The Ion Engine of Hayabusa2 and Potential Applications

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Abstract

Designed for asteroid exploration, the Hayabusa2 spacecraft has ion engines installed which powered the outbound journey from Earth to the near-Earth asteroid Ryugu and the flight back to Earth after collecting samples. But that wasn't the end of the mission. Hayabusa2 is currently on its way to a new destination, collecting valuable data to support humankind's exploration of the solar system. The ion engine that powers the spacecraft is a form of electric propulsion that has become the key to deep space exploration and is attracting a lot of attention. This paper provides an overview of spacecraft propulsion systems in general and the ion engine in particular, discussing NEC's role in the development of this advanced space propulsion system, how it performed on Hayabusa2, and how we plan to improve its performance for Japan's next deep space exploration mission named DESTINY$^+$.

Keywords

Hayabusa, Hayabusa2, ion engine, interplanetary travel (deep space exploration), microwave discharge, DESTINY$^+$

1. Introduction

The Hayabusa2 asteroid explorer was launched in December 2014 from the Tanegashima Space Center (Kagoshima Prefecture, Japan). It arrived at the asteroid Ryugu in June 2018, successfully collected 5.4 grams of samples in 2019, and returned to Earth orbit in December 2020. This six-year journey was powered by ion engines.

Types of spacecraft propulsion systems include chemical propulsion systems and electric propulsion systems. Chemical propulsion systems create thrust by generating combustion from a chemical reaction. This produces a huge amount of energy and consequently very powerful thrust force. Electric propulsion systems use electric energy for heating and acceleration and creates thrust by accelerating exhaust from the propellant, making it possible to reach a distant destination using only a small amount of fuel. The ion engine system mounted on Hayabusa2 is an electric propulsion system.

Fig. 1 shows the relationship between the thrust density (thrust per unit area at an injection port) and specific impulse (thrust per consumption rate of a propellant [equivalent to mileage]) of each thrust system. Among electric propulsion systems, the ion engine — while low in thrust — is high in specific impulse, as is clear from

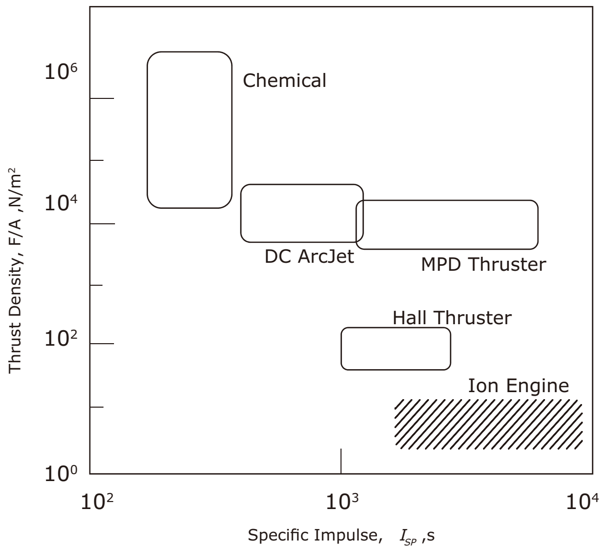

Fig. 1 Relationship between thrust density and specific impulse of electric propulsion systems[1).]

this diagram. In a deep space exploration mission like the Hayabusa mission, being able to reach a destination far from Earth is the most important factor, which makes an electric propulsion system like the ion engine the optimal choice.

NEC developed a microwave discharge ion engine system and mounted it into Hayabusa and Hayabusa2 in collaboration with the Japan Aerospace Exploration Agency (JAXA). Exploiting the knowledge gained through these projects to meet new mission requirements, we have developed a new and improved model which will be used in the next asteroid probe project — the DESTINY$^+$ deep space exploration technology demonstrator.

2. Overview of Ion Engine[2)3)]

Since ion engines generate thrust through electrostatic acceleration of plasma, they are also called electrostatic thrusters. **Fig. 2** is a schematic diagram of an ion engine. First, Xe gas — which is a propellant — is converted to plasma in the upstream discharge chamber. Next, the ions are accelerated by applying different electric potentials to three grids. Finally, the ions are electrically neutralized in a neutralizer and discharged into space to obtain thrust. There are multiple ways to generate plasma in the first step, one of which is the microwave discharge ion engine used by Hayabusa and Hayabusa2.

There are two main features of the microwave discharge ion engine. The first feature is that there is no service life limitation or any need to protect it from atmospheric exposure because there is no electrode for discharge. The second feature is that special procedures and additional devices are not necessary for plasma ignition, thereby reducing the number of components in the overall system. In addition, in the ion engine mounted in Hayabusa and Hayabusa2, the electrode has been eliminated from the neutralizer, removing another layer of complexity from the system and extending its service life. The performance of this system — the world's first ion engine without any discharge electrode at all — has now been successfully validated in space.

