DE-ORBIT DEMONSTRATION USING ELECTRODYNAMIC TETHER SYSTEM FOR SPACE DEBRIS DISPOSAL

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ABSTRACT

This paper presents a project of Electrodynamic tether (EDT) mounted on a 3U CubeSat. ALE and Japan Aerospace Exploration Agency (JAXA), as a part of the JAXA Space Innovation through Partnership and Co-creation (J-SPARC) project, are jointly working on the commercialization of post-mission disposal (PMD) device using the EDT and a field emission cathode (FEC) using carbon nanotube (CNT) electron emitter. ALE is collaboratively developing 3U CubeSat bus-system and EDT payload with Tohoku University and Kanagawa Institute of Technology (KAIT) respectively. Since the deployment mechanism is quite important for the PMD device, we developed a device that can securely deploy a folded tape tether even if the spacecraft has suffered an unrecoverable fault in this project. This device can enhance PMD compliance.

1 INTRODUCTION

1.1 Background

The rapid growth of space utilization, the increase in demand for small satellites and associated launch services, and the rise of mega-constellations are drastically increasing the number of space debris. These objects remaining in orbit can be an obstacle for future space development and will produce more debris due to the collision. In 2009, two communication satellites which are active US commercial satellite, Iridium 33, and derelict Russian military satellite, Cosmos 2251 accidentally collided in orbit [1]. Then, they produced a lot of debris, and 355 fragments from Iridium 33 and 1117 fragments from Cosmos 2251 are now cataloged [2]. Considering the current situation, the mitigation of space debris must be required.

Post-mission disposal (PMD) is one of the concepts, in which the spacecraft is transferred into a graveyard orbit or de-orbit and re-enter the atmosphere. The Inter-Agency Space Debris Coordination Committee (IADC) and several national guidelines have formulated less than 25 years to be the appropriate lifetime of the spacecraft in orbit. Also, the IADC guideline requests more than 90% of PMD compliance [3]. Therefore, the de-orbit system is essential for the PMD device. The thruster is one of the solutions, however, a long lifetime is required since it is used for main propulsion or station keeping before the de-orbit. If the thruster suffers from the uncoverable fault, it is difficult to de-orbit. Then, the Electrodynamic tether (EDT) can be a solution since it independently operates for a long time. The EDT deploys a bare tether to generate thrust from atmospheric drag and electromagnetic force without the need for a large power supply [4]. After the deployment of the tether, the EDT passively de-orbit. If the cathode operates at the edge of the spacecraft, the tether potential and the current in the tether are increased resulting in the enhanced electromagnetic force [5]. This EDT technique has been demonstrated several times [6-8].

1.2 Project Overview

ALE and Japan Aerospace Exploration Agency (JAXA) as a project of the JAXA Space Innovation through Partnership and Co-creation (J-SPARC) initiative, are engaged in the commercialization of space debris disposal devices that work by promptly de-orbiting satellites after the completion of their mission as a space debris mitigation. Having co-created the concepts of the project, the two partners have now moved on to the joint demonstration phase. In the joint demonstration phase, ALE and JAXA will collaborate toward launching their space debris disposal device aboard a nano-satellite during fiscal 2021 for demonstration in space. Following the demonstration, ALE aims to develop a business to manufacture and market the device.

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Our developed device employs carbon nanotube (CNT) as a field emission cathode (FEC) [9-12], and it accelerates the de-orbit velocity as shown in Fig.1. The FEC can emit electrons at low power consumption compared to the hollow cathode, and it does not need the propellant. Therefore, the EDT system can be designed in small size. The CNT-FEC was demonstrated and validated in orbit in The Space Technology 7 Disturbance Reduction System [13] and Kounotori Integrated Tether Experiments (KITE) [14].
In this project, ALE has developed the PMD device using EDT with Kanagawa Institute of Technology (KAIT) and developed a bus-system with Tohoku University. JAXA works on the development and validation of CNT-FEC and orbits analysis of EDT.

