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Parabolic Flight Micro-Gravity Experiment of Tethered Recovery in Tethered Sampling Method

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Abstract

The tether sampling method is a new minor-body sampling method proposed by the authors. It consists of three phases; 1) shooting a corer to penetrate the surface of a minor-body, 2) pulling up the corer with tether using a reel mechanism, 3) recovering the corer into a storage box. In this paper, recovery phase is focused on and checked its feasibility under micro-gravity using parabolic flights. The micro-gravity experiments were conducted under more realistic conditions than that of free-fall micro-gravity experiment previously conducted by the authors. The experimental setup, parameters and results are described in this paper.

航空機を用いた微小重量環境下における テザーサンプリング法の回収実験

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摘要

テザーサンプリング法は，次世代の小天体サンプルリターンミッションを実現するための新しい技術として，著者らが提案した方法である．テザーサンプリング法は，1) 小天体表面にテザーをつけた試料採取器(コアラ)を打ち込み，2) 探査機搭載のリール機構を用いてコアラを引抜き，3) 格納庫に回収する，と言う 3 つの段階で構成させている．本論文では，この一連の過程の中でも，コアラの引抜き・回収過程に注目している．著者らは，実現性を評価するために航空機を用いた微小重量実験を実施した．この実験は，過去に行った落下塔での微小重量実験よりも現実的な条件で行ったものである．本論文では，航空機を用いた微小重量実験について，実験装置や実験パラメータ，結果について述べる．

1. Introduction

The Japanese asteroid probe, HAYABUSA (Fig. 1.1), was launched and succeeded in rendezvous with the asteroid “ITOKAWA” in December 2005 and tried to collect sample by touching down. HAYABUSA’s sampling method was the bullet shooting method as shown in Fig. 1.2. The method can get a few hundred milligrams sample on the surface of the asteroid. For the next minor-body sample return mission, the sample collection which keeps depth information is required to investigate the inner structure of the asteroid. And getting much more sample quantity is also desired.

Fig. 1.1 HAYABUSA (©JAXA)

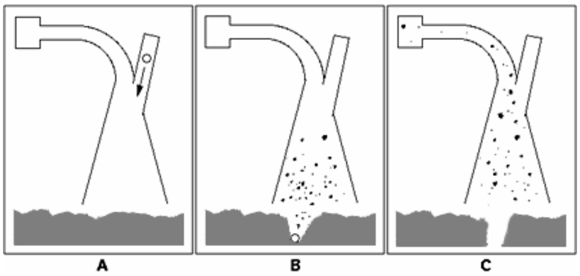

Fig. 1.2 HAYABUSA’s Sampling Method (©JAXA)

The tethered sampling method is a new sampling method proposed by the authors to satisfy the requests for next minor-body sample return mission [1-3]. It has three phases, 1) a corer connected with tether is shot to penetrate the surface of a minor-body, 2) the corer is pulled up with the tether using a reel mechanism and 3) the corer is recovered into a storage box (as shown in Fig. 1.3).

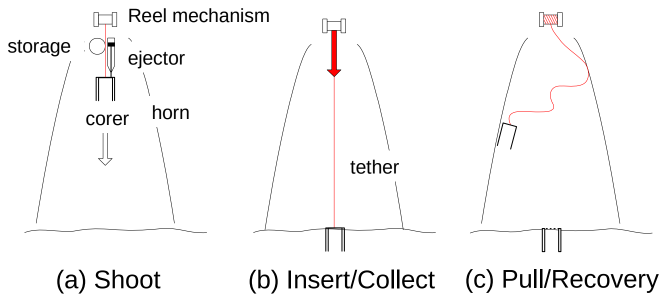

Fig. 1.3 Tethered Sampling Method

Pulling out and recovery phase were focused on in this research. Fundamental experiments under micro-gravity using a free fall capsule were previously conducted by authors [4-5]. But there are some disadvantages in experimental duration and space in the free fall capsule way. Experimental duration, about 4.5 seconds, is too short to observe a behavior of the corer and tether in retrieval phase. And experimental area in the capsule is too small to mount a full size sampler horn. So, the micro-gravity experiments using parabolic flight were necessary to conduct experiments under more realistic conditions. In this paper, the experimental setup, parameters and results are explained.

