J250-009 **Room: 202** **Time: May 23 16:00-16:15**

An Experiment on Multi Pulse Operation of Microwave Rocket

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Microwave rocket is an application of atmospheric discharge in a high power millimeter-wave beam. When a high power pulsed millimeter-wave beam is provided into a rocket, atmospheric discharge arises in the rocket. The induced plasma absorbs the following part of the millimeter-wave pulse and expands quickly and propagates towards rocket nozzle while generating a shock wave. The shock wave drives impulsive force. Then repetitive millimeter-wave pulses generate propulsive thrust.

This kind of propulsion system is called beamed energy propulsion (BEP). Because propulsive energy is provided from the beam source equipped on the ground, it is free from on-board energy sources. Furthermore, it can use atmospheric air as a propellant during flight in a dense atmosphere. For that reason, it is expected to achieve a higher payload ratio than conventional chemical rockets. Although energy can be transmitted to a vehicle either by a laser beam or a microwave beam in millimeter-wave band, use of a microwave beam is expected to realize a lower cost launcher than use of laser beam. Because, a GW-class microwave oscillator would be achievable by clustering existing high-power oscillators using the phased array technology.

In this study, a microwave rocket with a tube body was used. As the ionization front of atmospheric millimeter-wave plasma propagates in the tube absorbing microwave power generating a shock wave, the pulse detonation engine (PDE) model is expected to be useful. In this model, pressure in the thruster is constant during the propagation velocity of shock wave in the tube. Thus, microwave rocket thrust is estimated from pressure behind shock wave and shock wave velocity.

A 170GHz gyrotron developed in Japan Atomic Energy Research Agency was used as a microwave beam generator. This microwave source was developed as a plasma heating source for International Thermonuclear Experimental Reactor (ITER). Its maximum output power and energy converting efficiency are 1MW and 50%, respectively.

Multi pulse operation was conducted. Its repetition frequency was settled 50 Hz. The pulse duration t and peak power P of each pulse were about 3 ms and 300 kW, respectively.

A conceptual thruster model with a cylindrical tube with 60mm diameter and 500mm length was used. For plasma ignition, its end was cone with apex angle of 60 degrees. The pressure histories in the thruster were measured using a high speed pressure gauge fixed on the tube wall.

As a result, measured pressure histories had similarity to PDE model and the propagation velocities of a shock wave were deduced. Using the result of measure velocity of shock wave thrust was estimated under single pulse and multi pulse operation. The estimated thrust of single pulse operation was slight larger than the result of flight experiment.

Finally, repetitive impulsive thrust was successfully generated for 1s under repetitive pulse operation. Each pressure history was identical to each other and it provided the same impulsive thrust for each pulse. Its average thrust was estimated as 7N.