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Development of Ion Engines for Hayabusa2 Spacecraft
「はやぶさ２」イオンエンジンの開発

Kazutaka Nishiyama, Satoshi Hosoda, Ryudo Tsukizaki and Hitoshi Kuninaka
西山和孝, 細田聡史, 月崎竜童, 國中均

Japan Aerospace Exploration Agency
3-1-1, Yoshinodai, Chuo-ku, Sagamihara 252-5210, Japan
宇宙航空研究開発機構　〒252-5210　相模原市中央区由野台3-1-1

Hayabusa2 will be the second asteroid sample return mission by JAXA. The ion engine system (IES) for Hayabusa2 is based on that developed for Hayabusa with modifications necessary to improve durability, to slightly increase thrust, and to reflect on lessons learned from Hayabusa mission. Hayabusa2 will rendezvous with a near-earth asteroid 1999 JU3 and will take samples from its surfaces. More scientific instruments than Hayabusa including an impactor to make a crater and landers will be on board thanks to the thrust enhancement of the IES. An improved neutralizer with stronger magnetic field for longer life has been under endurance test in diode mode since August 2012 and has accumulated the operational hours of 19,000h (> mission requirement: 14,000h) by the middle of October 2014. Unified tuning parameters for four thrusters such as grid gaps, geometry of microwave tuning elements including antennas, waveguides and stub tuners improved performance variation. The spacecraft is scheduled to be launched from Tanegashima Space Center in Kagoshima Prefecture on-board an H-IIA rocket on 30 November.

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 1999 JU3 which is one of different type of asteroids from Itokawa. The launch is scheduled for November 30, 2014, arriving on the asteroid mid-2018 and returning to Earth at the end of 2020.

This paper briefly summarizes the development of the ion engine system (IES) for Hayabusa2.

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 at a frequency of 4.25 GHz. 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 ion engines

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%. 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 60 kg as Hayabusa's 65 kg 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)	65	60

3. Ion Source Development

The original well-tuned μ10 ion thruster can generate 8 mN at a specific impulse (including neutralizer flow) of 3000 s with consuming 32 W of microwaves and 2.35 sccm of xenon flow. Research effort after Hayabusa’s launch indicated that design change of gas injector layout had the large impact on thrust enhancement [2]. The highest thrust of 10 mN is generated when the xenon flow is divided at the ratio of 1:2 between the original injector deep in the waveguide and newly added injectors between magnets, respectively, when the total flow rate is 3.5 sccm. Mass utilization efficiencies are decreased from the original but can be improved by using a small hole accelerator grid whose aperture diameter was decreased from 1.8 to 1.5 mm. Decrease of screen grid thickness from the original value of 0.95 mm to 0.8 mm also helped the mass utilization recovery. The combination of above mentioned modifications (gas distributors, small hole accelerator grid and thinner screen grid) achieved the maximum thrust enhancement shown in Table I and required flow rate can be saved to 3.2 sccm as for flight model thrusters. Figure 2 shows plasma luminosity during the ground operation of one of flight thrusters.

Fig.2. Ground operation of one of flight thrusters

4. Neutralizer Development

Lifetimes of Hayabusa neutralizers ranged between 9579 and 14830 hours which were shorter than expected from the ground test's achievement of 20,000 hours by a prototype model. Most remarkable difference between in-space and on-ground conditions would be the temperature range and cycles. We have analyzed the stored prototype neutralizer and found many magnetized metal flakes. These may be immersed into the discharge plasma, may become a source of surface contamination of the dielectric part of microwave launcher by ion sputtering and sputtered metal deposition. Minimization of the operating voltage to improve the neutralizer durability were achieved by increasing the magnetic field inside the discharge chamber and by more intensive microwave impedance matching effort using a stub tuner. As of October 2014, still continuing endurance test of an engineering model of new neutralizer, including once-per-week on-off cycles like in orbit, accumulated the operational hours of 19,000h without any performance degradations.

5. Conclusion

The ion engine system for Hayabusa2 asteroid explorer has been successfully developed and is now ready for launch in Tanegashima Space Center.

References

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