SOLAR PADDLE ACTUATOR FOR SMALL SATELLITES USING SHAPE MEMORY ALLOY (II)

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Abstract

Quantitative experiments were conducted for a new type of actuator that uses shape memory alloy (SMA), which was developed for the solar paddle of small satellites and presented in the 9th ESMATS. The actuator can orient the solar paddle alone toward the sun, and is equipped with a counterweight to compensate for the rotating motion of the small satellite in microgravity. The actuator measures 100 mm in diameter and 127 mm in height, and weighs approximately 660 g including the counterweight (340 g). To rotate the solar paddle, we used six SMA springs, each of which has a cylindrical mirror in the rear in order to concentrate the sun's energy onto the spring. Drop shaft experiments were conducted to confirm the performance of the counterweight. Motion repetition experiments in vacuum were also conducted to investigate the degradation properties of the SMA. Ideas for improvement are proposed from the results.

INTRODUCTION

Recently, as a result of budget reduction and advances in microelectronics, small satellite systems weighing less than 500 kg have been actively developed. Their mission is wide-ranging: communications, remote sensing, science, military, technology demonstration and education. However, their resources are limited by their capacity and mass restriction. Moreover, their electric power is not exceptional: in most cases, not a deployable solar paddle but a solar panel is mounted on the satellite's body and as a result, less than 50 W power is generated. If we can generate more power, more mission flexibility will be enhanced.

More power can be generated if a deployable solar paddle and a solar tracking mechanism are used. However, the number of small satellites using a deployable solar paddle is small, because of the following reasons:

(1) The solar paddle actuator uses a motor and is heavy.
(2) A control system that likewise requires power is needed.
(3) Attitude control is required because the solar paddle motion induces the satellite reaction motion.

Using shape memory alloy (SMA), we have designed a small and light actuator that requires neither electric power nor control systems.

A number of SMA applications in space have been taken into consideration: antenna deployment of a spacecraft [1], large-scale structure materials [2], deployment actuators [3] and actuators for robotic mechanisms [4]. In the first three applications, only one motion is needed and therefore, no control is required after deployment. In the last application, although SMA does not present tribological problems, the SMA heating method using electrical power is not efficient and a large power supply is required. Our proposed mechanism uses SMA in the mission (not one motion). Since the heat energy comes from the sun, the efficiency problem is solved. Moreover, the mechanism is equipped with a counterweight to prevent the satellite from the reaction motion and the effect of the counterweight is confirmed in drop shaft experiments.

MECHANISM

The developed mechanism is shown in Fig. 1. The actuator can rotate 360 degrees continuously and orient the solar paddle alone toward the sun. It is equipped with a counterweight in order to compensate for the rotating motion of the small satellite in microgravity.

The developed actuator measures 100 mm in diameter and 127 mm in height, and weighs approximately 660 g including the counterweight (340 g). To rotate the paddle, we used six SMA springs, each of which is made of 0.8-mm-diameter wire and has 10 turns; the coil diameter is 5.8 mm and the mass is 0.8 g. Each spring has a cylindrical mirror in the rear in order to concentrate the sun's energy onto the spring. The type of SMA is TiNi (Ni 55.2 wt%) alloy and the transformation temperature is approximately 330 K.

The length of the spring at low temperature is 30 mm, whereas that at high temperature (above 330 K) is 8 mm, which causes the motion of the actuator. The force generated by the SMA spring is approximately 10 N, and thus the torque of the actuator is approximately 0.2 Nm, which is sufficient to rotate the solar paddle of a small satellite (the mass will be approximately 1 kg) in microgravity. The counterweight rotates in the direction opposite to the solar paddle rotation at two times the solar paddle speed, which is achieved by a combination of four gears. By assuming that the weight of the solar paddle is twice that of the counterweight, we have designed a smaller actuator by increasing the counterweight's rotational speed. The mechanism was developed based on the concept of the heat engine devised by Ginell et al. [5].

