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Ion Engines for Asteroid Explorer Hayabusa2
「はやぶさ２」イオンエンジン

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1. Introduction

Japan's first asteroid explorer "Hayabusa" came back to the earth on June 13, 2010. Hayabusa completed more than 7-year space mission, and finally Hayabusa could return the capsule to the earth, although Hayabusa had a lot of troubles and difficulties [1]. After careful inspections of about 1,500 grains found in the sample container, it turned out that we actually obtained rocky particles from the surface of Asteroid Itokawa. In 2011, Japan Aerospace Exploration Agency (JAXA) started the second project "Hayabusa2" for the asteroid sample return mission to another Asteroid Ryugu which is one of different type of asteroids from Itokawa and is thought to be rich in organic materials. Hayabusa2 departed from the Earth on December 3, 2014, will arrive on the asteroid mid-2018 and will return to Earth at the end of 2020.

This paper overviews the ion engine system (IES) for Hayabusa2 and space operation in the first year after launch.

2. Ion Engine System for Hayabusa2

The ion engine system for Hayabusa2 have been developed based on that for Hayabusa. Hayabusa2 spacecraft has four μ10 ion thrusters on a single plate called "IES plate" which was mounted on top of a two-axis pointing gimbal mechanism as shown in Fig. 1. An ion thruster consists of an ion source and a neutralizer both of which utilize microwave discharge with electron cyclotron resonance (ECR) at a frequency of 4.25 GHz. The magnetic flux density of 0.15 T inside the discharge chambers is provided by SmCo magnets. Microwaves are generated by commercial traveling wave tube amplifiers which are widely used on many satellites and other spacecraft for space telecommunication.

The maximum thrust generated by a single thruster was 10 mN by consuming a small flow rate (of order 0.3 mg/s) of xenon gas and an electric power of 420 W for plasma generation and ion beam acceleration.

Fig.1. Hayabusa2 spacecraft with four ion thrusters on the H-IIA launch vehicle No. 26.

Fig.2. Ground operation of one of flight thrusters.

IES specifications and mission requirements are summarized in Table I. Ion sources were slightly modified in that their propellant injectors were added in different places in the discharge chamber and ion optics thicknesses and aperture diameters were changed so that the maximally available thrust increases by approximately 20% [2]. The total impulse required by this new mission is 1.2 MN·s which is also 20% larger than Hayabusa's requirement. Estimated total operational hours of all thrusters are 41100 hours which is almost the same as Hayabusa achievement of 39637 hours. The increase of total impulse is due to the increase of spacecraft mass because required delta-V is almost the same as that of Hayabusa. This will be achieved by the thrust enhancement with almost the same thruster operational hours. The xenon load is nearly the same amount of 66 kg as Hayabusa's because both mission needs extra propellant for extended missions after return to the earth. Neutralizers have been improved for longer life according to lessons learned in the Hayabusa mission and ground experiments. Subsystem architecture of Hayabusa2 ion engines is almost identical to Hayabusa's although many components such as valves, pressure sensors, microwave components, and so on were discontinued in production and were replaced by new alternatives.

Table I. IES specifications (Middle of life)

	Hayabusa	Hayabusa2
Thrust per thruster (mN)	4.4 – 7.6	6.3 – 9.0
Specific impulse (s)	2760 – 3000	2740 – 2890
System power (W)	280 – 1150	380 – 1230
Total operational hours (h·units)	39637	41100 (planned)
Total impulse (MN· s)	1.0	1.2(planned)
Dry mass (kg)	58	66
Xenon (kg)	66	66

3. Space Operation in the First Year

Hayabusa2 was launched from Tanegashima Space Center in Kagoshima Prefecture by the H-IIA launch vehicle No. 26 on December 3, 2014. Launch-locks of the ion engine gimbal mechanism were released flawlessly during the first tracking pass. Three months were spent on the initial checkout of the spacecraft including the IES. Ion thruster firing tests were conducted from the end of December to the middle of January. All thrusters exhibited very frequent high voltage breakdowns between screen- and accelerator-grids of the ion optics due to outgassing at first, but automated recycle function implemented by the thruster control unit made continuous operation possible. The first 24-hour continuous operation of two thrusters at the same time was successfully achieved on January 20.

Cruise operation in which ion thrusters were continuously operated started in March, 2015. In order to update timeline commands stored in the data handling unit of the spacecraft and to change spacecraft weekly-fixed attitude, ion thrusters were stopped once per week for approximately three hours. Figure 3 shows time history of total impulses generated by four ion thrusters. Delta-V in the first year was executed in separated three terms in March, May and June. In addition, trajectory correction maneuvers for 11 hours in total by IES was conducted on September 1 and 2. Hayabusa2 has three high voltage power supplies to accelerate xenon ion beams of four ion thrusters. Relays are used to change combinations between thrusters and power supplies. Thrusters A and D were preferentially used in the first year because these two have only one high voltage power supply for each, while thrusters B and C have possible connections with two power supplies. Three thrusters A, C and D will be used in the next year and the thruster B will be saved as a backup.

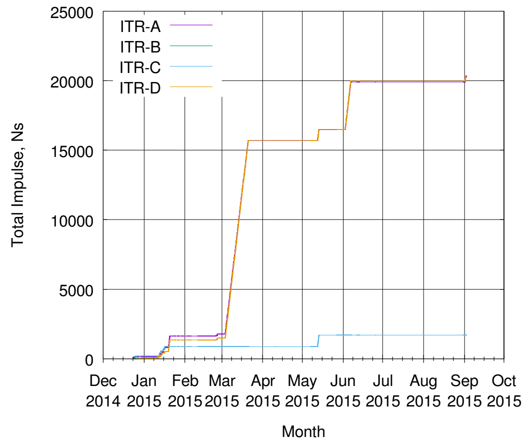

Fig.3. Time history of total impulses generated by four ion thrusters (ITR) A – D.

4. Conclusion

The ion engine system for Hayabusa2 asteroid explorer has been developed and the spacecraft was launched on December 3, 2014. During the first year in space, two of four ion thrusters have been operated for about 600 hours to accelerate the spacecraft by 60 m/s. Hayabusa2 is now ready for the next important event: Earth gravity assist scheduled in December 3, 2015.

References

[1] K. Nishiyama, S. Hosoda, H. Koizumi, Y. Shimizu, I. Funaki, H. Kuninaka, M. Bodendorfer, and J. Kawaguchi: *Proc. 46th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit*, 2010, AIAA-2010-6862.

[2] K. Nishiyama, S. Hosoda, M. Usui, R. Tsukizaki, H. Hayashi, Y. Shimizu and H. Kuninaka: Space Technology Japan, **7** (2009) 113.