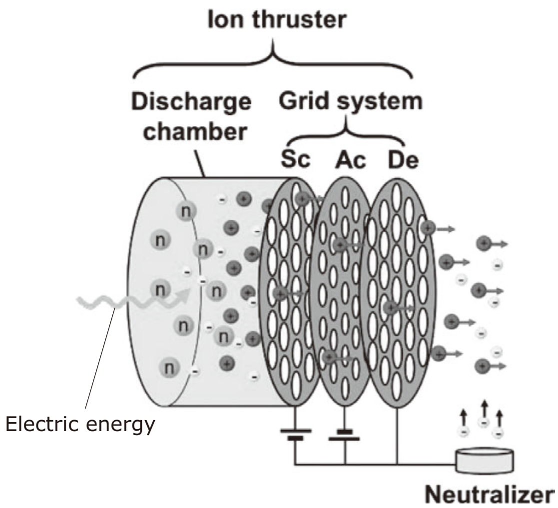

Fig. 2 Schematic diagram of an ion engine.

3. Development of the Ion Engine at NEC

Electric propulsion systems — including the microwave discharge ion engines — were researched at the National Aerospace Laboratory of the Ministry of Education, Culture, Sports, Science and Technology, which was the predecessor of JAXA's Institute of Space and Astronautical Science (ISAS). Research into the microwave discharge ion engine started around 1988. NEC launched a more comprehensive R&D effort in 1996 when the MUSES-C (Hayabusa) project began.

After development of the ion engine for Hayabusa, JAXA's ISAS continued its efforts to further improve performance, while NEC worked on making it more flexible so that it could easily be applied to other satellites. In 2011, the Hayabusa2 project was initiated, leading to accelerated development of the ion engine, focusing on its application to Hayabusa2.

Three primary objectives directed the development of the ion engine for Hayabusa. The first was a propulsion experiment, the second was a long-term operation experiment of the ion engine, and the third was acceleration operation in the Earth swing-by using the ion engine. All three were successfully validated.

Based on the technological validation of the ion engine in the Hayabusa project, it was required that we develop technology that would enable Hayabusa2 to travel to the asteroid and safely return to the Earth.

4. Development of the Ion Engine for Hayabusa2[4)]

The specifications of the ion engine for Hayabusa and

Table Ion engine specifications of Hayabusa and Hayabusa2[5)].

	Hayabusa	Hayabusa2
Operating thrusters/mounted thrusters	3/4 thrusters	3/4 thrusters
Thrust per thruster	8mN	10mN
Specific impulse @MOL	3,200 sec.	3,000 sec.
IES power consumption	1,050W	1,250W
Xe tank capacity	66kg	66kg

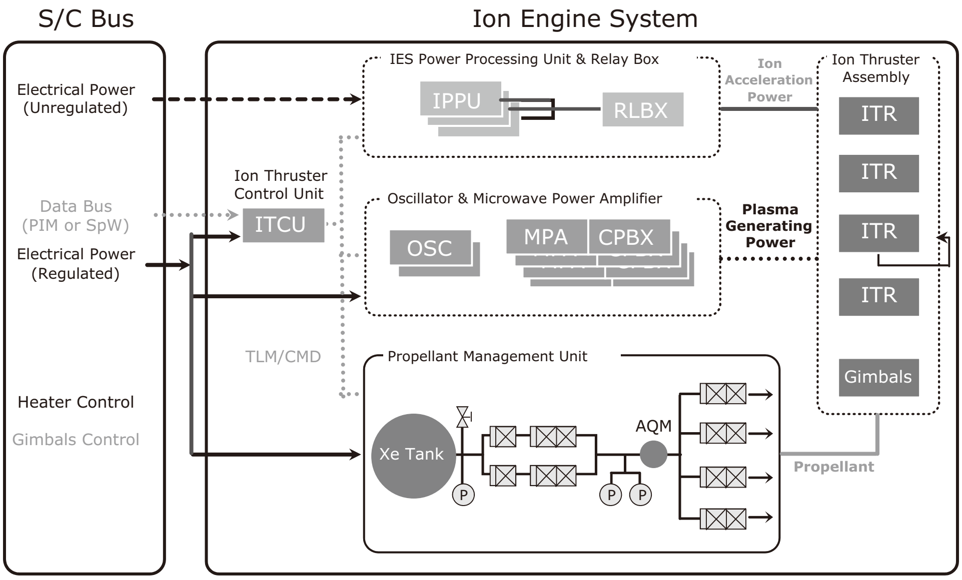

Fig. 3 Hierarchical structure of the ion engines of Hayabusa2.

