On-orbit Experiment System of Separation Mechanism for Pico-Satellite on Sub-Payload of M-V Rocket

Kyoichi UI, Naoki MIYASHITA, Kei Miyamoto and Saburo MATUNAGA
Mechanical and Aerospace Engineering, Tokyo Institute of Technology, Japan

Abstract

Laboratory for Space Systems (LSS) prepares an on-orbit experiment of a separation mechanism for nano-satellite on a sub-payload of M-V Rocket No.6. The sub-payload is a space for a counter weight to motion balance of the M-V rocket. LSS was permitted to use the space to conduct our experiments. The size of the sub-payload is about 300mm x 150mm x 124mm. The weight is 5kg, provided that the allowable margin of error is less than 5%. Our experiment system consists of the separation mechanism, a dummy mass instead of a pico-satellite, a measurement subsystem and a rocket interface subsystem. The dummy mass is a substitute for a pico-satellite. The size is 10cm cubic and weight is about 1kg. The measurement subsystem measures a separation speed, a motion of the dummy mass after separation and temperatures at four points. The rocket interface subsystem consists of a power, communication and timer receiving. The system attached B3PL of M-V rocket turns on before the launch and conducts a separation after 1421s from the launch. Acquired data in the separation are transmitted for 168s at Christmas Island in the Republic of Kiribati. The paper describes overview, development status and measurement item to verify the system.

M-V ロケット6号機サブペイロードを利用した超小型衛星用分離機構の軌道上実験システム

宇井 恭一，宮下直己，宮本径，松永 三郎(東工大・理工)

概要

本研究では，超小型衛星用分離機構の汎用化を目指し，M-V ロケット6号機のサブペイロードを用いて分離実証実験を行うべく準備を進めている。300mm x 150mm x 125mm の空間内に，分離機構，ダミー衛星，計測装置，電源制御，通信，分離信号処理システムなどを搭載し，打ち上げ1421秒後から168秒間，クリスマス島可視領域において実験を行う。本稿では，実験の概要，開発状況，評価のための解析項目などについて述べる。

1. Introduction

Laboratory for Space Systems (LSS), Tokyo Institute of Technology (Tokyo Tech) realized in a successfully launch of a pico-satellite called CubeSat from Russian rocket in June 2003. In 2005, Nihon University and University of Tokyo plan to launch each CubeSat. The increase of pico-satellite launch can be expected under the present circumstances all over the world. By the way, preparing a separation system in order to insert a satellite into an orbit is an important issue when developers want to launch a pico-satellite. In the CubeSat case, California Polytechnic State University (CalPoly) has developed a separation mechanism (Poly Picosatellite Orbital Deployer, P-POD) only for CubeSat. The mechanism is expected to become a standard system for CubeSat developer. P-POD is able to separate three CubeSats at once. But it has many problems that are responsibilities of CalPoly to handle many CubeSat and difficulties in communicating between international universities. Moreover, reliability of separation is expected to be not high. LSS developed an original separation mechanism by ourselves for Tokyo Tech’s CubeSat called CUTE-I last year. Figure 1 shows the separation mechanism with CUTE-I. The mechanism attached to Russian rocket and successfully separated CUTE-I from the rocket by receiving a signal from CUTE-I and confirming a deployment of three antenna and a solar cell paddle in downlink data [1]. LSS researches and develops its own separation mechanism for a future launch of our pico-satellite. A new separation mechanism is
improved based on the separation mechanism for CUTE-I. Objectives of the new mechanism improve reliability, simplify assembly and have several functions like low-shock, low-disturbance, spinning separation and confirmation of successful separation. Moreover, LSS got an opportunity to conduct an experiment on a sub-payload of M-V Rocket No.6 (M-V-6) which is JAXA’s solid rocket. Objectives of the experiment are to verify the functions of the new separation mechanism and to experience in pico-satellite launch using Japanese rockets. So far, LSS has developed mechanical interface (I/F) and electrical I/F which consists of power, telemetry communication and timer signal from the rocket with many staffs of JAXA/ISAS and several rocket makers. And we conduct the thermal, vacuum and vibration test and analyze the structural, vacuum and thermal condition in order to stand launch environments.

