Expand Space Utilization! Thruster for Very Small Satellites

Development of low-cost green propellant thruster using 3D printer

As a thruster for very small satellites, we will provide users with a propulsion system whose manufacturing cost is reduced by using a 3D printer and life cycle cost from manufacturing to operation is suppressed by using a low-toxic safe propellant.

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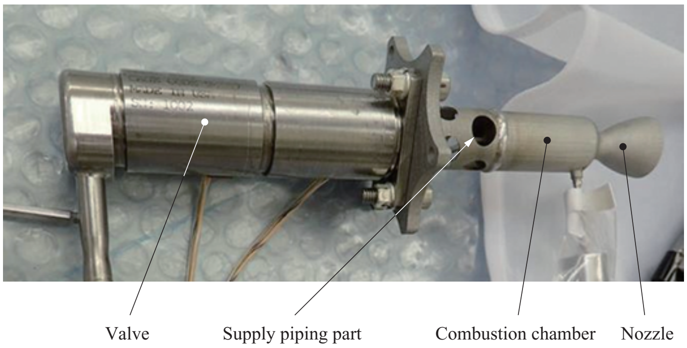


Schematic diagram of green propellant thruster for very small satellites

Thruster combustion test with thrust level of 4 N

What is the thruster required for very small satellites?

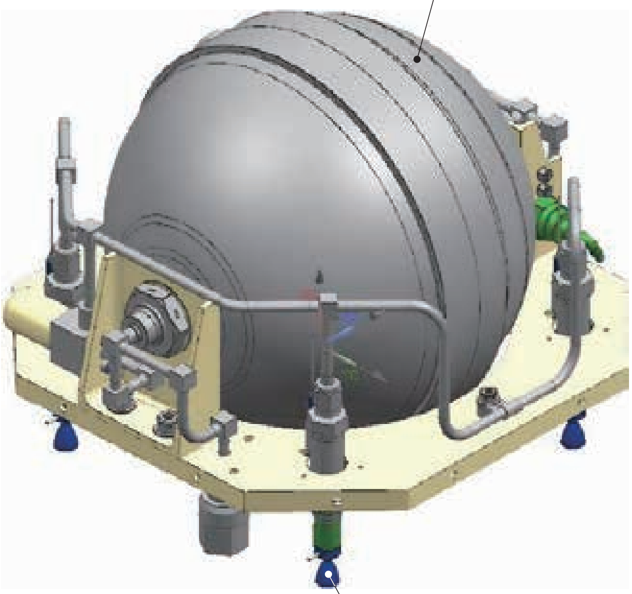
There are many plans to launch very small and small satellites with a mass range of 50 to 150 kg along with the recent progress of research and development at venture companies and university-related organizations. Such very small satellites use mechanical parts called a flywheel and a magnetic tracker for attitude control. However, a propulsion unit (thruster) adapted to jet gas for changing an orbit and maintaining orbital altitude has not been mounted much.

Providing functions of changing an orbit and maintaining orbital altitude makes it possible to form a constellation in which after simultaneous launch of multiple satellites, the satellites are deployed in their target orbits by their own thrust, and also to prolong the lifetime of a satellite more than ever.

Functions required for a thruster for very small satellites are roughly divided into the following three.

① Small size and lightweight
② Low cost
③ High level of safety

A conventional thruster using hydrazine as fuel satisfies the requirement ① above, but is difficult to handle because of the high toxicity of hydrazine, thus increasing life cycle cost from manufacturing to operation for safety measures. For



Schematic diagram of propulsion unit

example, when handling hydrazine, the wearing of a protective gear with an air supply function called a Self-Contained Atmospheric Protective Ensemble (SCAPE) suite is required, and in addition, air supply equipment is also required.

For this reason, a thruster using hydrazine as fuel for very small satellites has not been employed much. On the other hand, as a low-toxic propellant, hydrogen peroxide or cold gas (gas not involving a chemical reaction, such as nitrogen) is sometimes used, but has a limited application range because of its low thrust performance.