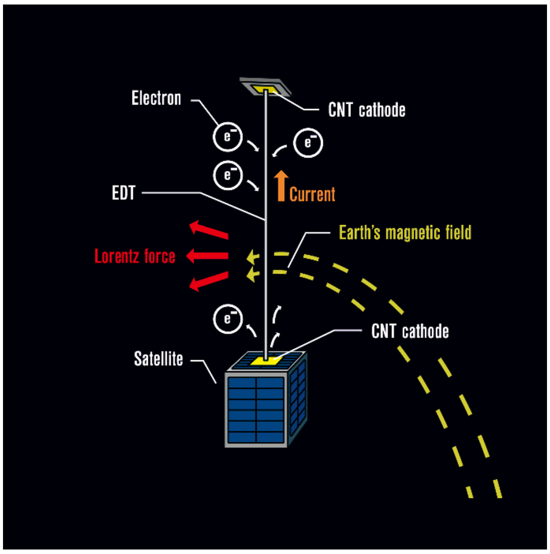

Figure 1. Concept of EDT using CNT cathode.

1.3 Mission Overview

To demonstrate the de-orbit by the EDT, we develop the nano-satellite employing the PMD device. The demonstration is conducted more than 500 km and less than 60° of inclination with 3U CubeSat which is named EDT-Sat. We are planning to launch the satellite in FY 2021. The success criteria of this mission are as shown in Table 1.

Table 2. Success criteria

Minimum success	Deploy tape tether and confirm the de-orbiting.
Full success	Confirm the change of de-orbit performance with switching CNT-FEC.
Extra Success	Clarify the relationship between the tether behavior and electromagnetic force.

To accomplish the mission, it is necessary to control the direction of the tether deployment and measure the current attitude with high accuracy [15]. Additionally, the deployment system must not deploy the tether during the launch and must securely deploy the tether after the mission.

2 SYSTEM DESIGN

2.1 Operation Sequence

An operation sequence can be categorized into four phases. First, the satellite is separated from the launch vehicle, it starts de-tumbling to suppress the rotation and deploys solar cell panels. Second, we confirm the condition of the bus-system and payload. Third, the attitude is controlled that the antenna is in the geocentric direction and tether deployment is to zenith direction. During deployment, the attitude is kept being controlled. Fourth, we start to measure the tether position and to confirm the de-orbit with using CNT-FEC.

2.2 System Structure

For the bus-system, validated components which have flight heritage were selected. These components are produced by GomSpace [16]. The payload is newly developed.
3-Unit CubeSat structure (ISIS structure) is used for the EDT-Sat structure. The payload and the bus-system are allocated to 1U and 2U, respectively. The total mass is around 5 kg. When the solar panels are completely deployed as shown in Fig. 2, at least 9 W can be generated.
The payload which is the PMD device consists of parent-sat and child-sat. the CNT-FEC and the deployment mechanism are mounted on the parent-sat, and the child-sat plays a role in end mass. A 300 m folded tether is packaged in the payloads and it can be deployed by the command from the ground station. Both the parent- and the child-sat employ GPS receivers to use the measure how much tether is deployed in orbit.
NanoPower P31 is power control substrate and NanoPower BP4 is a battery unit. S-band communication between EDT-Sat and the ground station uses the antenna, NanoCom ANT2000, and transceiver, NanoCom SR2000. The SR2000 is compatible with CCSDS 131.0-B-3 recommendation. The ground station utilizes the facility of Kongsberg Satellite Services (KSAT), which ALE has experienced in the ALE-1 and ALE-2 project [17]. This facility is connected with ALE's operation room via Virtual Private Network (VPN), and the operation is performed within ALE. NanoMind A3200 is an onboard computer that carries out the command and processes the housekeeping data and the mission data. The attitude control system also uses NanoMind A3200 which equips with a geomagnetic aspect sensor (GAS) and gyroscopes (GYRO) to measure the attitude. fine sun sensors (FSS) are attached on the side. coarse sun sensor

(CSS) is mounted on the solar panel, and it is used to judge whether there is sunshine or not. As actuators, magnetotorquer (MTQ) and reaction wheel (RW) are used. The MTQs are integrated with solar cells and the are attached to two directions. The MTQ is used for the de-tumbling of saturation in RW.

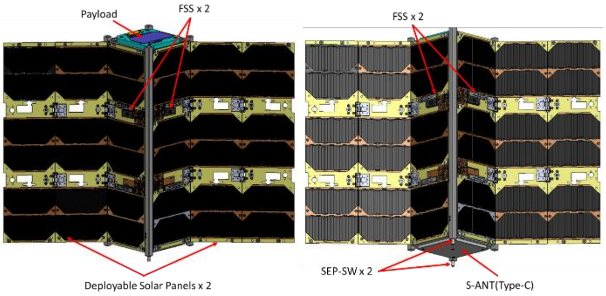

Figure 2. Exterior of EDT-Sat.

