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Position Control Characteristics of Antagonism Type SMA Actuator Based on Resistance Feedback Control

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Abstract: The actuators using shape memory alloy can work as an actuator to control or retain positioning without using sensor device. In order to utilize the shape memory effect, the external force is required to deform the shape memory alloy in martensitic phase. For a method to give an external force to, a bias mode and an antagonism mode are used. In this work, the effects of a control displacement and an external load on the positioning characteristics by an antagonism type actuator are investigated. The Ti-Ni-Cu alloy wire is used as an actuator element. The positioning characteristics such as settling velocities, position error, and position stability are discussed in relation to a control displacement and an external load. The results show that settling velocity of an antagonism in heating process is slower than those of two bias mode of a const mass and a bias spring, but in cooling process, settling velocity of an antagonism is faster than those of two bias modes. Furthermore, position error is not affected by an external load. However, position stability in heating process is affected by an external load.
Key words: actuator, position control, shape memory alloy, antagonism type, position error, position stability

1. INTRODUCTION

Since the shape memory alloy (SMA) has a sensor function, the actuators using SMA can work as an actuator to control or retain positioning without using sensor device [1]. This type of sensor-less system brings about many merits like simplification of the system and easy and simple operability. The actuators, applying this characteristic to position control of SMA with resistance feedback, have been reported [2].

SMA has a characteristic that electric resistance varies due to the phase transformation in the process of heating and cooling. Furthermore, the resistance values of SMA show non-linear characteristics with hysteresis [3], resulting in giving different position information for rising and lowering processes of temperature. This means that the real-time resistance values cannot be fed back, as is, for the positioning information.

Position control systems using the PID control by resistance feedback have been reported [4-8], but they remain only at the continuous positioning control or power control. Thus, most applications are limited for the back and forth movement between two given points.

Authors have proposed the new resistance feedback control system that positioning can be set and retained at an arbitrary position and have investigated the positioning characteristics of the bias type control system [3, 9].

Objective of this paper is to investigate the position control characteristics of an antagonism type control system in relation to a control displacement and an external load. Positioning characteristics such as settling velocity, position error, and position stability are discussed comparing with those of bias type control system.

2. EXPERIMENTAL PROCEDURE

2.1 Antagonism type position control system

The antagonism type position control system by resistance feedback control is shown in Fig.1. The system is composed of a function generator, a position control unit, a data logger, and a potentiometer. Input voltage is controlled by a function generator. Off time and blanking time are controlled by a position control unit. A potentiometer is linked to the rotation axis of a rotary

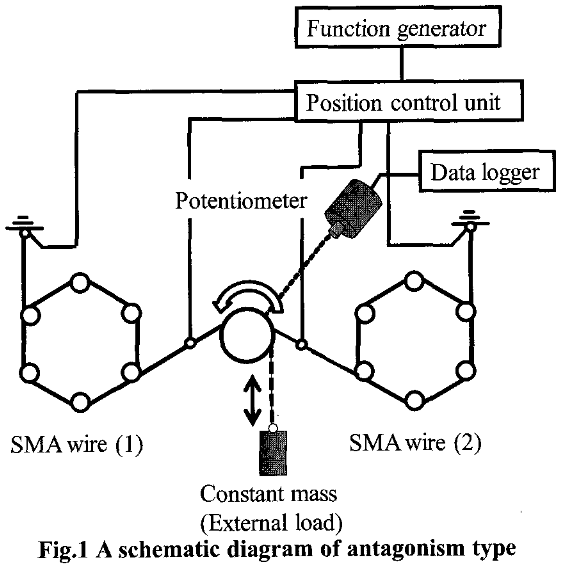

Fig.1 A schematic diagram of antagonism type position control system.

pulley. Variation of a control displacement measured by a potentiometer is recorded by a data logger. The SMA element used for the actuator is Ti-Ni-Cu alloy, which has a relatively small transformation temperature hysteresis. The alloy wire, which is memory processed in a linear shape, has a length of 400mm and a diameter of 0.156mm. The transformation temperatures obtained from the resistance-temperature characteristics are A_f=350K, A_s=312K, M_s=336K and M_f=290K. A constant mass (external load) is 10-110 grams.

2.2 Measurement of settling velocity, position error, and position stability

Figure 2 shows the variation of a input voltage, a desired displacement, and a control displacement with time. The P_1 and the P_2 denote the initial controlled position and the desired position, respectively.

The time from the initial controlled position P_1 to the desired position P_2 by heating is defined as the settling time t_{SH}. The settling time t_{SC} at cooling is also defined as the time from the desired position P_2 to the initial controlled position P_1.