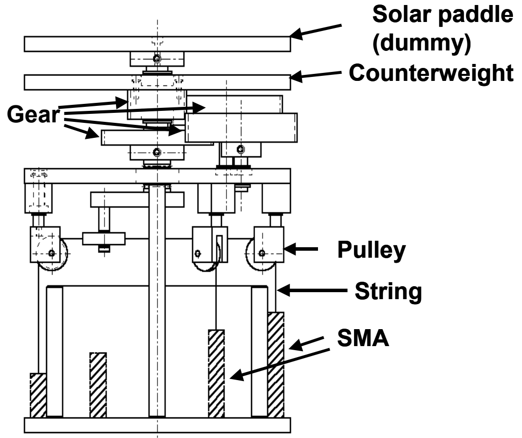

Fig.1 Solar paddle actuator.

EXPERIMENTS

In order to confirm motion in a space environment, motion experiments in a microgravity field and in vacuum were conducted.

Microgravity Experiments

In order to confirm that the counterweight is appropriately designed to avoid attitude disturbance of the small satellite, we conducted experiments in a microgravity field. We have reported previously the result of experiments conducted using an air table; however, the effect of the counterweight was not clarified because drift motion occurred above the air table [6].

Therefore, we conducted drop shaft experiments using the drop shaft of Japan Microgravity Center (JAMIC), which can generate ten-second microgravity (this facility was closed in February 2003). Because the microgravity quality was good (10^{-4} g), we were able to confirm the counterweight effect. The solar paddle actuator is fixed on a small satellite model (Fig. 2). The main body of the satellite model does not move during paddle motion (Fig. 3). The time in the figure indicates the time after the attitude measurement program was started, and was approximately six seconds before the free fall started. On the other hand, in the case of no counterweight, we observed attitude disturbance of the main body of the small satellite model in response to the paddle motion (Fig. 4). The results in Fig. 4 confirmed that the motion of the satellite model after 11000ms is caused by collision with the object surrounding the experimental rack.

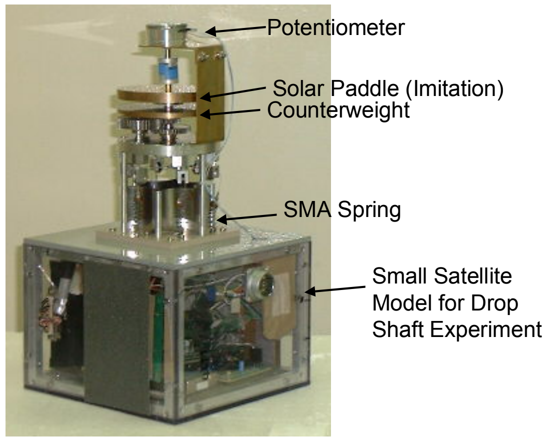

Fig. 2 Solar paddle actuator fixed on small satellite model.

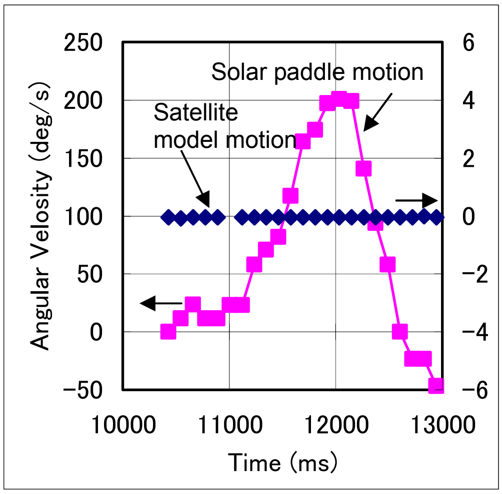

Fig. 3 Motion results with counterweight.

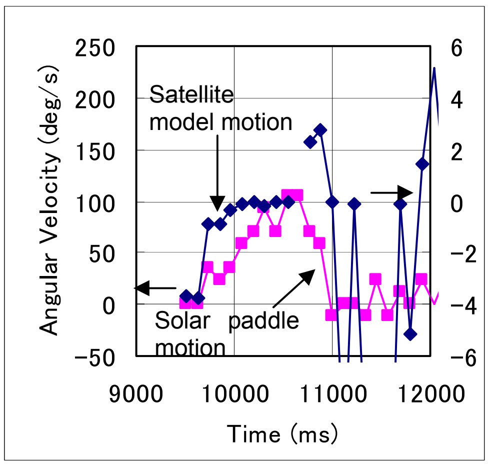

Fig. 4 Motion results without counterweight.

Vacuum Experiments

In order to estimate motion in space, we conducted motion repetition experiments in vacuum. Figure 5 shows the block diagram of the experiments.