In this paper, at first we specify the features, advantage/disadvantage and lessons learned about our separation mechanism. Secondly we describe the new separation mechanism and experiment system attached M-V-6 sub-payload. Finally, we explain a future plan of LSS’s separation system development.

2. Review of Separation Mechanism for CUTE-I

2.1 Overview
In this section, overview of the separation system for CUTE-I is reviewed briefly because we improve the separation system released CUTE-I.

A typical separation mechanism consisting of a marmon clamp band and pyrotechnic devices is not suitable for pico-satellite, because the weight and size are relatively small and the specific rigidity and strength are relatively high to the standard satellite. Therefore design methodology to be applied to the separation mechanism for pico-satellites is much weaker rigidity and strength. The use of pyrotechnic devices is prohibited from rocket provider because the devices generate great impact on not only pico-satellites but also other satellite and rocket. Non pyrotechnic devices like a pin puller can be applied to rocket but they are not also suitable for a pico-satellite separation system. Pico-satellites doesn’t have spaces for separation mechanism because its size and weight are very severe. Pin pullers remain on a wall or inside a satellite after separation.

We developed a separation system for CUTE-I in considerations of characteristics of CUTE-I and launch condition as shown in Figure 2. The system consists of the separation mechanism and a separation signal processing circuit. The mechanism consists of four jaws, a nylon line, a nichrome line and a main structure. Main structure has 4 pillars and guides to fix CUTE-I. These jaws hold pillars of CUTE-I and are tightened by the nylon line as shown in Figure 3. When the nichrome line burns off the nylon line, the jaws release the CUTE-I pillars. Then springs inside the mechanism push CUTE-I, and separate it. The explanation of the separation signal processing circuit is left out because it specially made to order for Russian rocket.
2.2 Comparison to Other Separation Mechanism for Pico-Satellite

Currently separation systems, which insert a pico-satellite into an orbit actually, are P-POD, T-POD and our separation system. P-POD is the standard separation system for CubeSat developer [2]. T-POD was developed by University of Tokyo in order to launch its CubeSat last year and it was designed P-POD. P-POD is shown in Figure 4. P-POD is a rectangular shape and can be inserted 3 CubeSats as well as separate them at the same time. Deployment begins when a spring-loaded door opens. The door is held closed by a Vectran line. To release the door retaining line the line is melted using a Line Cutter.

![Figure 4 P-POD ©California Polytechnic State University](image)

Compared with our separation mechanism, Advantages/disadvantages of P-POD are the followings.

<Advantages>
- P-POD is possible to launch three pico-satellites at once.
- CubeSats are protected against accidental touches.
- Other equipments of a main satellite and a rocket are protected against picosatellite trouble.
- The structure of P-POD is relatively simple.

<Disadvantages>
- The friction between P-POD and CubeSat is very serious because contact area between P-POD and CubeSat is very large.
- 3 CubeSats collide against each CubeSat and P-POD door into P-POD.
- If the CubeSat which is nearest to the door cannot separate, the following CubeSats cannot separate too.
- It is difficult for P-POD manager to handle 3 CubeSats in launch campaign.
- It is difficult for especially non-US universities to negotiate several interfaces between P-POD and CubeSat.

In our separation mechanism, contact areas are as small as possible in order to reduce the friction between satellite and mechanism. But CubeSat is exposed outer circumstances in our mechanism.

2.3 Lessons Learned and Current Circumstances

LSS learned lessons from the development of the separation mechanism for CUTE-I. Lessons learned are the followings.
- Rigidity and strength of the mechanism and pico-satellite are too much high.
- It is not redundant system but a single error point to use only a pair of a nylon line and a nichrome line.
- It does not have a confirmation system for separation successfully if it can downlink the telemetry data.

