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Development of Microwave Engine

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Abstract

Based on a new concept, a low power electrostatic thruster is being developed for its application to 50 kg class satellite, which is named "Microwave Engine". The proto-model (PM) of the microwave engine was manufactured and the qualification test (QT) was conducted. The estimated performances operated at 26.6W are 1250 seconds in specific impulse, 0.36mN in thrust and 10% in thrust efficiency, respectively. In future work, we started to research the new microwave engine which is operated at higher power using hydrazine as propellant for applications of geostationary satellites.

INTRODUCTION

At the present time, there is new tendency in which a constellation of small satellites is launched into low earth orbit for their networking operations, instead of launching traditional large geostationary satellites. For this new change, the demand of low power electric propulsion system for an attitude control and station keeping of small satellites is getting larger. Based on this situation, a low power electrostatic thruster has been developed for its application to 50-100 kg class satellite, which is named "Microwave Engine". In this mechanism, the advantage of generating plasma by microwave made the low power operation of Microwave Engine possible. This operational performance was obtained in the previous work [1,2]. The objectives of this paper are to.

1) manufacture the microwave engine PM,
2) conduct the qualification test (QT) .

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Tl

thruster are there. This thruster comprises an ion acceleration chamber and electron emitter (neutralizer). Propellant gas is xenon. The plasma is generated using microwave discharge. Two electrodes are located at upstream and downstream of the discharge chamber, respectively. The neutralizer is combined with the electrode of the downstream as well as the hall type accelerator. Applying acceleration voltage between two electrodes, an electrostatic field gradient is formed in the plasma, accelerating ions to generate thrust. The principle of the microwave engine is represented in Fig.1.

Figure 2 shows the photograph of the microwave engine head which equips eight neutralizers on the front surface and four igniters inside the discharge chamber. The aperture diameter of the thruster is one centimeter. Figure 3 shows the photograph of the microwave engine operation. Typical performances of the microwave engine are described in Table 1.

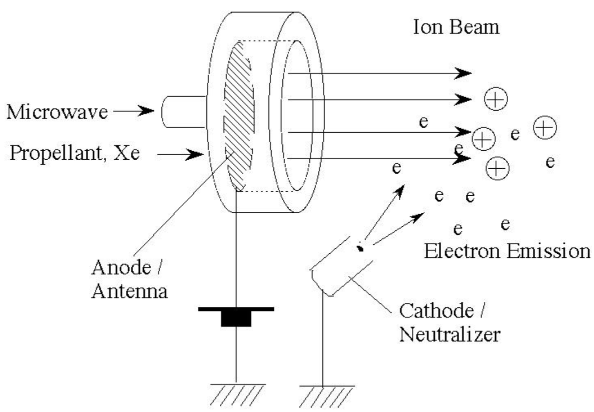

Fig.1 Principle of Microwave Engine

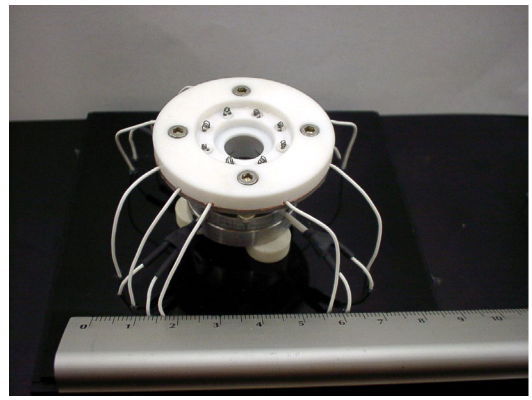

Fig.2 Microwave Engine Head

Fig.3 Operation of Microwave Engine in Vacuum Chamber

Table 1 Performances of Microwave Engine System

Propellant	**Xenon**
Propellant Mass Flow Rate	**0.3 sccm**
Thrust	**0.36mN @0.3sccm**
Specific Impulse	**1250 sec**
Power Consumption	**26.6 watts nominal**
Weight	**Engine Head : 94 g**
Size	**Engine Head : 46 mm x 57 mm x 89 mm**
Vibration Level	**20 Grms**
Operation Tempareture	**-10C to +50C**
Operation Voltage Input	**12V DC**
Life	**>5000 hours continuous firing (TBD)**
Status	**PM**

BLOCK DIAGRAM AND INTERFACE

The thruster system consists of engine head, propellant management unit, microwave power unit, acceleration power unit, neutralizer power unit, ignition power unit, interface unit and onboard computer (including CPU over-current protection circuit). The operation status is directed by the command via the interface unit and the onboard computer controls each electric device in accordance with the programmed sequence. The telemetry monitors success/ unsuccess of each sequence, acceleration voltage, beam current, thruster temperature, propellant tank pressure and so on. The block diagram of the engine system is shown in Fig.4.

