P08

電気推進噴出流の照射による宇宙デブリの減速・降下過程の研究とその実証超小型衛星プロイテレス４号機の開発

Study on Non-Contact Space Debris Deorbit Technology and System by Using Irradiation and Reaction of Electric Thruster Exhaust Flows and Development of the Osaka Institute of Technology 4th PROITERES Nano-Satellite for Its Practical Experiment in Space

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近年、小型衛星や超小型衛星による宇宙利用が世界的に拡大している。一方で、地球周辺軌道上での宇宙デブリの数は爆発的に増加しており国際的な問題となっている。衛星にデブリが衝突し甚大な被害が発生する事例が度々起こってきた。そこで、大阪工業大学では、宇宙用スラスタ、特に電気推進機の研究開発の技術・経験を活かし、電気推進機そのものを用いた、新たな非接触式デブリ処理方法の研究開発を行ってきた。その方法は電気推進機の噴出流をデブリに照射し、反力（力積）を与え、デブリを減速させ、デブリを降下させることにより、大気圏再突入までの期間を短縮するというものである。この方法ではデブリの回転制御も可能である。今発表では、パルスプラズマスラスタ、ホールスラスタを用いて、除去の対象となるデブリを想定したターゲットにプラズマ流を照射し、力積・反力を測定した結果を報告する。さらに、図 1 に示すような、大阪工業大学・超小型衛星プロイテレス4号機を用いた、本研究技術の宇宙実証実験の概要についても紹介する。

The Osaka Institute of Technology (OIT) 4th PROITERES satellite, as shown in Fig.1, is planned as a nano-satellite in order to achieve a main mission in which space debris makes deorbit by electric propulsion. The principle of deorbiting space debris is exposure of thruster plume to space debris by an electric thruster; that is, reaction impulse is given to debris, and after that debris decreases velocity and deorbits. Accordingly, the 4th PROITERES can deorbit space debris with safety without contacting with space debris and the satellite. Our university is developing four kinds of electric propulsion. These electric thrusters are investigated, and for the 4th PROITERES satellite for deorbiting space debris a suitable electric thruster will be selected. Reaction impulse bit of a pulsed plasma thruster (PPT) is measured on a downstream plate by pendulum method. As a result, a reaction impulse bit is average 1.718mNs. Because a previously directly measured thruster impulse bit of the PPT was about 2.2mNs, a reaction impulse bit is about 30% decrease. Now, the 4th PROITERES satellite is developing for launching in 2020.

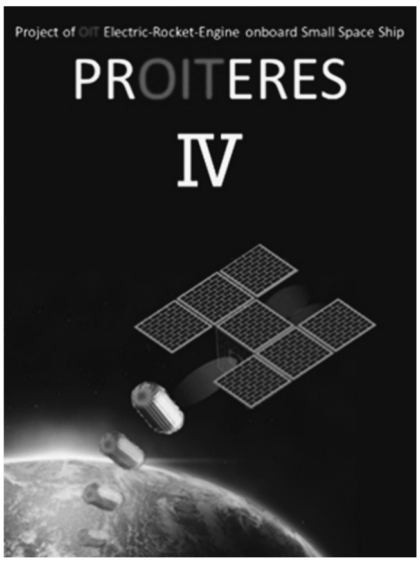

Fig.1 OIT 4th PROITERES Nano-Satellite for Non-Contact Space Debris Deorbit.

電気推進噴出流の照射による宇宙デブリの減速・降下過程の研究
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概 要 (1)

大阪工業大学(Osaka Institute of Technology: OIT)では、宇宙用スラスタ、特に電気推進機の研究開発の技術・経験を活かし、電気推進機そのものを用いた、新たな非接触式デブリ処理方法の研究開発を行ってきた。その方法は、電気推進機の噴出流をデブリに照射し、反力（力積）を与え、デブリを減速させ、デブリを降下させることにより、大気圏再突入までの期間を短縮するというものである。
この方法ではデブリの回転制御も可能である。

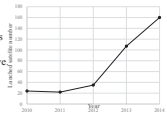
概 要 (2)

本発表では、電気推進機の1つである、電熱加速型ルスプラズマスラスタ (Pulsed Plasma Thruster: PPT)を用いて、除去の対象となるデブリを想定したターゲットにプラズマ流を照射し、力積・反力を測定した結果を報告する。
さらに、大阪工業大学・超小型衛星プロイテレス4号機を用いた、本研究技術の宇宙実証実験の概要について紹介する。

Background (1)

In recent years,
Space development, specially near-earth satellites launch and activities, large geo-synchronous and observation satellites, small/nano-satellites, is very active.

