SHAPE MEMORY ALLOY ACTUATOR BASED SATELLITE SEPARATION DEVICE USING PLASTIC DEFORMATION

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ABSTRACT

This paper describes the development of non-explosive separation device which can be equipped on a small satellite. It comprises separation mechanism itself and spring-type shape memory alloy(SMA) actuator. In order to design SMA actuator properly, the necessary actuation force is measured. Based on that result, SMA actuator is designed and fabricated. Finally, SMA actuator and the proposed mechanism are integrated. In order to evaluate performance of the developed non-explosive separation device, we carried out a response time test, ultimate-load test and shock level test.

1. Introduce

Owing to the rapid growth of nano-technology, it is possible to make small satellites which include all functions that medium and big size satellites have. In the viewpoint of cost effectiveness, these small satellites have many advantages comparing to medium and big size satellites. Therefore, many countries are developing the small satellite and trying to localize the parts of satellite. As the size of the satellite decreases, many devices in the satellite should be integrated tightly. Therefore it became more sensitive to shock and vibrations. The pyrotechnic devices, which have been used for the medium and big size satellites, produce high shock and contaminants, therefore they cause malfunction of the satellite. For reasons of that, the pyrotechnic devices are not suitable for small satellites[1].

In this paper, we design and manufacture the non-pyrotechnic device using SMA-actuator for small satellites and perform the tests such as ultimate-load, shock level and response time that are important factor to evaluate the separation device.

2. Device design and operating

2.1. Device design

The proposed separation device is designed to hold the separating part with high binding force and generate low shock in the release sequence. As shown in Fig. 1, it consists of the deformation module, two release springs, a block, a SMA actuator to deform the deformation module, and a blocker to prevent releasing of the deformation module from housing.

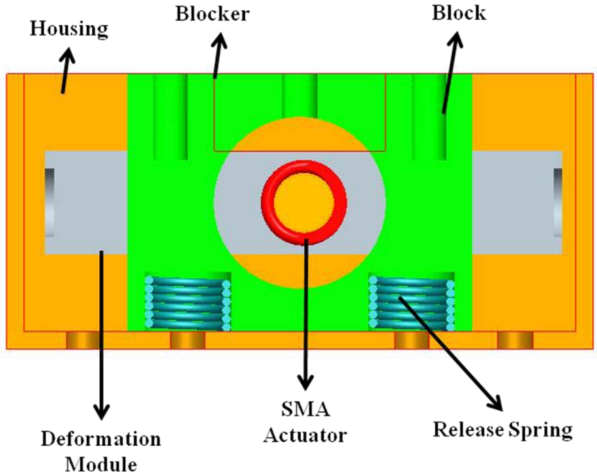

Figure 1. Structure of separation device

2.2. System principle

The main purpose of the separation device is to bind the appendage to the main body of the satellite before the mission and to release it on time by the command. In order to generate low shock that causes the minimum effect on both satellite and separating part, the separation device need to be actuated by small force. Therefore, the spring type SMA actuator is employed in this device.

Figure.2 shows top and side view of the proposed device when it is installed and deformed respectively**.** At the initial stage, the deformation module which combined with a block is blocked by the blocker that is welded on the housing. In order to keep contact between the deformation module and the blocker, two release springs are disposed under the block. A SMA actuator is installed in the deformation module under elongated condition. At the operation stage, as the SMA heater is activated by input power, it heats up the SMA actuator. Consequently, the spring-type SMA actuator is retracted and it causes plastic deformation of the deformation module. Then, the deformation module is released from the blocker. Finally, the block is released from the housing since the compressed release spring elongates and pushes out the block.

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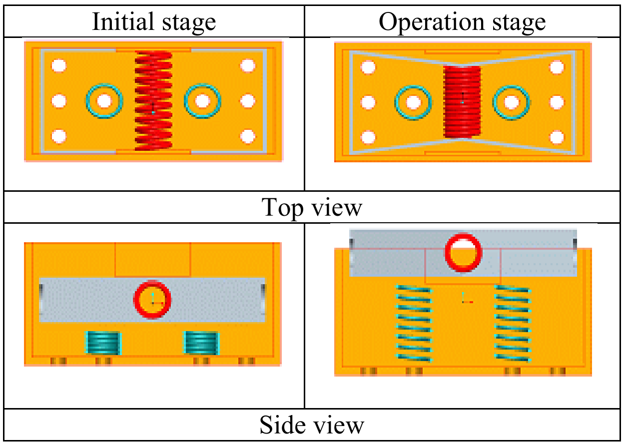

