18PB-066

Characteristics of electric heating electrode thruster by applying a hollow cathode discharge

ホローカソード放電を用いた電熱型電気推進機の特性

Kazuhito Shukuwa, Masayuki Watanabe
宿輪一仁, 渡部政行

Graduate School of Quantum Science and Technology, Nihon University
1-8-14, Surugadai, Kanda, Chiyoda-ku, Tokyo 101-8308, Japan
日本大学大学院量子理工学専攻　〒101-8308　東京都千代田区神田駿河台1-8-14

Electric propulsion is useful technology for a space development project. Since the specific impulse of the electric propulsion is high as compared with the high power solid rocket, it has been loaded in many spacecraft in recent years. However the electric propulsion developed its performance rapidly, the unsolved problem is the shorter lifetime of the electrode due to the heat. In this research, an electric heating hollow electrode thruster has been developed for a new type of longer lifetime electric propulsion. Design and construction of the thruster and the initial experimental results of the plasma discharge and plasma jet parameters are presented in detail.

1. Space development project

Various technological applications demand a plasma jet because the plasma jet easily generates a high temperature and a high density plasma flow. In particular, the powerful plasma jet has been applying to a propulsive system in outer space and so on. Missions of the spacecraft of japan “Hayabusa" archive success in recent years.[1] The main purpose of the space mission is to sample the asteroid. For the success of such missions, the electric propulsion is the one of the important subject. Technology of the electric propulsion has been developing rapidly and reliability is improved in recent years. However, the electric propulsion have still a many problems. In particular, electrode damage that affect the performance of the spacecraft is important issue.

2. Electric propulsion

The relationship of specific impulse and thrust density of chemical propulsion, nuclear propulsion, and electric propulsion are shown in Fig 1. Advantage of applying the electric propulsion thrust as follow:

1. Most all devices on the spacecraft is driven by an electric.
2. Electrical energy can be supplied easily from the sun by the solar cells.
3. Electricity is less dissipation of energy during transmission.
4. Propellant weight is light.
5. Controllability of the thrust power is high.
6. Specific impulse is larger as compared to the other propulsion.

The electric propulsion is very useful in space navigation. There are three basic types of electric propulsion systems which is categorized according to the method of the acceleration of the propellant.[2] Electro-thermal system is accelerated by using a reaction force when jetted thermally propellant turned into plasma by electrical heating. Electro- magnetic system is accelerated by using a Lorentz force and the propellant turn into a plasma in the same process. Electrostatic system is accelerated by using a Coulomb force of the plasma.

3. Electric heating electrode thruster

This paper describes here a new-type of plasma jet, which is formed by using a hollow cathode discharge. The hollow cathode discharge is a

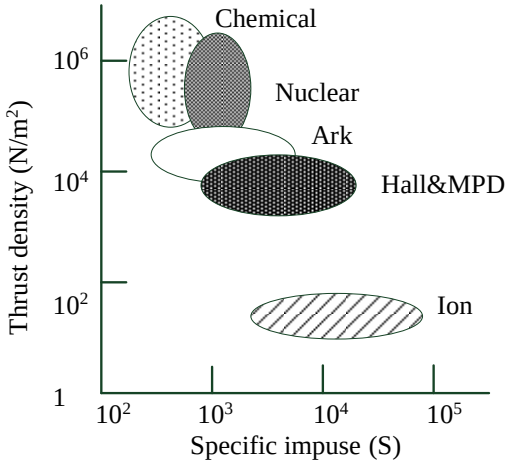

Fig 1. Relationship between thrust density and specific impulse[3]

low-pressure gas discharge with a pair of parallel disk electrode. Figure 2 show the Geometry of the electrodes. The conventional single plane cathode (See Fig.2(a)) is replaced by a cathode with a circular hole on the axis (See Fig.2(b)). The cathode has a cylindrical cavity behind the circular hole. The hollow cathode discharge is characterized as follows: (i) Discharge is formed through the electrode holes. (ii) Breakdown voltage is a function of plasma pressure. (iii) The hollow cathode effect is appied. (iv) High current glow discharge is formed.