Over 100 units small/nano-satellites are launched for a year.



In general, satellites take several decades in space (small/nano-satellites with 600 km in altitude: 20-25 years) until re-enter the atmosphere.

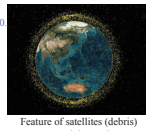
Background (2)

The collision of Iridium and Cosmos satellites.
Explosion of satellites and/or final launching-rocket mass.

Now, the number of debris,
10 or more cm debris exist over 20,000.
1 to 10 debris exist over 500,000.

New debris made by debris called
Kessler Syndrome
（ケスラーシンドローム）

The increase of debris accelerated.



Feature of satellites (debris) around the earth.

Background (3)

1-cm-class debris collision

All equipment are destroyed.
Many broken pieces are produced.

Produced debris such as,
Bolts
Broken devices, piece
et al.

10-cm-class debris collision

Satellites are destroyed completely.

Produced debris such as,
Large or nano-satellite itself
Large volume and mass
et al.

Debris removal technology is attracting attention!
It is required all over the world!

Background (4)

Procedure of debris removal

Contact

Electrodynamic Tether

Non-contact

DC&MPD Arcjet Thruster

Hall Thruster

Pulsed Plasma Thruster

Electric Propulsion
and
Chemical Propulsion

PROITERES Nano-Satellite R&D Project

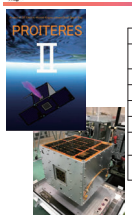
PROITERES
PRoject of OIT Electric-Rocket-Engine onboard Small Space Ship

2007 Start of the Project

2012 The 1st PROITERES nano-satellite was launched in India.

Present R&D of 2nd, 3rd and 4th PROITERES satellites

Summary of the 2nd PROITERES

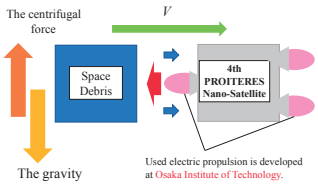


Summary of the 2nd PROITERES

Mass [kg]	50
Dimension [mm]	500 x 500 x 480
Power [W]	60
Altitude [km]	613
Orbit	Sun-Synchronous orbit
Life time [year]	1
Attitude control	Magnetic control Reaction wheel
Main mission	Changing altitude 50-100 km by electric propulsion (PPT)

All technologies of the 2nd PROITERES will be applied to the 4th PROITERES.

Debris Removal Procedure (1)



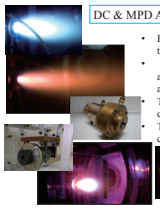
Debris Removal Procedure (2)

電気推進機そのものを用いた、新たな非接触式デブリ処理方法は、電気推進機の噴出流をデブリに照射し、反力（力積）を与え、デブリを減速させ、デブリを降下させることにより、大気圏再突入までの期間を短縮するというものである。
この方法ではデブリの回転制御も可能である。

Debris Removal Procedure (3)

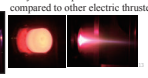
The principle of deorbiting space debris is exposure of thruster plume to space debris by an electric thruster; that is, reaction impulse is given to debris, and after that, debris decreases velocity and deorbits. Accordingly, the 4th PROITERES satellite can deorbit space debris with safety without contacting with space debris and the satellite. Also, rotation control of debris can be made by using this procedure.

Direct-Current (DC) or MPD Arcjet Thrusters

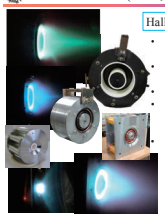


DC & MPD Arcjet Thruster

- Electrothermal and Electromagnetic type electric propulsion.
- In general, hydrazine (N_2H_4), ammonia (NH_3) and hydrogen (H_2) are used for propellants.
- They can be used together with chemical propulsion systems.
- They have simple structure compared to other electric thrusters.