Current world situation of thruster development and IA's activities

As an alternative to hydrazine, low-toxic and high-performance propellants have been studied in Europe, US, and Japan since approximately 20 years ago. As the low-toxic propellants, there are ones using HAN (hydroxylammonium nitrate) and ones using ADN (ammonium dinitramide). However, among such low-toxic propellants, only a small number of propellants have been put into practical use, but are not widely spread. This is due to the problems that the combustion temperature of any of the low-toxic propellants is high, and therefore an existing combustion chamber material cannot resist the high temperature and the lifetime of a catalyst supporting combustion is shortened due to deterioration. Accordingly, it is indispensable to increase the heat resistance of the combustion chamber material and catalyst, thus increasing cost.

Another problem of the low-toxic propellant is that although the propellant is low toxic, it has a property called auto catalytic reaction which may cause explosive combustion depending on handling because it is a high energy material. Therefore, it is necessary to control the autocatalysis. IHI AEROSPACE Co., Ltd. (IA) has found composition not causing such abnormal combustion, and confirmed through a thruster combustion test that the composition is safe, has high responsiveness, and can serve as an alternative to hydrazine. However, we have not succeeded in reducing cost while increasing the heat resistance of the combustion chamber material and catalyst in order to resist the high combustion temperature of the low-toxic propellant as described above, and still cannot put it into practical use.

In addition, any of the green propellant thrusters researched so far has the problem that the responsiveness of combustion gas jet to a jet start signal is low, so improvement of the responsiveness is also a problem.

Low-cost green propellant thruster embodied by IA

IA set constellation satellites as target very small satellites, and decided to start development for providing a thruster early at low cost.

In order to obtain the low-cost propulsion system for the very small satellites, we worked on the following two challenges.

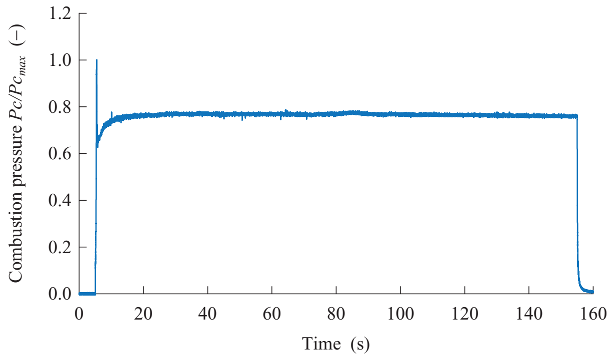
① To set a low-toxic propellant as fuel to be used, and eliminate the need for special handling/operation.

② To reduce the number of parts to thereby reduce manufacturing cost by using 3D printer technology.

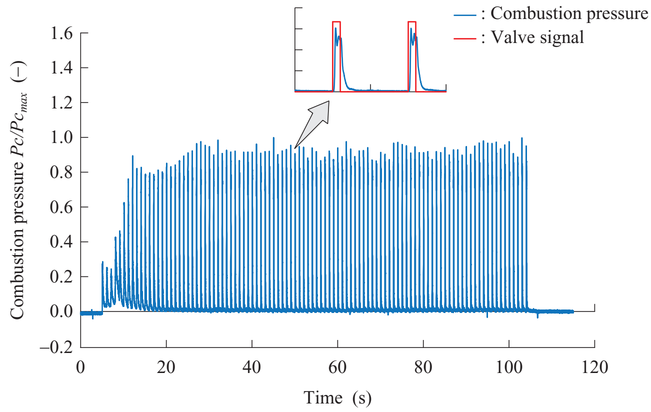
In order to overcome the challenge ①, we developed a low-toxic propellant HNP whose propulsion performance was slightly lower than that of hydrazine but combustion temperature was comparable. As described above, the combustion temperature of any of the previous low-toxic propellants was as high as approximately 2 000°C, and therefore it was necessary to use an expensive heat resistant alloy, which was one of factors increasing manufacturing cost. Using HNP enabled manufacturing cost to be reduced without the use of a highly heat resistant material of a special type for the component parts of the thruster.