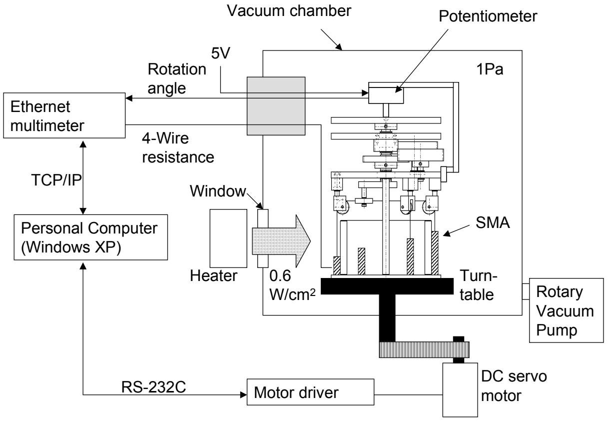

Fig. 5 Block diagram of vacuum experiments.

Air is pumped out of the vacuum chamber by a rotary pump, and the pressure inside the chamber is approximately 1 Pa. We consider the pressure sufficient for simulating thermal conditions in orbit. The heater outside the chamber heats the SMA through a glass window. In most cases, the measured heater power density inside the chamber is 0.6 W/cm^2, and is slightly lower than the solar energy density. The actuator is set on a turntable. Perfluoropolyether (PFPE) grease is used for vacuum lubrication.

The turntable is driven by a DC servo motor that is controlled by a PC through a motor driver. The turntable rotates 180 degrees for 2700 s initially, then returns to the original position and rests for 1500 s (i.e., one routine takes 4200 s). This motion simulates the orbit condition, and is repeated. The actuator motion is measured by a potentiometer. The SMA electric resistance is also measured by the four-wire method because of the small resistance (less than one ohm). The SMA for resistance measurement is located in front of the heater at the beginning of the measurement.

The motion results and the resistance variations are shown in Figs. 6 and 7, respectively. In Fig. 6, ideal motion means the motion made by the solar paddle facing the heater. Despite the use of six equally spaced SMA springs in the mechanism, the motion is smooth. In addition, because the heater heats two or three SMA springs at the same time, ideal motion does not occur (the motion range is reduced by approximately 50 degrees at both ends). The reduction of the motion range is observed in the case of 1000 motion repetition. We are currently conducting motion experiments at repetition numbers in excess of 1500.

Figure 7 shows that the SMA is cooled gradually in the initial 2700 s and heated from 2700 s to 4200 s. As the temperature difference among four points of the electrodes for resistance measurement is generated by the difference in thermal conductivity between the two ends of the SMA spring, thermal electric force is generated. As a result, the measured resistance is small when the SMA is heated. In the case of 10 motion repetitions, the heating condition is different: the heating power is larger than that of the other cases. As a result, the resistance in the heating period is small. From 1800 s to 3000 s, the resistance in the 10 and 100 motion repetition cases shows fluctuation; however, this disappears after 400 repetitions. Therefore, the fluctuation is caused by a kind of initial nonuniformity effect. We did not observed any signs of malfunction from the resistance measurement.

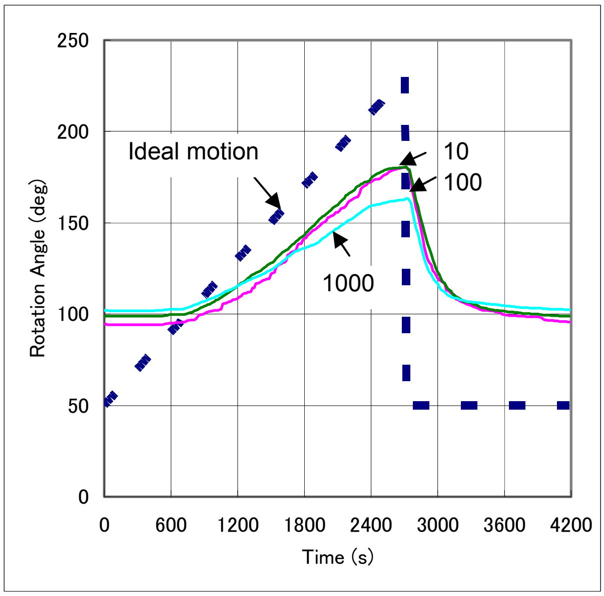

Fig. 6 Motion results.