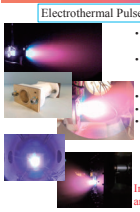
Hall Thruster (SPT, TAL and CHT)



Hall Thrusters: SPT, TAL, CHT

- Electrostatic acceleration (Hall effect) type propulsion.
- Three kinds of Hall thruster: SPT, TAL and CHT.
- Xenon is used for a propellant.
- High propulsive efficiency and specific impulse than other electric thrusters.
- Generally, Hall thrusters have magnetic field produced with solenoidal coils and permanent magnets, and cathodes for electron emission.

Electrothermal Pulsed Plasma Thruster (PPT)



Electrothermal Pulsed Plasma Thruster (PPT)

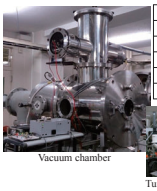
- PTFE（Polytetrafluoroethylene: Teflon®）is used for solid propellant.
- Therefore, liquid or gas propellant storage tank and some valves can become unnecessary.
- Very simple system structure.
- Can be reduced in size, weight.
- 0.5-2 Hz repetitive pulsed operation with a capacitor charging energy of 0.5-30 Joule (pulse width (Discharge duration time of one shot: few nanosecond)).

In the present study, PPT is selected and used for initial measurement.

Initial Experiment and Result

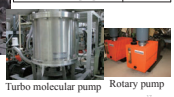
Reaction impulse bit of a Pulsed Plasma Thruster (PPT) was measured on a downstream plate by a pendulum method.
As a result, a reaction impulse bit was average 1.718mNs.
Because a previously directly measured thrust impulse bit of the PPT was about 2.5mNs, a reaction impulse bit is about 30% decrease.

Experimental Facilities



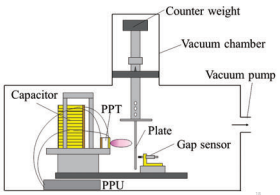
Vacuum chamber

Vacuum Chamber	
Length [mm]	1,250
Diameter [mm]	600
Turbo Molecular Pump	
Exhaust Velocity [l/s]	3,000
Pressure [Pa]	3.0×10^{-2}



Turbo molecular pump Rotary pump

Measuremental System for Reaction Impulse



Experimental Condition of Electrothermal PPT

Items	Value [mm]
Discharge channel diameter	4
Discharge channel length	50
Nozzle (Cathode) diameter	20
Nozzle (Cathode) length	14
Plate size	200 x 200
Distance between the PPT and the plate	75

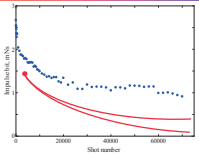
The PPT was operated with several shots on this condition, impulse bits given to the plate were measured. Accordingly, the average reaction impulse bit was evaluated as an initial performance of the PPT.

Initial Result

Measured reaction impulse bit was 1.718 mNs.
At this time, measured thrusting impulse bit of PPT itself has been clarified to be 2.5 mNs from previous measurements.

The reaction impulse is about 30% decrease compared with the thrust impulse!

Predicted Reaction Impulse to Debris



Reaction impulse bit history is predicted like these red curves from the present experimental result.

Conclusions & Future Works

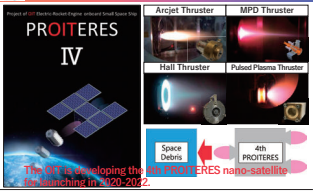
Conclusions

- A new procedure of non-contact debris removal with electric thrusters was proposed.
- Research and development of a debris removal satellite is; that is, the OIT 4th PROITERES Nano-Satellite, was started at OIT.
- Lots of Electric propulsion developed at OIT will be applied.
- As an initial experiment, a reaction impulse bit was measured, and the average reaction impulse of 1.718 mNs was obtained although the measured thrusting impulse bit was 2.5 mNs. (30% in decrease!)

Future Works

- Changes of reaction impulse bit will be investigated; changing distance between the PPT and the plate, changing the plate size, and radially changing exposure location.
- All data of reaction impulse or reaction force will be measured with all kinds of electric thruster (and chemical thruster).
- Developing all systems of the 4th PROITERES for launch in 2020-2022.

4th PROITERES Nano-Satellite R&D



New Non-Contact Debris Removal Technology Using EP