SHAPE MEMORY ALLOY (SMA) ACTUATOR BASED SEPARATION DEVICE

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ABSTRACT

We develop a shape memory alloy (SMA) actuator based separation device that can be operated with low power, and fast response time. It consists of an actuation module, a holding module, a releasing module and the housing. An actuation module comprises the SMA holder and an SMA actuator for first actuation and redundant actuation. A holding module to hold securely the appendage until release on orbit consists of a rigid ball, and a central key. A release module is functioned with a spiral spring, the rotation part, and a separation pin. All modules are covered by the housing. In order to prove reliability of the device, some qualification tests such as the operating time, shock level and preload test are carried out. The operation time was about 0.45 sec. Stable activation is accomplished up to 50 kg_f. In that case, it activates within 0.5 sec and induces minor shock of about 4g when it operates without preload. Therefore, we expect the proposed SMA Actuator based separation device can be utilized to replace the typical explosive type separator.

1. INTRODUCTION

In order to carry out the mission of the satellite successfully, the satellite should be separated from rocket on time without giving any damage to the satellite. In addition, some appendages such as an antenna and solar panel should be also separated stably. Since failure of separation closely related to failure of satellite mission, they should be separated on time. The separation device can be classified into pyro based separator and non-explosive separation device. In early stage of satellite, pyro based separator with simple operation concept was utilized widely. Since pyro based separator comprises gunpowder, however, it requires careful handling and storage. In addition, it causes high shock to the satellite system and generates large quantities of contaminates when it activates. The high shock can be fatal accident to the system of small satellite that comprises all components in small space. Contaminates can cause malfunction of electronic equipment in a satellite [1]. Therefore, non-explosive separation device for the small satellite is an essential component for successful mission. It is because small satellites are very popular with advantages of low cost, fast development time and small size. Reflecting those needs, some companies already commercialize non-explosive separation devices based on shape memory ally (SMA) actuator [2]. In order to contribute all efforts to replace the pyro-tech based separator to non-explosive separator, we propose a new SMA and torsional spring based separation device for small satellite.

2. DEVICE DESIGN AND OPERATING

2.1. Device design

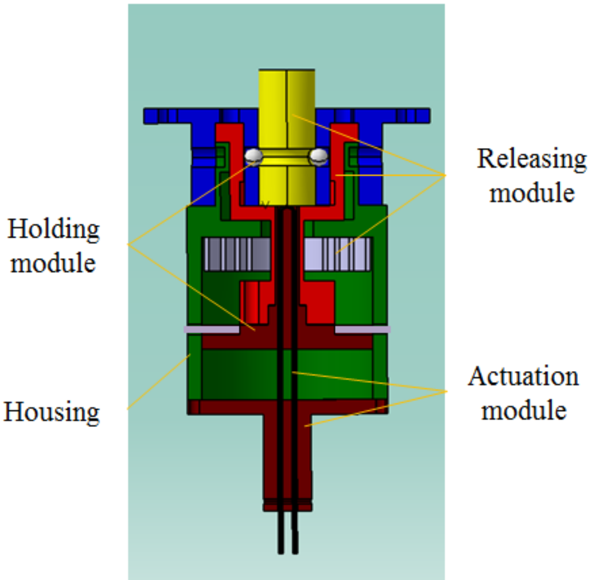

Figure 1. Stricture of separation device

We develop a shape memory alloy (SMA) actuator based separation device that can be operated with low power, and fast response time. As shown in Fig. 1, it consists of an actuation module, a holding module, a releasing module and the housing. An actuation module comprises the SMA holder and an SMA actuator for an actuation. A holding module to hold securely the appendage until release on orbit consists of a rigid ball, and a central key. A release module is functioned with a torsional spring, the rotation part, and a separation pin. All modules are covered by the housing.