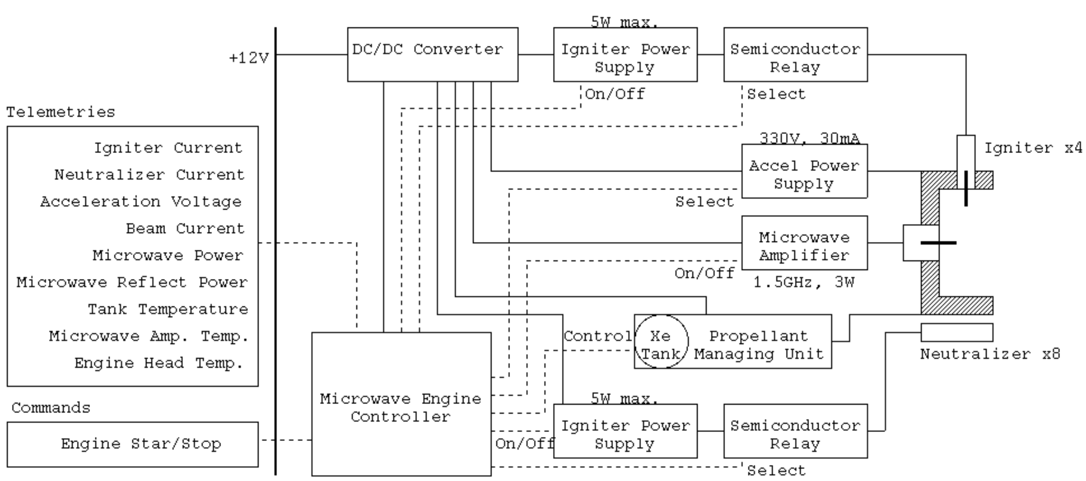

Fig. 4 Block Diagram of Microwave Engine System

RANDOM VIBRATION TEST

The purpose of this test was to subject the units to the Qualification Random Vibration Test. The unit has subjected following spectrum summarized in Table 2. At first, the unit has subjected to the AT level for every axis. After AT vibration, the unit has subjected to the QT level for every axis. Each axis is defined as follows.

1) X Axis – At random radially to the engine head
2) Y Axis – Mutually perpendicular to the X and Z axis.
3) Z Axis – Parallel to the direction of the thrust vector

The test configuration is shown in Fig. 5.

Examination of the unit after completion of testing disclosed no visible damage or deterioration as a result of the test conditions. The unit was considered to have passed the qualification random vibration test.

Table 2 QT Level Power Spectrum Density: All axis Duration: 3 minutes

Frequency [Hz]	PSD [G2/Hz]	Slope [dB/oct]	Tolerances
10 - 100	0.007 – 0.75	+6.0	10-1000 Hz: +- 1.5 dB 1000 Hz over : +- 3.0 dB
100- 800	0.75	0	
800 - 2000	0.75 – 0.121	-6.0	
Over All	30.18 Grms	-	

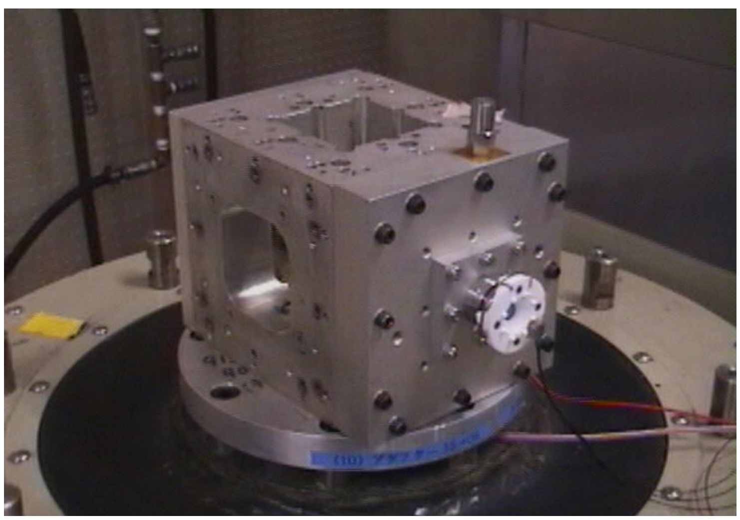

Fig.5 Y-axis Vibration Setup

THERMAL DESIGN

The engine head is made of steel where magnets are located. The engine is mounted to spacecraft through GFRP mounting brackets.

The key thermal design of the microwave engine is to maintain the magnets temperature below 110 degrees centigrade under any possible microwave engine flight configuration. These conditions includes:

1) The microwave engine is thermally decoupled from spacecraft
2) The microwave engine could be in any orbital orientation and could experience any orbital fluxes input
3) The microwave engine has a constant

power dissipation of 3W

To ensure the thermal design and analysis of the microwave engine will work in all the potential LEO orbits.

We assumed that the engine is mounted to a spacecraft and the spacecraft panel is sufficient large to block any direct solar radiation to the engine. For all the orbital fluxes computation, the following orbital thermal conditions are assumed:

(i) Orbital attitude = 650 km
(ii) Solar constant = 1420 W/m^2
(iii) Albedo = 0.36

To minimize the orbital flux influence and maximize the engine heat rejecting capability, we decided to apply white paint to all surfaces of the engine assembly.