Figure 2.Basic working principle concept

2.3. Design of the SMA actuator

The force that can deform 1mm of deformation module made of aluminium is calculated by the finite element analysis(ANSYS®). Considering actuation force and structural dimension, the SMA actuator with minimum wire diameter is designed to have maximum response time by using following equations.

$$d = \sqrt{\frac{8Wpc}{\pi T_c}} \quad (1)$$

$$n = \frac{dS}{\pi D \Delta \gamma} \quad (2)$$

$$K = \frac{Gd^4}{8nD} \quad (3)$$

Where :

d = Wire diameter

n = Number of active turns

K = Spring rate

$c = \frac{D(\text{Spring diameter})}{d(\text{Wire diameter})}$

$W = \frac{4c-1}{4c-4} + \frac{0.615}{c}$ (Wahl factor)

$T_c = 200MPa$ (Max shear stress)

$\Delta\gamma = 0.005338165$ (Shear strains)

G = high temperature shear modulus

From Eq.(1),Eq.(2) and Eq.(3), SMA actuator with the specific spring diameter and wire diameter is designed.

$$F = K \cdot x \quad (4)$$

From Eq.(4), the generative force can be calculated with designed stroke. Finally, considering safety margin, the generative force of the SMA actuator is decided[2].

3. Performance test

For the space application, reliability of the device is the most important factor. In order to improve the reliability, functional and environmental tests were carried out. Among the test requirements, ultimate-load test, shock-level test and response time test were performed.

3.1. Determination of the axial load

In the developing stage of the satellite, the maximum tensile force, which the separation device should stand, is determined based on quasi-static load according to launching environment. The quasi-static load is acceleration load that exerted on the mass centre of the satellite. Therefore, every part has different quasi-static load according to shape of the satellite. In other words, there is no specific value for quasi-static load, because it can be changed by the satellite size, folding number of the solar panel and many other variables. Based on the launching experience equation, the quasi-static load from relationship between mass(m) and acceleration(a) can be calculated[3].

$$a = 50 / m^{0.3} [G] \quad (5)$$

From the Eq.(5), if we assumed a solar panel has 5kg of mass, it has 30.8G of quasi-static acceleration and consequently, it will be under 1509N of quasi-static load. Therefore, ultimate-load test for the developed device is performed by 1509N. As aforementioned, some parameters such as mass of solar panel, safety factor and binding point are assumed for this specific case. Therefore, we need to determine the quasi-static load according to design of each satellite. Accordingly, load requirement can be satisfied through controlling some design parameters such as thickness and shape of the deformation module of the proposed separation device.

3.2. Ultimate load test

In order to estimate the ultimate-load of proposed separation device, computer simulation using commercial code of Ansys® is utilized. Based on simulation result, ultimate load is determined and ultimate-tensile test(MTS-810 from MTS Korea®) was performed by the value obtained from simulation. The simulation and experimental result shows 1,510N and 1,597N respectively. It means we can design any device that requires specific ultimate load by controlling some design parameters such as thickness and shape of the deformation module.

3.3. Shock test

The low shock level is the biggest advantage for this non-explosive separation device. The shock level when the separation device works is measured on satellite body made of aluminium.

3.3.1 Preload generator

To measure the shock level, preload that comes from the weight of solar panels should be engaged to simulate the actual satellite situation. Adding dummy mass is common way to generate the preload, however, preload generator should be able to reduce momentum from gravity and be designed to change the preload easily.
Therefore, preload generator is designed using action and reaction phenomena. Figure.3 shows working principle of the preload generator[4].