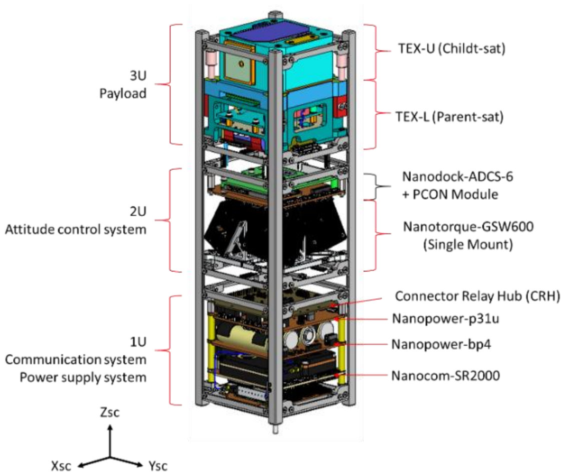

Figure 3. Interior of EDT-Sat.

3 DEPLOYMENT MECHANISM

The child sat is ejected springs when the Dyneema is burned off. To avoid unexpected deployment, we developed the original circuit for the deployment system as shown in Fig.4. A latching relay is designed by the circuit, and it works as one of triple redundancy, which consists of the latching relay and two CPUs.
Also, as a triple redundancy to deploy the tether, the system has two bus powers and a battery. Although our developed PMD device has 3 units for redundancy, and each unit has the latching relay and two CPUs, we use the circuit with a single unit in this CubeSat because the objective of this project is the demonstration of de-orbit. Additionally, Since the power supply is required to have redundancy with two-fault tolerance due to the launch safety, the two bus powers, and the battery work for it. Therefore, this PMD device has a reliable deployment mechanism with triple redundancies for tether deployment and unexpected tether deployment, respectively.

4 SUMMARY

In this project, we developed a PMD device that can be mounted on the nano-satellite including CubeSat for space debris disposal. Our developed PMD device employs the CNT-FEC as an electron emitter enabling to design of the device in a small size. This device never deploys the tether in the launch vehicle and securely deploys whenever we want with the two triple redundancies. Therefore, it can improve PMD compliance.
This EDT-sat is planned to be launch in FY 2021, and the demonstrate the de-orbit in space.

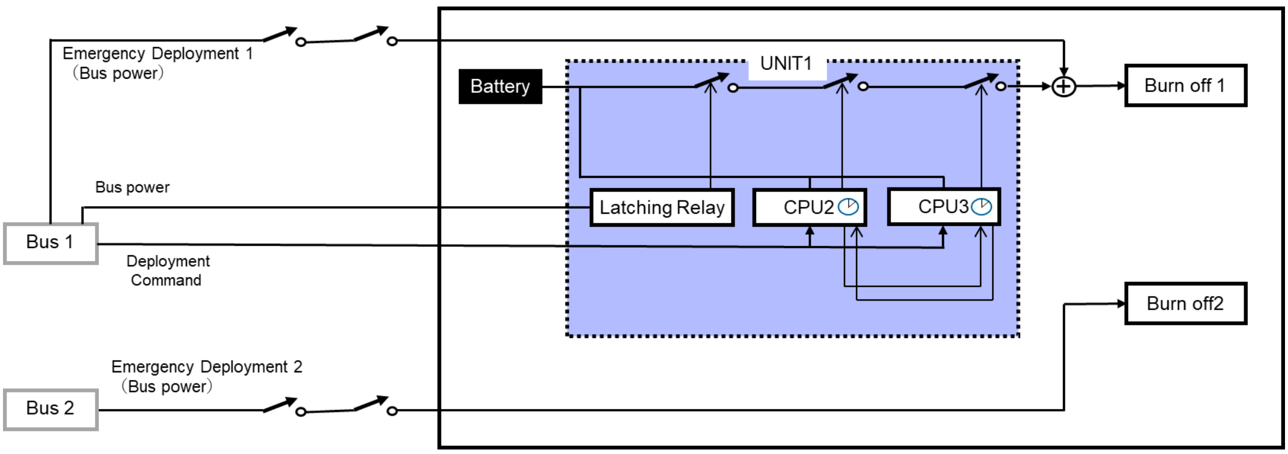

Figure 4. Circuit of deployment system.

5 ACKNOWLEDGEMENT

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