Figure 3 shows the measurement method of the settling velocity, the position error, and the position stability. The position error is defined by the displacement difference between the initial position P (i) and the controlled position P (i+1) during heating and cooling. The position stability is defined by the fluctuation of desired position ΔP during heating and cooling.

The settling velocity V_H at heating and V_C at cooling, the position error ΔE_{P1} at cooling and ΔE_{P2} at heating, and the position stability ΔS_1 at cooling and ΔS_2 at heating are obtained by following equations.

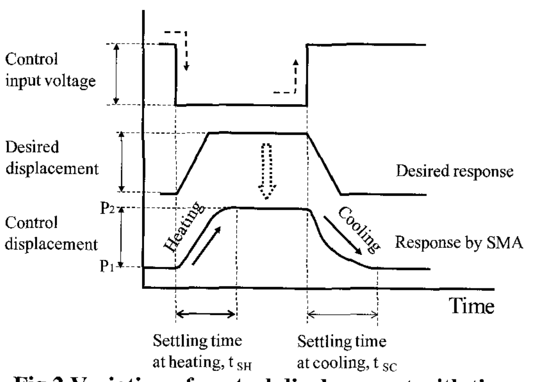

Fig.2 Variation of control displacement with time.

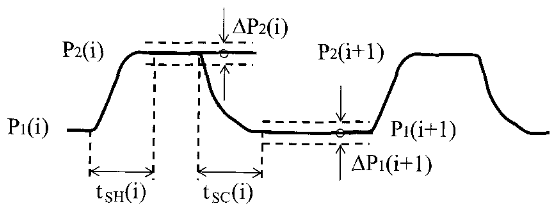

Fig.3 Measurement of settling velocity, position error, and position stability.

$$V_H = \frac{1}{n}\sum_{i=1}^{n}\frac{\{P_2(i)-P_1(i)\}}{t_{SH}(i)} \quad (1)$$

$$V_C = \frac{1}{n}\sum_{i=1}^{n}\frac{\{P_2(i)-P_1(i)\}}{t_{SC}(i)} \quad (2)$$

$$\Delta E_{P1} = \frac{1}{n}\sum_{i=1}^{n}\frac{|P_1(i)-P_1(i+1)|}{P_1(i)} \quad (3)$$

$$\Delta E_{P2} = \frac{1}{n}\sum_{i=1}^{n}\frac{|P_2(i)-P_2(i+1)|}{P_2(i)} \quad (4)$$

$$\Delta S_1 = \frac{1}{n}\sum_{i=1}^{n}\frac{\Delta P_1(i)}{P_1(i)} \quad (5)$$

$$\Delta S_2 = \frac{1}{n}\sum_{i=1}^{n}\frac{\Delta P_2(i)}{P_2(i)} \quad (6)$$

3. RESULTS AND DISCUSSION

3.1 Effect of control displacement on position control characteristics

Figure 4 shows the effect of the control displacement on the position error. The position errors of ΔE_{P1} at cooling and ΔE_{P2} at heating are below 0.3%. Furthermore, both ΔE_{P1} and ΔE_{P2} are not almost affected by the control

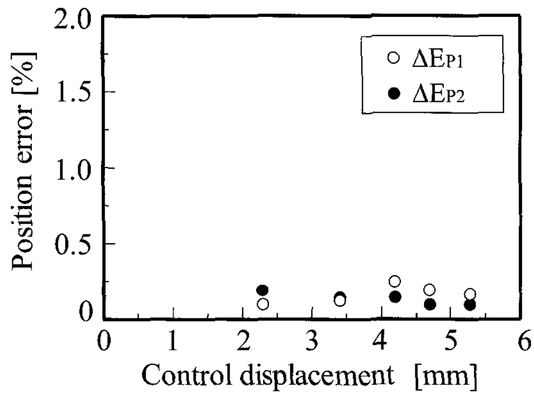

Fig. 4 Variation of position error with the control displacement.

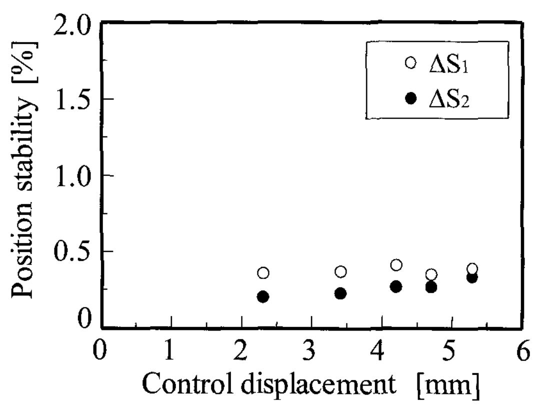

Fig. 5 Variation of position stability with the control displacement.

displacement. Thus, antagonism type position control system can precisely control the positioning in an arbitrary position.

