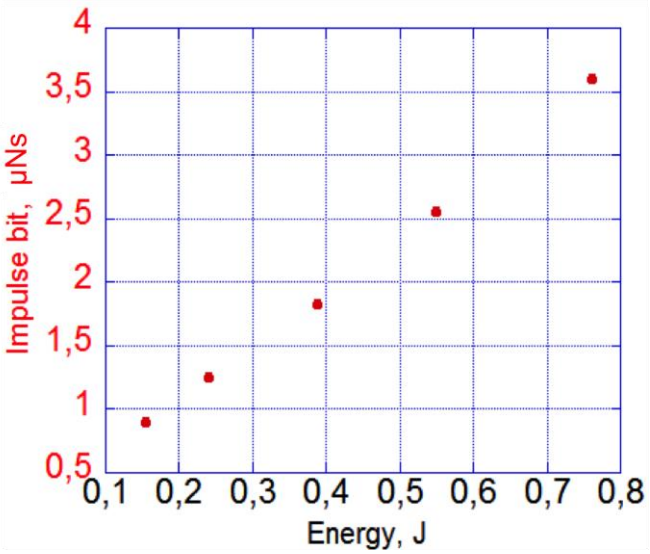

Figure 9. Impulse bit dates for VAT with CFRP

Knowing discharge period and impulse bit was calculated thrust for VAT which will be operate on-board Horyu-4 with 300 V apply and CFRP propellant with frequency 0.83 mHz.As we can see from the results on the Figure 9, Impulse bit at 300 V apply and 10 microF discharge capacitance (0.45 Joule) is 2 microNs.

$$\mathrm{F} = \mathrm{I_{bit}} \cdot \mathrm{f} = 2 \cdot 10^{-6}\mathrm{Ns} \cdot 0.83\mathrm{mHz} = 1.66\ [\ \mathrm{nN}] \tag{2}$$

and efficiency of this thruster:

$$\delta = \frac{I_{bit} \cdot v_E}{2 \cdot W} \cdot 100\% = \frac{2 \cdot 10^{-6} Ns \cdot v_E}{C \cdot U^2} \cdot 100\% = 2.66\ \% \quad (3)$$

where is C- discharge capacitance in main electric circuit, 10 microF, U-apply voltage, 300 V, vE- average velocity, 12 km/sec.

According to the center of mass of VAT and Horyu-4, and momentum of inertia 1.9E-7 Nm, was calculated angular velocity produced by thruster per one discharge- 50microdeg/sec/discharge.

If we will see to AODS Horyu-4 gyrosensor, his resolution is 0.008 deg/sec. So thruster has to makes 160 discharges to be detected by this gyro. If each discharge we are waiting 20 min, we need 3200 minutes for detecting by AODS system or around 54 hours.

IV. Conclusions

Was presented Vacuum Arc Thruster for Horyu-4 microsatellite. Described satellite project with main missions. For VAT provided testing to indicate the best propellant, this is CFRP. For simple model of VAT measured arc numbers and calculated discharge frequency. To know, how much is VAT thrust, we calculated impulse bit dates from discharge experiments, and know, that at 300 V apply voltage with 10 microF capacitor in discharge circuit thruster has 1.6 nF of thrust and may produce anglar velocity 50 microdeg/sec/discharge. One of the way to improve frequency and angular velocity- it's using new type of CFRP propellant or magnet system [5].

V. Reference

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