In Japan, JAXA/ISAS works to launch pico-satellite utilizing sub-payload space of M-V rocket. Sub-payload is originally space for counter weight to adjust rocket mass balance. The space is open to laboratories and other institutes from JAXA/ISAS. LSS submitted a proposal to conduct an experiment of new separation mechanism on sub-payload in autumn 2002 and has researched the new mechanism and prepared the experiments. And LSS starts to develop next CubeSat type pico-satellite called “Cute-1.7” [4]. We consider whether Cute-1.7 is launched with P-POD or our separation system because the selection of separation system depends on a launch vehicle. Improvements of the new separation mechanism which we have developed are explained in the next chapter.

Other developer of separation system for pico-satellites from P-POD also learned lessons and concerns about cost-reduction, high-reliability and confirmation of successfully separation. The P-POD will be reduced the cost because P-POD plans to be mass-produced as a standard separation system for CubeSat. The change from line cutter and heater to separation nut with SMA (Shaped Memory Alloy) aims to realize high-reliability. Signal as downlink telemetry is sent in order to confirm the separation when a door of P-POD opens 90degree. Moreover, a separation system for larger satellite which consists of CubeSats as a unit is realized to combine several P-PODs.

3. Improved Separation Mechanism

3.1 Objectives

When we designed the new separation mechanism, LSS was accepted the proposal of the sub-payload experiments launched in 2005. And LSS has developed Cute-1.7 which needs a reliable separation system. Furthermore, candidate of launch vehicle for Cute-1.7 is M-V rocket. Therefore, objectives of a new separation mechanism are to be more reliable and be attached
to M-V rocket with minimum improvements. Main objectives are the followings.
- The improved system aims to be attached to the sub-payload of M-V rocket.
- The hold/release system, which consists of a pair of a nylon line and a nichrome line, improves more redundant.
- The system has the confirmation sensors of successfully separation because it can downlink telemetry from M-V rocket.

3.2 Overview of the Improved Separation Mechanism Design

The improved separation mechanism is shown in Figure 5. The Figure is made by 3DCAD software. Improved points are the followings.
- Base plate became as small as possible in order to fit the mechanical I/F of sub-payload of M-V rocket.
- One more pair of a nylon line and a nichrome line is added to the hold/release system to be more reliable. Each nichrome line plans to burn off both nylon lines. The redundant system protects from unexpected accidents of nylon line and nichrome line. The system shows in Figure 5.
- Mechanical switches are attached to guide part of the mechanism. The switches play roles of separation sensors by detecting whether the pillars of pico-satellite leave or not. The switches are located not to generate torque on a pico-satellite.

We verify the effects of improved points through various ground experiments and on-orbit experiments of M-V rocket.

4. Experiments on Sub-payload of M-V Rocket No.6 of JAXA/ISAS

4.1 Overview

We plan to conduct a separation experiment on orbit using M-V Rocket. The experiment system is attached to the sub-payload of M-V Rocket No.6 (M-V-6). But in this time we use not an actual satellite but dummy mass, because it is prohibited to release anything out of the rocket. The main-payload of M-V-6 is ASTRO-E2 which is Japanese fifth X-ray astronomy satellite. Sub-payload is attached to the third stage of the rocket shown in Figure 6.

![Figure 6 Location for TSD in the Third Stage of M-V-6](image)

The rocket will launch in the summer of 2005. ASTRO-E2 is separated from M-V-6 at 1301s after the launch (X+1301s) and a separation experiment is conducted at X+1421s (X is the launch time). We will receive the telemetry data from the rocket until X+1589s. M-V-6 left all components except the third stage and works fine three axis attitude control mode at our experiment time. The telemetry data are received at the Christmas Island down range station in the Republic of Kiribati. Received telemetry data will be sent to us by e-mail. We need to prepare not only the separation mechanism but also experiment support systems including M-V rocket I/F and ground segments. We submitted the proposal to JAXA/ISAS in autumn 2002, conducted mechanical I/F check in March 2003, electrical I/F check in August 2003 and ground segment I/F check in January 2004. Moreover, we will conduct I/F recheck in July 2004, assembly operation at the Uchinoura Space Center of JAXA in March 2005 and flight operation in the summer of 2005.