HNP consists of HAN, HN, methanol, and water. HAN is a one-component propellant derived from liquid propellant originally developed for shell shooting in US, and as compared with hydrazine, low toxic and high combustion performance. HN (hydrazine nitrate) is low toxic as compared with existing hydrazine (anhydrous hydrazine), and high combustion performance as with HAN. In addition, HN has a function of facilitating the control of combustion while suppressing the auto catalytic reaction of HAN. Methanol is combined to enhance combustion performance, and water is combined as a solvent for HAN and HN. By finding out the composition suppressing the auto catalytic reaction on combustion, we succeeded in developing the low-toxic and safe propellant.

The reason to overcome the challenge ② is that even the



Continuous jet mode test (Combustion pressure waveform)



Pulse jet mode test (Combustion pressure waveform)

number of main thruster parts alone is 10 or more, and precision assembly work including welding, brazing, and other such processes are required. For this reason, by applying the 3D printer technology, the number of parts was minimized to reduce the effort for the assembly work, thereby reducing manufacturing cost.

In recent years, 3D printers have been significantly developed in technology and widely spread, and it is also said that the 3D printers will give rise to the Fourth Industrial Revolution. Specifically, the 3D printer technology is one adapted to uniformly spread fine metal powder and shape the metal powder in a layer using a laser or other means, and even a complicated structure can be integrally shaped. In addition, as far as the work size of manufacturing equipment permits, by shaping multiple parts simultaneously, manufacturing cost per part can be reduced. Potential applications include prototypes of aerospace parts and automobile parts such as a turbine blade, medical parts, and so on.

The high precision 3D printer technology capable of producing fine flow passages required for the small thruster was employed this time, and cost reduction was attempted by reducing the number of parts (by approximately 75% as compared with a conventional one) using integral shaping to reduce the number of assembly steps.

In order to verify the above concept, the thruster was prototyped based on the same shape design as that for the long-proven thruster using hydrazine as fuel, and performance was evaluated by a thruster combustion test with a thrust level of 4 N.

Combustion test of low-cost green propellant thruster for verification

At the IA Aioi Test Facility (Hyogo Prefecture), the combustion test was performed in a vacuum chamber for simulating the use of the thruster in space. Thruster combustion modes include a continuous jet mode for continuously generating thrust and a pulse jet mode for repeating a short jet. It turned out that the prototyped low-cost green propellant thruster had sufficient capability as a thruster for the very small satellites as follows.

[Continuous jet mode]
As can be confirmed from the combustion pressure waveform, combustion pressure quickly reaches a steady state, and in the steady state, stable combustion can be seen without any spike-like variation in combustion pressure.

[Pulse jet mode]
The pulse waveform of combustion pressure reaches a steady state after about 10 pulses, and after that, stable pulse generation with a small variation in waveform can be confirmed. The responsiveness of a combustion gas jet to a jet start signal is also high, so in terms of the improvement of the responsiveness as well, which is the problem of the previous green propellant thrusters, this thruster is comparable to the conventional thruster using hydrazine.

Basic performance of low-cost green propellant thruster

The basic performance of the thruster obtained by the combustion test was as follows. Thrust: 1 to 3 N, the number of pulses: 4 000 or more, total impulse: 1 000 N·s or more (thrust × time), specific impulse: 170 s (Isp: time during which unit thrust can be produced per unit mass of propellant. Unit: second (s)), and throughput: 1.0 kg or more (maximum use amount of propellant).