2.2. Working principle

The releasing procedure is presented in *Fig. 2.*

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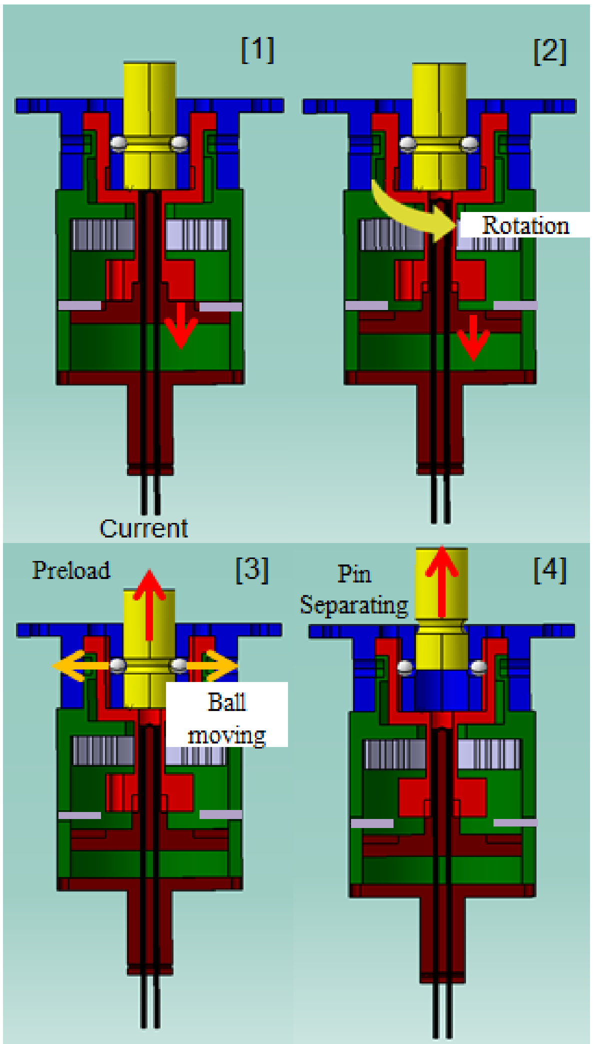

Figure 2. Activation sequence

(1) Locking condition: Winded torsional spring is locked by central key.

(2) Activation: By supplying power to SMA actuator, it is contracted and pulls down the central key. Consequently, the torsional spring is released and rotated.

(3) More power is supplied and the SMA contracts more. It will make free rotation of the torsional spring from the central key. Then the rigid ball moves outward.

(4) Release completed: As a result of movement of the rigid ball, the separation pin under preload releases from the holding module.

3. PERFORMANCE TEST

In order to carry out successfully the mission of the satellite, reliable operation of the separation device is the most important factor. Therefore, some performance tests such as separation time test, preload test and shock-level test are performed [3].

3.1. Separation time test

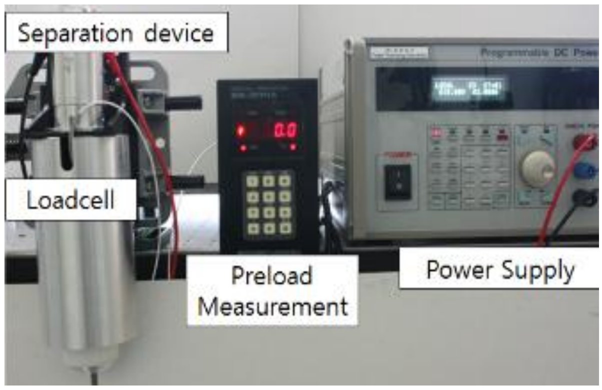

Figure 3. System configuration for separation time test

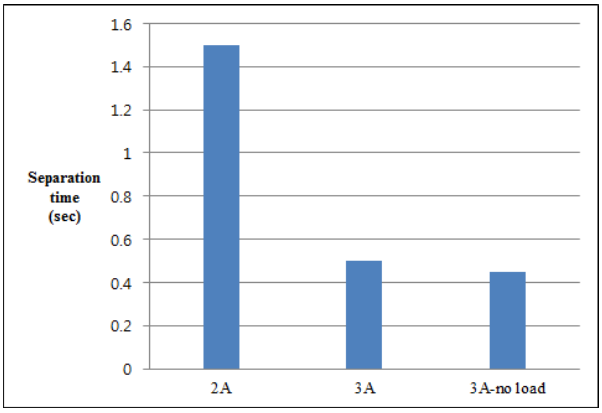

Figure 4. Separation time according to power input and preload.

Power supply for a satellite is critical issue for normal operation after it reach on orbit. Therefore, stable deployment of solar panel should be guaranteed. In order to supply stable power, therefore, the separation device which fixes solar panel to satellite should be operated on time.

A configuration for separation time test is shown in *Fig. 3.* A Separation time test is performed using power supply that can be adjusted with resolution time of 0.01sec. The operation of separation device is checked under variation of supplying time of power. In other words, separation time was measured by control of power supplying time.