The primary objective of the experiments is to verify the separation mechanism and other subsystem in order to launch a pico-satellite with M-V rocket. Our experiment system is named Tokyo Tech Separation system Demonstration called TSD. Detailed mission items of TSD are the followings.
- Various I/Fs between rocket and TSD, which consists of mechanical, power, PCM telemetry (communication) and separation signal, are developed.
- TSD is designed to withstand an extreme launch environment of M-V rocket based on the structural and thermal analyses.
- TSD measures temperatures on orbit.
- TSD measures various points about separating behaviour in order to verify the improved points of separation system.
- We have precious experiences from negotiations with the staffs of JAXA/ISAS and various industries. Through the experiments, LSS has one foothold to launch pico-satellite by M-V Rocket.

**4.2 Requirements for Experiment System**

TSD satisfies the following requirements in order to be attached to M-V-6.
- Dimensions: L300 x W150mm x H125mm (now)
- Weight: 5.0kg (an error of less than 5%)
- Downlink Baud rate: 3200bps
- Experiment Period: X+1421s – X+1589s (168s)
- Attitude Stability: less than 1deg/s
- Altitude in the Experiment: about 400km
- Thermal Condition: under estimation by JAXA/ISAS
- Vacuum: 10⁻⁸torr
- Vibration (QT Level): 21.6Grms (random)
- Other requirements: TSD must not separate any other object from the rocket. TSD must not influence other components mechanically and electrically when several accidents occur.

**4.3 Description of Experiment System**

TSD is a closed box to meet the requirements mentioned at section 4.2 and conduct the experiment only inside the box. The actually size of an experiment box of TSD is L300mm x W150mm x H136 shown in Figure 7.

![Figure 7 Overview of TSD](image)

In the experiment, TSD measures the followings items to verify the separation mechanism through the measurement subsystem shown in Fig. 9.

- Temperature measurement makes us confirm the thermal condition at the separation time using two thermisters on the wall and that the nichrome heats to burn off the nylon line.
- Measurement of pushing speed by spring into the mechanism is realized to measure displacement between dummy mass and the mechanism using a displacement sensor.
- Separation detection is realized with four mechanical switches, called separation switches, located beside the pillars of dummy mass shown in Figure 9.
- Four mechanical switches on the opposite wall, called contact sensors, measure the behaviour of the separated dummy mass and confirm the separation surely shown in Figure 9.
- The separation speed after the separation is measured by calculating each detecting time of separation sensors, photoelectric sensors...
area sensors) and contact sensors shown in Figure 9.

The measurement system has various and many sensors to verify the mechanism certainly at only one time by compensating with many data.

Figure 9 Measurement Subsystem

Figure 10 Mission Time Line

Mission time line of TSD is shown in Figure 10. Before the separation, TSD sends the real time data which consists of system status and wall temperature data. TSD receives the separation signal from M-V-6 at X+1421s. TSD starts to heat the nichrome lines and resets all sensor data when TSD receives signal. TSD measures experiment data with five types of sensors and writes SRAM at 4kHz for 5sec. Nichrome line burns off nylon line for 2s or 3s. Dummy mass is separated after burning off the nylon line and collides against the opposite wall in less than 0.3s after the separation. TSD reads SRAM data and sends them after 5s from receiving signal. The Written data size is estimated about 160,000bit. TSD sends the same data repeatedly about five times until LOS time in order to get the telemetry data certainly.

5. Summaries and Future Works

The features and reviews about the separation mechanism for CUTE-I are explained. Firstly, we compared with other separation mechanism for pico-satellite, especially P-POD. Next, the improved separation mechanism is introduced. Finally, we describe the experiment outline on the sub-payload of M-V-6 and explain the experiment system.

We have already confirmed the rocket I/F subsystem until July 2004. We have already developed TSD and now preparing the ground segment including user interface. Moreover, we will conduct the vibration test in November 2004 and thermal, vacuum and long time operation test as the occasion demands. And we prepare the structural and thermal analysis as well as an estimation of the separation behaviour.

Our primary objective in the research is that LSS has one foothold in pico-satellite launch using M-V Rocket. Furthermore, we plan to launch our next pico-satellite, called Cute-1.7, using M-V-8.

References


[4] Cute-1.7 web site URL; http://lss.mes.titech.ac.jp/ssp/cute1.7/rev0/index_e.html