It is desirable that there is little in the fluctuation at the desired position as much as possible. Figure 5 shows the effect of the control displacement on the position stability. The amount of fluctuation of the desired position controlled by heating and cooling is less than 0.5%.

3.2 Effect of external load on position control characteristics

The transformation temperature M_s and the reverse transformation temperature A_f increase linearly with increasing in applied load. When an external load becomes large, it is necessary for recovering the SMA wire to the original length to heat it up to high temperature. Therefore, the settling time t_{SH} in heating process becomes large according to the increase of the external load and the settling velocity V_H in heating process decreases with increasing in the external load as shown in Fig.6. Figure 6 also shows the results of bias type control system. In case of a bias spring, since the force of the spring is proportional to the length that a spring is lengthened, the average value of the force of a spring is used as the external load. In case of a bias spring, the settling velocity V_H is faster than those of a constant mass and an antagonism because the load of a bias spring becomes smaller according to the shape recovery of SMA.

On the contrary, when the position moves to the controlled position P_1 by cooling from the desired position P_2, the settling time is dependent on the cooling velocity of SMA wire. Since the martensite start temperature M_s also increases with increasing in applied load, the cooling time when the temperature of SMA wire is below M_s becomes shorter according to the increase of applied load.

Figure 7 shows the effect of the external load on the settling velocity V_C in cooling process as a function of a constant mass, a bias spring, and an antagonism. These three settling velocities increase with increasing in the external load. In case of an antagonism, when the SMA wire (1) is in cooling process, SMA wire (2) is in heating process (see Fig.1). Therefore, the settling velocity of an antagonism is faster than those of a bias spring and a constant mass because the recovery force of SMA wire (2) is added to the wire (1). In case of a bias spring, since the M_s decreases according to the decrease of the load of a spring, the settling velocity of a bias spring is slower than those of a constant mass and an antagonism.

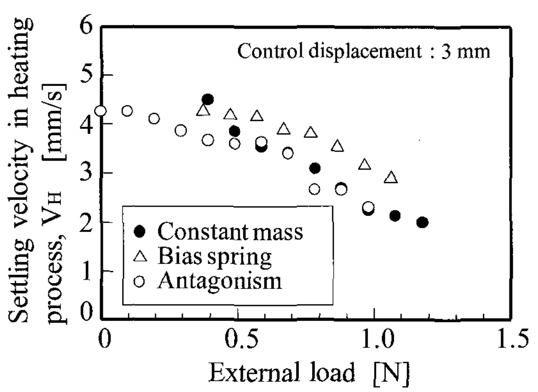

Fig. 6 Variation of the settling velocity V_H with the external load at the control displacement of 3mm.

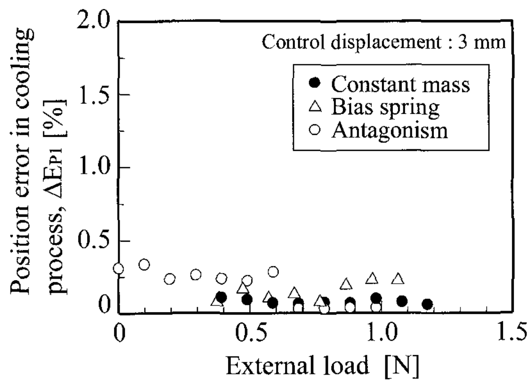

Fig. 8 Relationship between the positional error ΔE_{P1} and the external load at the control displacement of 3mm.

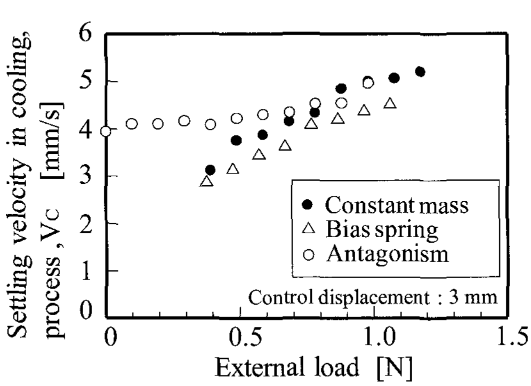

Fig. 7 Variation of the settling velocity V_C with the external load at the control displacement of 3mm.