On the basis of the basic performance, an orbit velocity increment (ΔV) obtained as a result of assuming that a very small satellite used this thruster, and an HNP propellant amount necessary for it were estimated. The horizontal axis represents ΔV, and the vertical axis represents the propellant amount. It turns out that when the mass of the satellite is 50 kg, a velocity increment ΔV of 25 m/s or more can be obtained at a propellant amount of 0.8 kg. This velocity increment ΔV enables the orbit of the very small satellite to be changed and orbital altitude to be maintained. On the other hand, when attempting to achieve the same velocity increment ΔV using hydrogen peroxide with an Isp of 80 s, a propellant amount of 1.8 kg is required, and this is double or more the HNP amount, thus increasing the mass of the satellite.

Field of action of low-cost green propellant thruster

By applying the low-cost green propellant thruster to a very small satellite, the following effects can be expected.

[Orbit change/Attitude control]

By providing a very small satellite with a function of changing an orbit, multiple very small satellites for observing the earth can be placed in their orbits as constellation satellites. This is expected to lead to the observation of the earth at observation points and frequency desired by a satellite user and to the realization of space observation of an observation object, which has not been observable in the past, and planetary exploration. The green propellant thruster developed by IA is high in responsiveness, and is therefore applicable to attitude control as well, and an increase in the degree of freedom at the time of satellite operation is expected.

[Orbital altitude maintenance]

A satellite is subjected to air resistance of the thin atmosphere in orbit and thereby reduced in velocity, and without a thruster, altitude is also gradually reduced to fail to maintain orbital altitude.

As an application example of orbital altitude maintenance, assuming a satellite having a mass of 50 kg and dimensions of 50 × 50 × 50 cm, ΔV of 25 m/s obtained at a propellant amount of 0.8 kg as estimated above makes it possible to maintain orbital altitude for approximately 2 years.

[Piggyback]

It has not been permitted until now to mount a very small satellite filled with hydrazine as a piggyback satellite that rides on a large rocket together with a main satellite. The green propellant thruster is safer than a hydrazine thruster, and therefore may be permitted to be mounted as a piggyback propulsion system, and the opportunity of launching very small satellites is expected to increase.

[Deorbit]

It is expected that in the future, the problem of space debris such as satellites remaining in their orbits and having completed their operations will be more and more revealed along with the acceleration of space development by individual nations. This thruster will also play an active role in a technology called deorbit that purposely plunges a satellite having completed its operation into the atmosphere to remove it from an orbit.

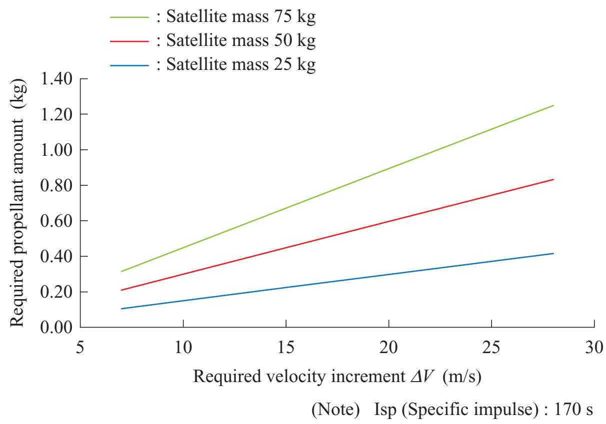
Next step

This report introduced the low-cost green propellant thruster developed using the 3D printer technology. In order to apply the 3D printer technology to the propulsion system for very small satellites, not only the thruster but components such as a propellant tank, valves, and structural members must be finished, and they are currently under development separately.

In the future, we are planning the following efforts.

(1) To carefully examine the performance of components (such as a thruster, tank, valves, structural members, pipes) required for the propulsion system, and complete the prototype of the propulsion system for very small satellites.

(2) To introduce the prototype of the propulsion system to customers, and link feedback from the customers to the early completion and sale of the product.



Orbit velocity increment ΔV and required propellant amount when using low-cost green propellant thruster

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