2. Experimental Setup

Micro-gravity experiments using parabolic flight were conducted to check the feasibility of the corer and tether retrieval. 38 experiments were conducted in total, and the validated data were obtained in 27 of them. In the experiment, the duration of micro-gravity was about 20 seconds and gravity level was 1/100G order.

The experimental setup used in the experiments consists of a reel mechanism, a shutter mechanism and a corer holder, as shown in Fig. 2.1. Five video cameras are also installed. Two of them are located in front of the experimental area for stereovision. Another two of them are located at the upside and lower side of the experimental area. The other camera is located at the side of the reel mechanism. The size of the experimental area is 660mm*560mm*700mm. The tether is in the initial, and each experiment is ended when the corer reaches a storage box. A photograph of the experimental setup is shown in Fig. 2.2. The experimental area is in the left rack and control devices are in the right rack.

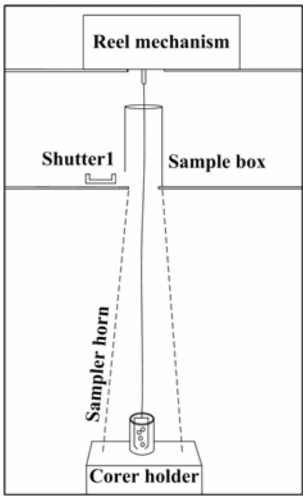

Fig. 2.1 Pattern Diagram (Left Side Rack)

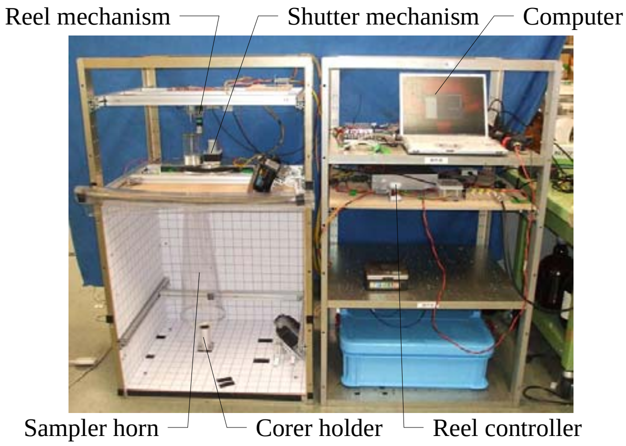

Fig. 2.2 Experimental Setup

The reel mechanism which is necessary to pull up and retrieve the corer is shown in Fig. 2.3.

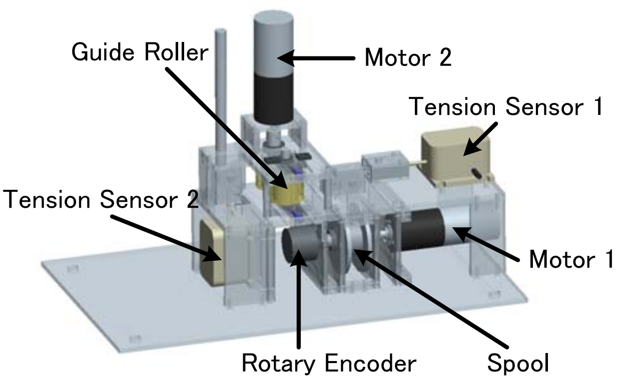

Fig. 2.3 Overview of Reel Mechanism

It consists of two motors, two rotary encoders, two tension sensors and a guide roller. Motor 1 and motor2 are connected directly with the spool part and the guide roller respectively. The guide roller divides tether tension into outer tension and inner tension as shown in Fig. 2.4. Keeping the inner tension positive prevents tether from getting entangled. The tension sensor 1 measures twice of the inner tension and the sensor 2 measures the outer tension. These measurements value are fed back in the motor control. Each motor driver has two control modes: one is a current mode and the other is a voltage mode.