The baseline design is to apply white paint on all the surface of the microwave engine assembly. The resulted maximum engine head temperature is 81 C including the +/- 5 C modeling uncertainty, the maximum engine head (including magnets) will be 86 C, well below the specified temperature limit of 110 C.

FUTERE WORK: HIGH POWER AND HYDRAZINE PROPELLANT

In future work, we started to research the new microwave engine which is operated at higher power range of 1 kW using hydrazine as propellant for applications to geostationary satellites as shown in Fig.6. As a preliminary experiment, we have operated the microwave engine using a nitrogen which is a major component of the hydrazine decomposed gas. Figure 7 represents the operation of the microwave engine at the microwave power of 10 W and the acceleration voltage of 100 volts. The violet plume, which is a peculiar for the nitrogen plasma is exhibited.

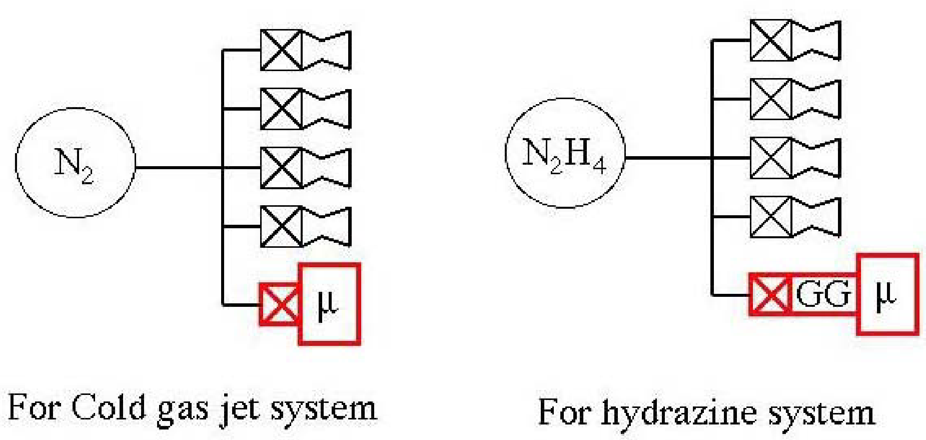

Fig.6 Concept of large microwave engine system

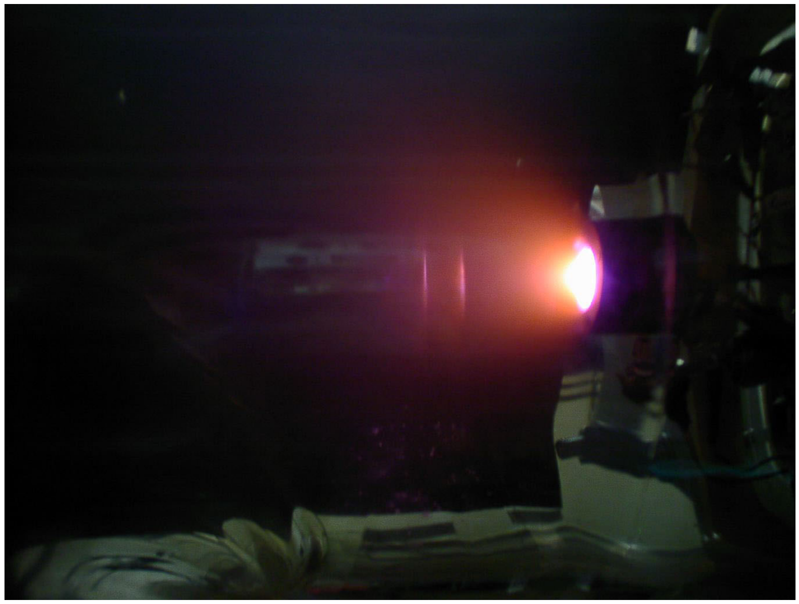

Fig.7 Operation of Microwave Engine Using Nitrogen : A Major Component Of Hydrazine Decomposed Gas

CONCLUSIONS

Proto-model of the microwave engine was built and its qualification test was conducted. Following performances were obtained: thrust of 0.36 mN, specific impulse of 1250 seconds, total power of 26.6 at nominal condition.

The random vibration test of the microwave engine head was conducted. No visible failure was observed and its tolerance on the mechanical environment was confirmed.

The thermal analysis concluded to apply white paint to all surface of the microwave engine assembly and use the engine mounting bracket as radiator surfaces. This design gives a maximum on-orbit temperature of the engine head (including both magnets) of 86 C, well below the maximum temperature limit of 110 C.

REFERENCES

[1] Satori, S., Okamoto, H., Sugiki, T.M., and Aoki, Y., "NEW ELECTROSTATIC THRUSTER FOR SMALL SATELLITE APPLICATION", July 2000, AIAA-2000-3

[2] Satori, S., Okamoto, H., Aoki, Y., Nagata, A. and Sugiki, T.M., "Design Status of Engineering Model of Microwave Discharge Electrostatic Thruster", 3rd International Conference on Spacecraft Propulsion, Cannes-France, Oct. 2000