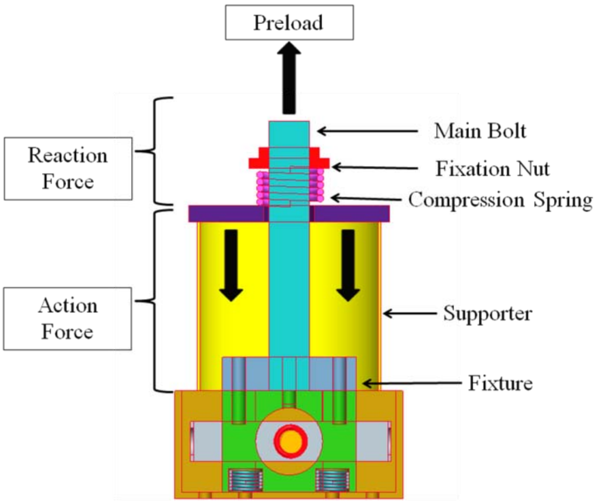

Figure.3 Design and concept of preload generator

3.3.2 System configuration for shock level test

Figure.4 Shock test setup configuration

The separation device will be in zero G state when it operates in the space environment. Test environment is simulated by using bungee cables that hanging to gravity opposite direction to consider rigid body motion in space. Also, the satellite body is made of 500x500x6mm aluminium panel. The preload of 150N is set by using the preload generator. The accelerometer is installed at 30mm(Pos.1), 60mm(Pos.2) and 90mm(Pos.3) respectively from installed position of the separation device. Shock test setup and measurement setup on panel were shown in Figure.4 and 5.

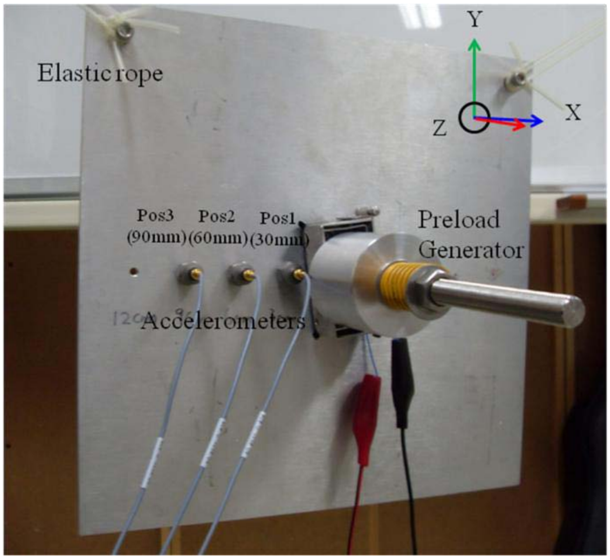

Figure.5 Shock measurement setup on panel

3.3.3 Shock test result

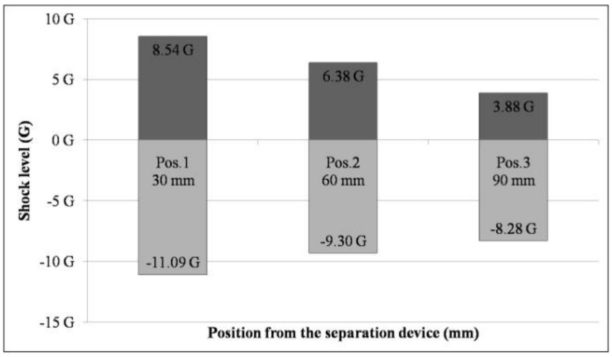

Figure.6 Shock level test result

In general, the explosive separation device generates shock level over 1000G and shock level of non-explosive separation device is required under 500G. Comparing those requirements, very low shock from the proposed non-explosive separation device is generated. Figure.6 shows shock level test result under 150N of preload. Without preload, it just generates maximum -5.71G on the Pos.1(30mm).

3.3.4 Release time test

Using high-speed camera(Mikrotron, EoSens), release time is measured by analyzing captured frame. We use two ways to activate SMA actuator. At first, using ceramic heater, it takes 14 sec to operate the device. Secondly, by passing an electrical current through SMA, it is heated internally. At that time, response time is 5 sec[5].

Ambient temperature	22°C
SMA activating temperature	155.5°C
Power (using heater)	35W
Power (direct connect to SMA actuator)	60W

Table.1 Test parameters for response time test

4. Conclusion

Using SMA actuator and plastic deformation of aluminium module, a novel non-explosive separation device is designed, manufactured and tested. Experimentally, we could confirm that the proposed device could stand by 1510N of the quasi-static load. Also, the shock level, one of important factor for small satellite, was measured as 11.09G under 150N of preload. With 60W of the operation power condition, release time was 5 second. Through the thermal, thermal vacuum and vibration test, we will obtain reliability for the proposed separation device.

5. Acknowledgements

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6. Reference

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