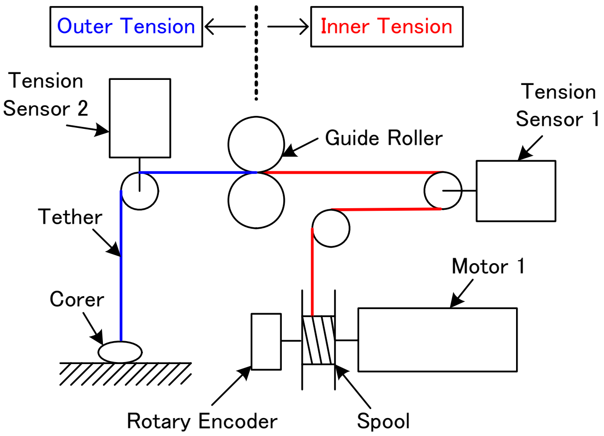

Fig. 2.4 Pattern Diagram of Reel Mechanism

As initial condition, the corer is in the corer holder, as shown in Fig. 2.5, on the assumption that the corer is inserted into the minor-body. The corer is fixed by a sponge inside the corer holder. Pulling out angle can be changed, as shown in Fig. 2.6.

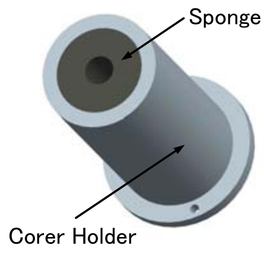

Fig. 2.5 Corer Holder

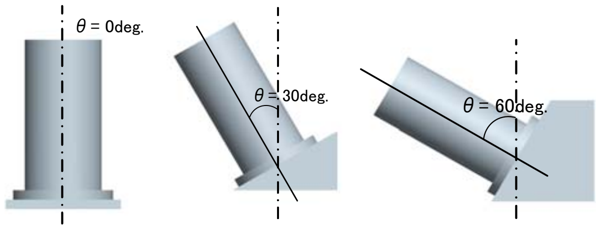

Fig. 2.6 Pulling Out Angle

3. Experimental Parameters

The experimental parameters are following below,

- Two types of pulling out force
- Four types of initial conditions combined corer position and pulling out angle
- Three types of tether retrieval speed
- Three types of motor control laws

Pulling out force can be changed by using single corer and dual corer. The dual corer consists of outer and inner cylinders, as shown below. Pulling out force of the dual corer is smaller than that of the single corer because the outer cylinder prevents pressure on the inner one. Pulling out mechanism using the dual corer is illustrated in Fig. 3.2.

Fig. 3.1 Dual Corer

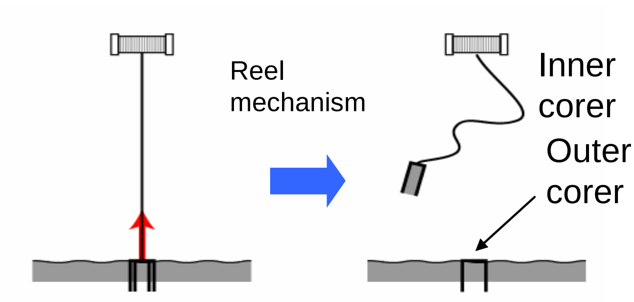

Fig. 3.2 Pulling Out with Dual Corer

Fig. 3.3 shows the four types of initial conditions of the corer.

- Pulling out angle: 0 deg.
  Position: Beneath the sampler horn
- Pulling out angle: 30 deg.
  Position: Beneath the sampler horn
- Pulling out angle: 60 deg.
  Position: Near the sampler horn
- Pulling out angle: 60 deg.
  Position: Away from the sampler horn

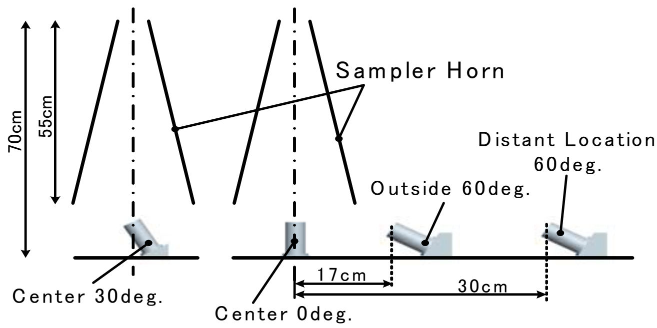

Fig. 3.3 Corer Initial Arrangements

There are three types of tether retrieval speeds, low (0.06m/s, 0.07m/s), middle (0.1m/s) and high (0.15m/s). The motor control laws for constant velocity are the followings,