The separation time is 1.5sec under preload of 10kg$_f$ when input voltage and current for operation are 3V and 2A respectively. When the current is increased to 3A, the separation time is decreased to 0.5sec. In case the preload is not applied, the separation time is decreased to 0.45sec. That means the preload influences separation time marginally since the preload causes high friction force between rotational parts and the housing in separation device. Separation tests are performed 5 times and the averaged time is presented in Fig. 4.

Most of separation time is for heating SMA wire. Therefore, increasing input electric current could reduce significantly the separation time. However, more than input power of 3V and 3A causes permanent deformation of SMA wire (diameter of 0.51mm) that is manufactured by DYALLOY Inc.'s FLEXINOL® [4]. Conclusively, amount of input power to SMA wire is most significant parameter to determine separation time.

3.2. Preload test

The solar panels are folded by the separation device until a satellite settles on the orbit. At that time, the separation device takes the preload through a hinge which connects a satellite with the solar panel. Therefore, the separation device should be operated under a specific preload that is generated from the solar panel.

The preload that comes from the weight of solar panels should be engaged to simulate the actual satellite situation. Adding dummy mass is a common way to generate the preload. However, the preload generator should be able to reduce momentum from gravity and be designed to change the preload easily. Therefore, the preload generator is designed using action and reaction phenomena. Fig. 5 shows the working principle for the preload generator [5].

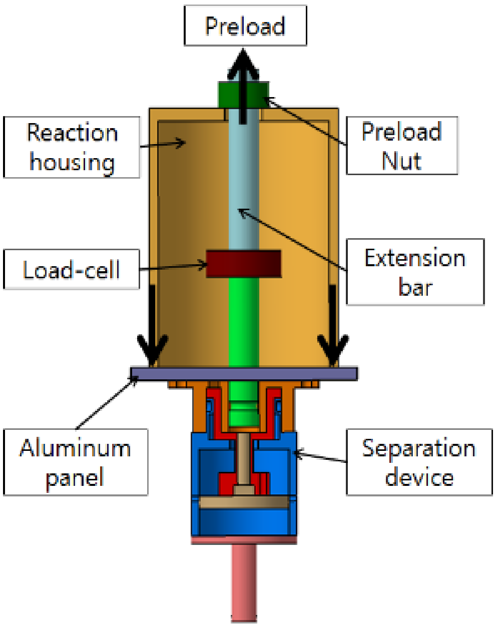

Figure 5. Configuration of preload generator.

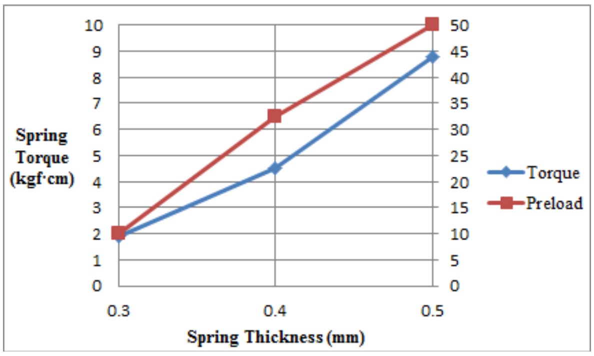

Figure 6. Maximum separable preload according to stiffness of torsional spring.

The preload is generated when the end of extension bar fastens tightly with a nut. Thus, we can control the preload using nut's tightness. And we install a load cell between the separation pin and the extension bar to measure the preload. When we perform the separation test with power of 3V and 2A, the separation is accomplished up to preload of $10kg_f$.

Based on assumption that maximum separable preload is controllable by changing stiffness of a spiral spring, we investigate maximum separable preload according to thickness of a spiral spring. As we expect, higher stiffness of a spring overcomes higher preload. As shown in Fig. 6, maximum separable preloads are $32.5kg_f$ and $50kg_f$ respectively in case thicknesses of a torsional spring are 0.4 mm and 0.5 mm respectively. It is because bigger stiffness of a torsional spring generates higher torque. Consequently, higher torque can overcome higher preload that is given by appendage through a release pin.

3.3. Shock test

The separation device will be in a zero G state when it operates in the space environment. The test environment is simulated by using bungee cables to suspend the device in order to emulate the rigid body motion in space.