In our device, the electro-thermal force accelerat a plasma. Since the thruster by applied a electro-thermal force can is possible to operate a low voltage compared with other electric propulsion system, it does not require a large-capacity capacitor and it can be driven by the power supply unit compact. Figure 3(a) shows a schematic drawing of a general electrothermal thruster. The general electro-thermal thruster have problem with electrode becomes locally high heat for heating the propellant by arc discharge using a rod-shaped cathode, the cathode is thermal wear easily. Figure 2(b) also shows a schematic drawing of electro-thermal thruster which is applying the hollow cathode discharge. Because main plasma discharge reasion is supplied with a large amount of electrons even during high-current discharge by the hollow cathode effect, a hollow cathode is possible to maintain the glow discharge. Also, since it is glow discharge, heating damage of the electrode is small, cooling system and external coils is not required hollow cathode is possible to reduce size of the device and cost. To increase the thrust from the electrode nozzle, the exit of the propellant is a Laval nozzle is a kind of high-speed nozzle to accelerate to supersonic speed fluid. The laval nozzle has a smaller flow path cross sectional area gradually toward the center of the nozzle from the inlet of the propellant, throat, has a cross-sectional area of the smallest and is located in the center and larger flow path cross-sectional area gradually toward the exit of the nozzle from the center. This nozzle generate thrust by characteristic, velocity of the fluid inside is accelerated as the flow channel cross-sectional area is smaller when the subsonic, fluid is accelerated as the flow channel cross-sectional area is larger when the supersonic.

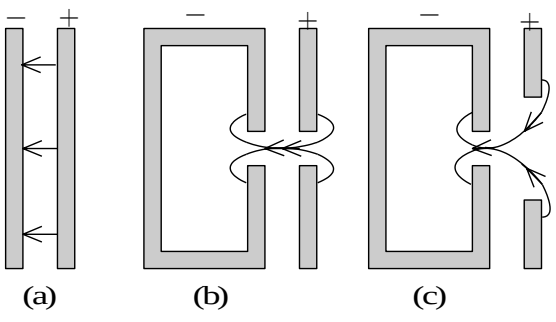

Fig.2. Geometry of the electrodes (a) Parallel Plane Gap (b) Gap for a hollow cathode discharge (c) Gap for MPD plasma jet . Arrows show the discharge path.

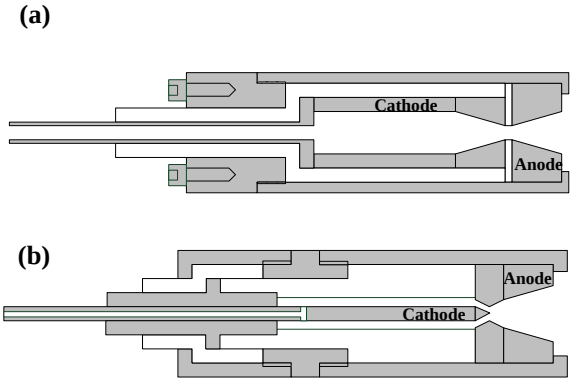

Fig 3. The schematic drawing of (a) a electric heating electrodethruster and (b) a electric heating hollow electrode thruster

4. Experimental device and setup

Vacuum vessel with multiple ports is used for attaching the device. Thrusters is inserted the vacuum region and propellant is supplied by using a stainless steel tube to the part of electrodes. An oil diffusion pump and a rotary pump are products a vacuum of 10^{-4} Pa. Ionization and pirani vacuum gauges measure the pressure in the vessel. Electrode give a high voltage by a DC power supply. Propellant is argon gas or air in this experiment. Temperature and density of the plasma jet is measured by an electrostatic probe (a double probe).[4] The temperature and density are estimated by a voltage applied to the probe and the current due to the plasma to flow into the probe. Overview of the electro-thermal thruster using a hollow cathode, and the measurement of the temperature and density are reported in the poster.

References

[1] J. Plasma Fusion Res. Vol.86, No.5 (2010)282-292
[2] G.P. Sutton: Rocket Propulsion Elements (1995)
[3] K. Kuriki and Y. Arakawa: Introduction to Electric Propulsion (2003)20-21
[4] T. Suzuki: Development of a small sized plasma jet by using a pseudospark discharge (2008)38-41