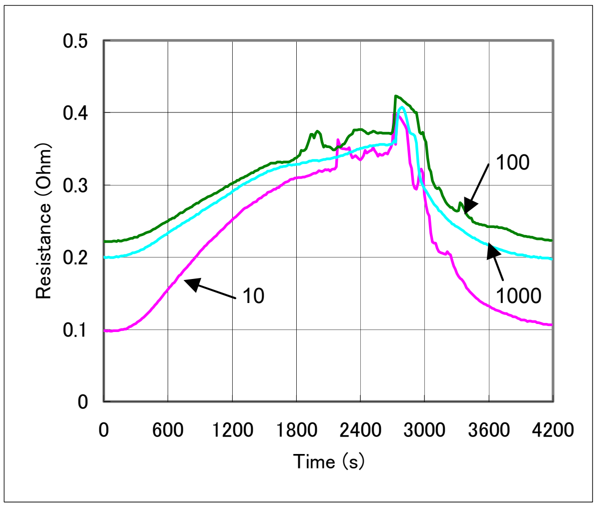

Fig. 7 Resistance results.

DISCUSSION

Improvement of Mechanism Performance

As shown in Fig. 6, the motion range is reduced by approximately 50 degrees at both ends. To overcome this problem, the mechanism should have a speed-up gear and offset. Figure 8 shows the results obtained when offset is -23 degrees and a 2.2-fold speed-up gear is used, as calculated from Fig. 6. In this case, the direction error is within 20 degrees in most of the motions. This means that power loss caused by misalignment from the sun in most of the motions is less than 10 % (cos20°= 0.94).

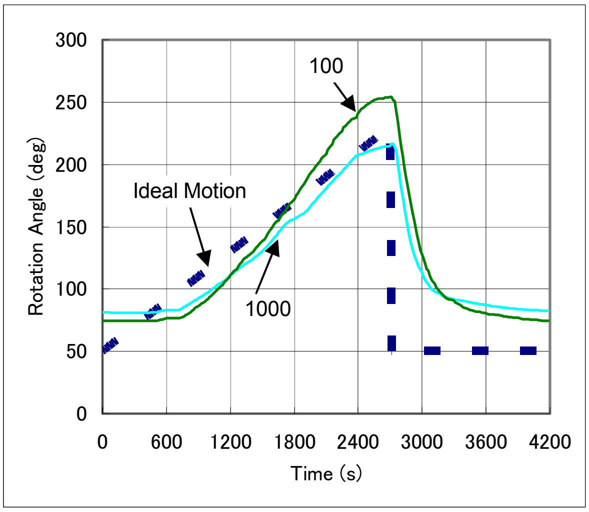

Fig. 8 Improvement of mechanism performance.

Future Plan

We plan to conduct the following studies in the future.

(1) To realize use in space, the mechanism will be subjected to vibration test and sound test for launching simulations.
(2) To obtain an optimal design, an offset will be set and a speed-up gear will be equipped in the mechanism.
(3) To confirm any signs of malfunction, the resistance measurements will be conducted continuously.
(4) To improve the SMA cooling property, a net-structured SMA actuator (Fig. 9) will be used instead of spring.

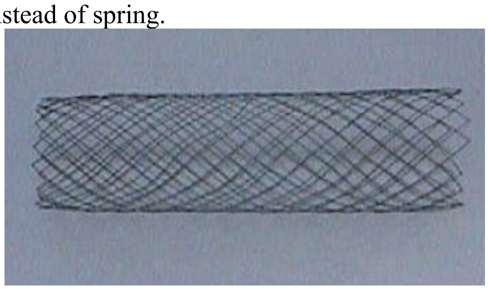

Fig. 9 Net-structured SMA.

CONCLUSIONS

The study is summarized as follows.

(1) A solar paddle actuator using SMA springs was designed and tested in microgravity and in vacuum.
(2) The counterweight worked well in canceling the reaction motion of the satellite.
(3) The mechanism is capable of more than 1000 motion repetitions in vacuum.
(4) Offset and speed-up gear are required for more effective motion.

ACKNOWLEDGEMENT

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Back to Contents