- Feed back PID control (current input mode)
- Feed back P control (voltage input mode)
- Constant command control (voltage input mode)

4. Results

Fig. 4.1 and 4.2 show the result of the experiments affected by pulling up force. The graph represents the inner tension, outer tension and retrieval speed. The common parameters of both of the experiments are the followings,

- Retrieval speed: Middle (0.1m/s)
- Pulling out angle: 60deg.
- Position: Away from the sampler horn

According to these figures, pulling out motion is detected at approximately 2 seconds and pulling out force of dual corer and single corer are about 0.4N and 6.8N respectively. The motion of the corer indicates that strong pull out force causes increase of the number of corer impact on inside the sampler horn. Sample becomes less and less as the number of corer impact more increases.

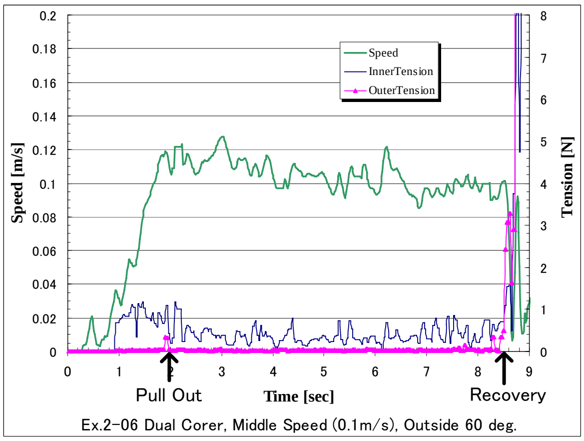

Fig. 4.1 Small Pulling Out Force (Dual Corer)

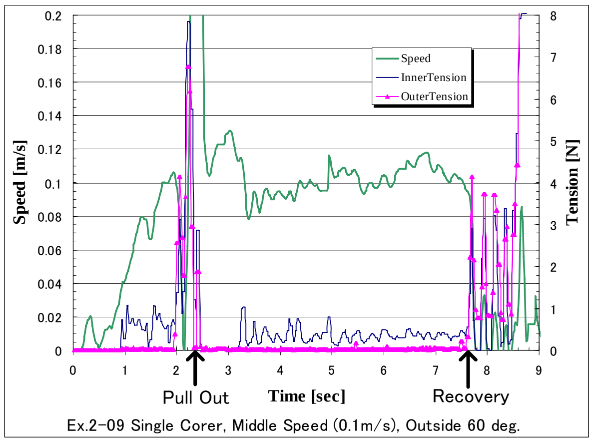

Fig. 4.2 Large Pulling Out Force (Single Corer)

Fig. 4.3 to 4.5 show the result of the experiments affected by initial conditions of the corer: 0 deg. beneath the horn, 30 deg. beneath the horn and 60 deg. near the horn. The common parameters of these experiments are the followings,

- Pulling up force: Small (dual corer)
- Retrieval speed: High (0.15m/s)

According to the these experiments, it is found that the corer can be recovered even if it is placed outside of the sampler horn and it is inserted sidlingly beneath the horn.