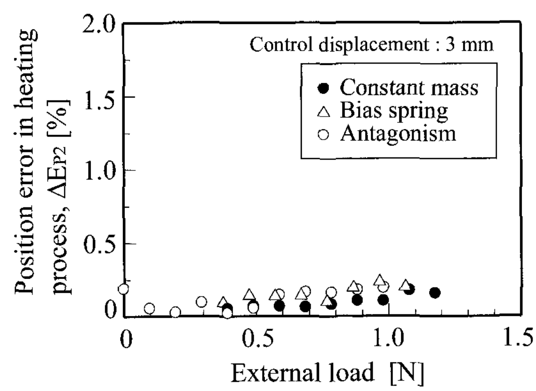

Fig. 9 Relationship between the positional error ΔE_{P2} and the external load at the control displacement of 3mm.

Figures 8 and 9 show the effect of the external load on the position error. Figure 8 shows the position errors in cooling process. The position error of an antagonism decreases slightly with increasing in the external load. However, three different bias modes are almost independent on the external load and are below 0.3%.

Figure 9 shows the variation of the position errors in heating process with the external load. The position errors of three modes increase slightly with increasing in the external load. These values of position error are also below 0.3%.

From the results of Fig.8 and 9, position errors of ΔE_{P1} and ΔE_{P2} have few differences by the three modes of an antagonism, a bias spring, and a constant mass.

Figures 10 and 11 show the variation of the position stability with the external load as a function of three different bias modes of an antagonism, a constant mass, and a bias spring. The position stability in heating process is affected by the external load and its positional deviation increases with increasing in the external load. However, the positional deviation in cooling process does not vary with the external load. Furthermore, the position stability of ΔS_1 and ΔS_2 is no differences among an antagonism and two bias modes and their positional deviations are below 1%.

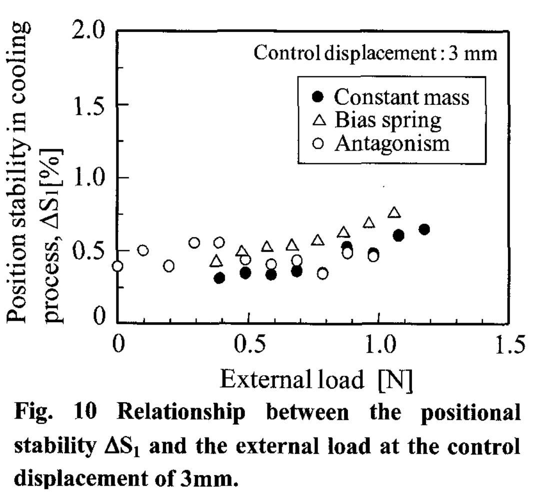

Fig. 10 Relationship between the positional stability ΔS_1 and the external load at the control displacement of 3mm.

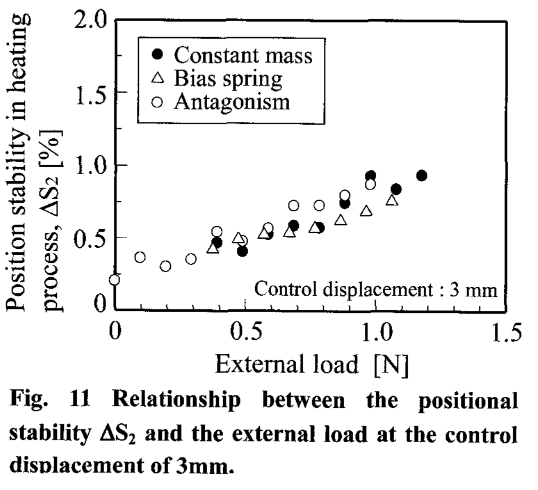

Fig. 11 Relationship between the positional stability ΔS_2 and the external load at the control displacement of 3mm.

4. CONCLUSIONS

A position control system with three different biasing mechanisms is produced and evaluated. Investigation is made on such positioning characteristics as the settling velocity, the position error at heating/cooling, and the position stability. The following conclusions are derived from results.

(1) Since the austenite start and finish temperatures increase linearly with increasing in applied load, the settling velocity in heating process decreases with increasing in the external load. Furthermore, the settling velocity of an antagonism is slower than those of a constant mass and a bias spring because the deformation force is added.

(2) The settling velocity in cooling process increases with increasing in the external load because the martensite start temperature increases according to the increase of the external load and the cooling rate become faster. In case of an antagonism, since the recovery force is added, its settling velocity is faster than those of two bias modes.

(3) The position errors in heating/cooling process are almost affected by the external load and are below 0.3%.

(4) The position stability in heating process is affected by the external load and increases with increasing in the external load. Furthermore, the position stability is no differences among three bias modes.

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