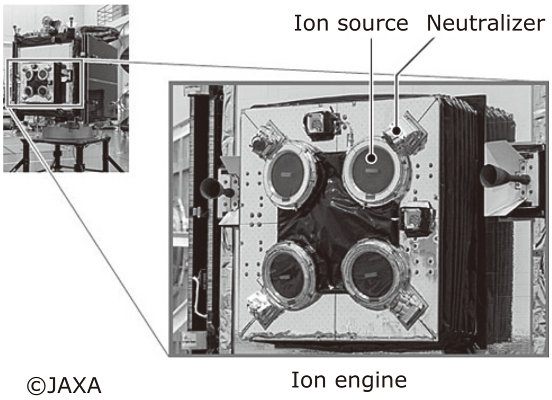

Fig. 4 Installed ion engines.[6)]

Hayabusa2 are shown in **Table**, their hierarchical structure in **Fig. 3**, and the external view with IES mounted in **Fig. 4**.

The main differences between Hayabusa2 and Hayabusa include longer service life while preventing problems in the neutralizer and a 25% increase in thrust (from 8 mN to 10 mN)[4)].

Hayabusa and Hayabusa2 have basically the same configuration. In addition to the ion engines, IES power processing units (IPPUs), and IES thruster control unit (ITCU), there is a microwave discharge system, which is an exclusive component of this system. Four ion engines are installed on a single plate, and up to three of the four engines can be operated at the same time to create the thrust necessary for changing the orbit of the spacecraft.

Also provided are a function to change the thrust direction using gimbals and a throttling function that changes the thrust force according to the fluctuation of supplied power.

As mentioned in section 3, improved operational reliability was requirement for Hayabusa2. A thorough reliability analysis was performed with tests conducted under conditions as closely matched to the actual space environment as possible.

5. Results of Ion Engine Operation on Hayabusa2

Fig. 5 shows the outward journey of Hayabusa2 from the launch to the asteroid and return journey from the asteroid to the Earth.

Traveling on the trajectory shown in Fig. 5, each ion engine of Hayabusa2 operated for about 6,400 hours on the outward journey and for about 3,000 hours on the return journey. While malfunctions prevented Hayabusa from operating all its ion engines until the end of the mission, Hayabusa2's four engines have operated reliably throughout the mission and continue to operate even now. This has established the performance and reliability required for going to and returning from an asteroid. Shortly after returning to Earth orbit, Hayabusa2 began the journey to its next destination, the asteroid 1998KY26. Its ion engines continues to operate to this day.

6. Improving Performance for the Next Project

Having consolidated the ion engine technology with Hayabusa2, we have further refined it to improve per-

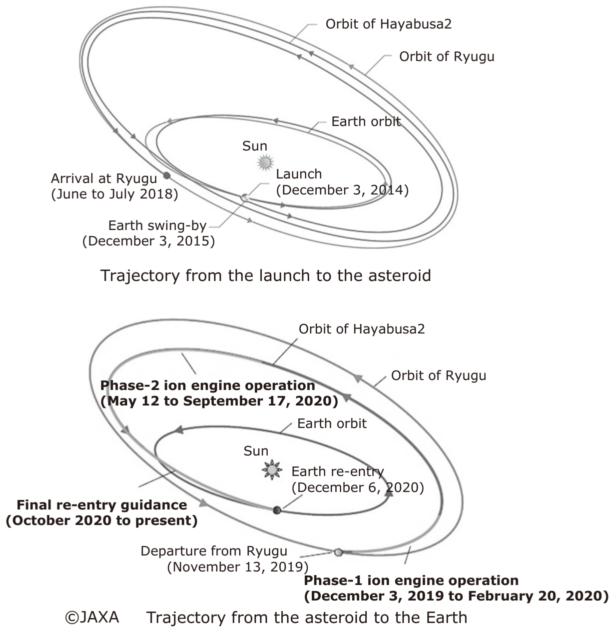

Fig. 5 Trajectories of Hayabusa2.[7)]

formance and reliability. The new system will be mounted in the DESTINY+ deep space exploration technology demonstrator, which is our next deep space exploration mission. After being launched into Earth's orbit, DESTINY+ will break away from Earth and travel to its destination maintaining acceleration with the ion engines. Considerable thrust will be required to break away from the Earth's orbital sphere. Unlike Hayabusa2, DESTINY+ will stay in the Earth orbit for an extended period of time, which means that the heat exhaust and heat insulation capability will be required to cope with the environment in Earth orbit. We will take advantage of this improvement in the performance to expand the application range of the ion engine beyond asteroid exploration.

7. Conclusion

This paper introduced the ion engine developed by NEC in collaboration with JAXA. As demand for electric propulsion systems grows worldwide in the field of spacecraft development, we will continue to push forward development of these systems with focus on ion engines. We would like to express our gratitude to JAXA for their invaluable guidance and support throughout the project.

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