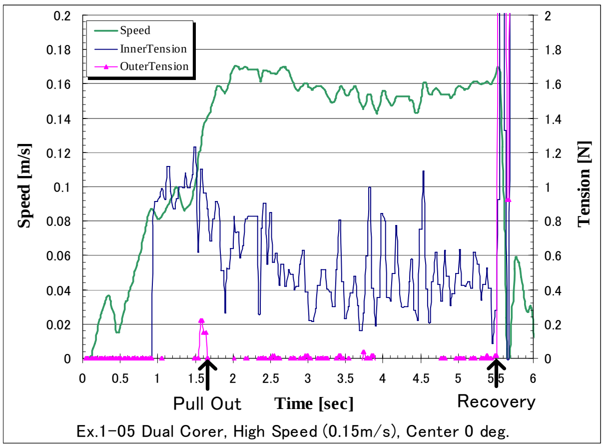

Fig. 4.3 0 deg. Beneath the Horn

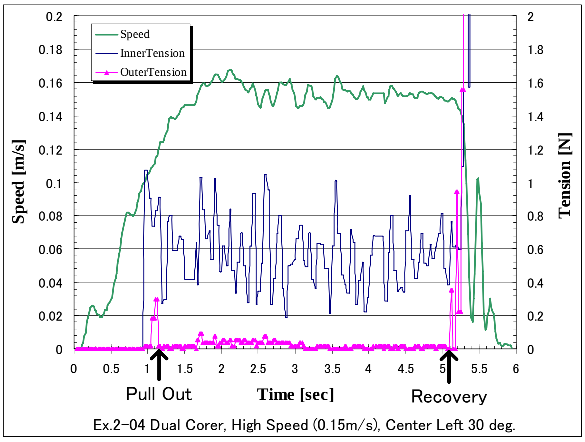

Fig. 4.4 30 deg. Beneath the Horn

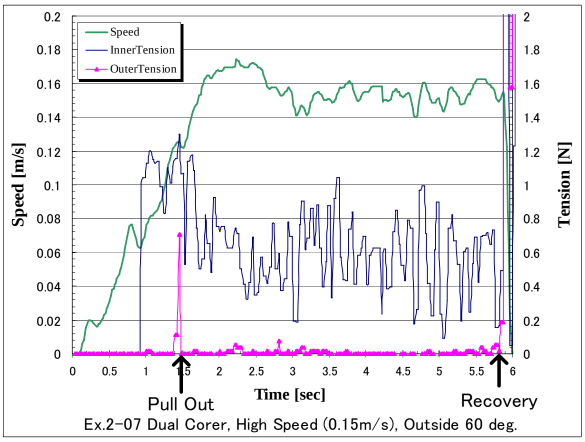

Fig. 4.5 60 deg. Near the Horn

Fig. 4.6 to 4.8 show the result of the experiments affected by retrieval speed: low (0.06m/s), middle (0.1m/s) and high (0.15m/s). The common parameters of these experiments are the followings,

- Pulling up force: Small (dual corer)
- Pulling out angle: 30deg.
- Position: Beneath the sampler horn

According to the camera images, it can be seen that the tether did not go soft largely and the corer did not rotate roundly when retrieval speed was almost the same as initial speed just after pulling up.

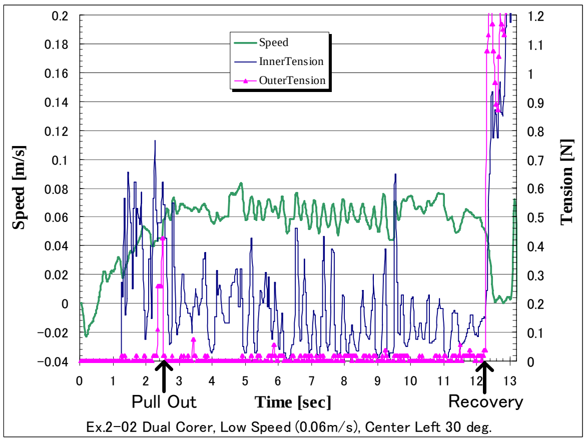

Fig. 4.6 Low Speed (0.06m/s)

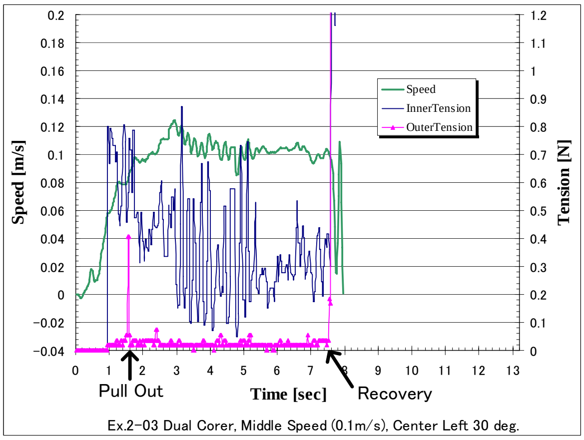

Fig. 4.7 Middle Speed (0.1m/s)