The satellite body is made of 500x500x600 mm aluminum panel. The preload of $10kg_f$ is set by using the preload generator. The accelerometer (DeltaTron®, Brüel&Kjær) is installed at 30 mm (Pos. 1), 60 mm (Pos. 2) and 90 mm (Pos. 3) respectively, from the installed position of the separation device. The measurement set-up on the panel and experimental configuration for shock test are shown in Fig. 7 and Fig. 8. The generated shock, while the device is separating, is measured by output voltage of accelerometer through the A/D channel of the DAQ board with the Labview® software. After the separation device is activated, the shock data is presented in *Fig. 9.*

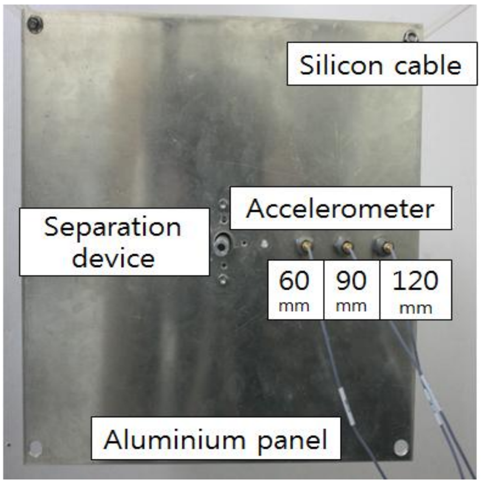

Figure 7. Shock measurement setup on panel

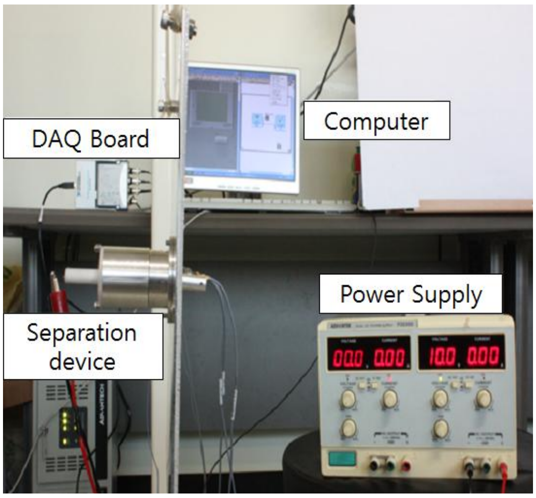

Figure 8. System configuration for shock test

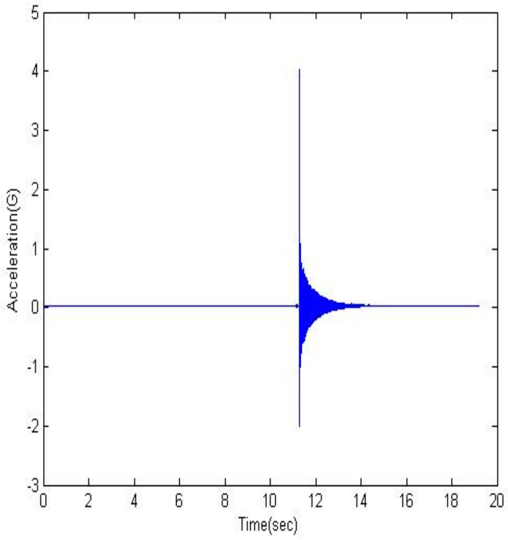

Figure 9. Shock test result

In general, the explosive separation device generates a shock level of over 1,000 G and the shock level of a non-explosive separation device is required to be under 500 G [1]. In comparing those requirements, the very low shock (4.03G at 60mm) from the proposed non-explosive separation device is generated [6]. It is because we utilize the torsional spring with low stiffness. In the viewpoint of shock, the proposed device shows good performance. But, it activates with very slow response time. Therefore, more investigation for response time and shock level according to stiffness of a spring should be performed to improve performance.

4. CONCLUSION

In this paper, we designed and fabricated non-explosive separation device for small satellite, using new SMA and torsional spring. In order to confirm the performance of the proposed separation device, we carried out experiments for separation time, maximum preload for activation, and shock level.

From the result of experiments, we verified that the proposed separation device has successfully separated under 10kgf preload within 0.5sec of separation time. Furthermore, the shock of 4.03G occurred at 60mm from center of shock which is minor shock level for small satellite.

In near future, we will investigate design parameters such as the separation time and shock level according to stiffness of torsional spring and the diameter of SMA wire. Through environment tests such as vibration test and thermal vacuum test, the proposed non-explosive separation device is expected to replace pyro based separation device [7].

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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