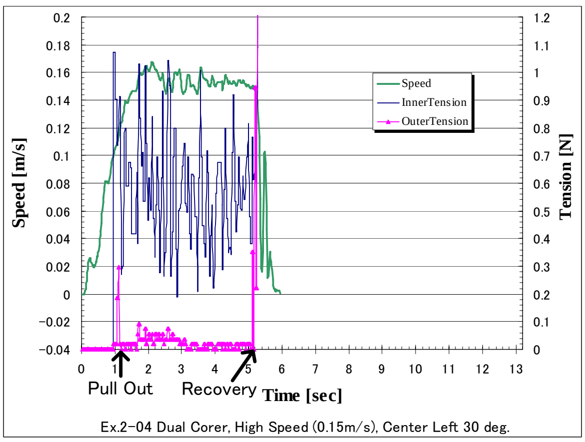

Fig. 4.8 High Speed (0.15m/s)

Fig. 4.9 and 4.10 show the result of the experiments affected by control laws of the reel mechanism. The common parameters of both of the experiments are the followings,

- Pulling up force: Small (dual corer)
- Retrieval speed: High (0.15m/s)
- Pulling out angle: 0deg.
- Position: Beneath the sampler horn

The reel mechanism was controlled by feeding back the number of spool rotations, changing the mode of the motor drivers such as current mode or voltage mode. Although big differences are not observed from the camera images in both experiments, the response and convergence of the motor driven on voltage mode are obviously much better than that of current mode from the data of the spool rotation speed.

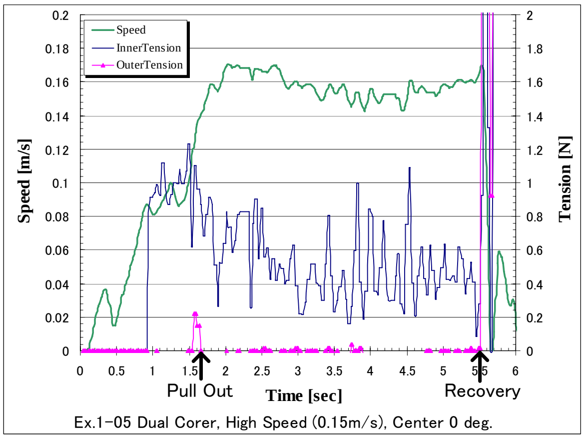

Fig. 4.9 Current Mode

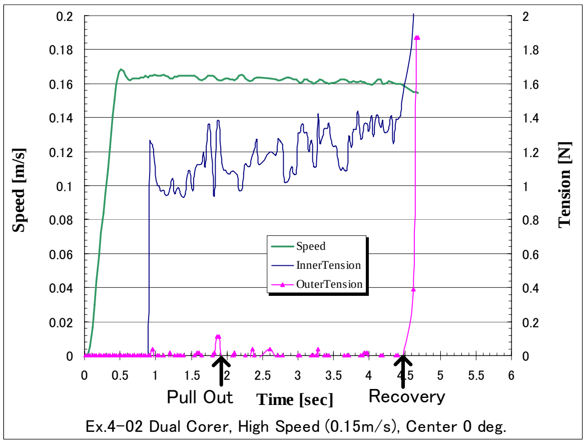

Fig. 4.10 Voltage Mode

5. Conclusions

In this paper, the results of the micro-gravity experiments using parabolic flights for the corer and tether retrieval in tethered sampling method are described. The experimental results indicate that the retrieval phase in tethered sampling method is feasible to work under micro-gravity.

Some improved points related to the structure and control law of the reel mechanism are found, as shown below,

1) Small pull out force enables the corer to grasp more samples because it prevents the corer from impacting on inside of the sampler horn.
2) Small pull-out force keeps reel control easy because it prevents motors from overshooting.
3) Tether recovery speed is supposed to be almost the same as the corer initial speed just after pulling out not the tether to get large slack.

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