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SHAPE MEMORY ALLOY ACTUATORS

Piotr Kuryło
University of Zielona Góra, Faculty of Mechanical Engineering, Institute of Machine Design and Machinery Operations, ul. Prof. Szafrana 4, 65-246 Zielona Góra, Poland, P.Kurylo@ibem.uz.zgora.pl

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Abstract: The paper deals with experimental measurement of properties of the shape memory alloy (SMA) wire actuator. Statics and dynamic characteristic is determined via experimentally way. Step response for activation and deactivation of actuator has been obtained. Shape memory alloy actuators seem to be as progressive actuators.

1 Introduction

Shape Memory Alloys (SMA's) are famous materials which are able to return to a predetermined shape when heated. The SMA, which is cooled below its transformation temperature, has low yield strength and it can be easy deformed into any whatever new shape. After heat-ing above the transformation temperature, it changes crystallographic structure and it returns to the original shape. The SMA crystallographic structure changes between two phases, the low temperature (marten-site) and high temperature (austenite) phases (Figure 1). It is able to pro-duce extremely forces from the viewpoint of volume to force ratio. SMA could be used also as force sensors and after that again as actua-tor. Consequently, the SMA belongs into group of smart materials. The most famous SMA material is Nitinol, which is an alloy of nickel and titanium. It has been discovered in Naval Ordance Laboratory in sixty years of twentieth century. Phenomenon of SMA is occurs in more then 20 alloy types. The SMA actuators are made in wire, spring or ribbons shape.

The shape memory effect - SME described above, whereby only the parent austenitic phase is remembered by the alloy, is known as the one-way SME. It is also possible to make an alloy remember both the parent austenite phase and the martensite shape simultaneously. This is known as the two-way SME. In this case, the alloy has two stable phases: a high temperature austenite phase, apparent on heating and a low-temperature martensite phase, apparent on cooling. Although SMA of two-way SME provides contractive and tensile forces, its ten-sile force is much smaller than contraction force and recoverable strain normally less than half that of one-way SME type. Thus SMA actuators of oneway SME are more attractive in mechatronic applica-tions and usually preferred. The oneway SMA needs a reverse-bias force to return the wire to its original length. Bias forces can be creat-ed by many methods: gravitational pull, spring, magnetic force, oppos-ing SMA wire [1-3].

Thermal activation of the SMA can be easily driven by electrical cur-rent via Joule heating. Cooling of the SMA can be realized via heating radiation into surroundings at the room temperature. Other methods of improved cooling are to use: forced air, heat sinks, peltier elements, increased stress (this raises the transition temperature and effectively makes the alloy into a higher transition temperature wire), and liquid coolants. Combinations of these methods are also effective.

Hysteresis and nonlinearities cause the control troubles. Heat losses during the phase transformation phases (owing to internal friction or structural defects) cause hysteretic behaviour of SMA as shown in figure 2.

In the [5] has been presented mathematic model of the SMA behav-iours as equation:

$$\frac{dR}{R} = \pi_e \cdot d\sigma + K_\varepsilon \cdot d\varepsilon + \alpha_{RT} \cdot dT \qquad (1)$$

where, R is resistivity, π_e - piezoelectric coefficient, σ - stress, K_z - coefficient of shape sensitivity, ε - strain (deformation), α_{RT} - coefficient of thermal expansion, T - temperature.

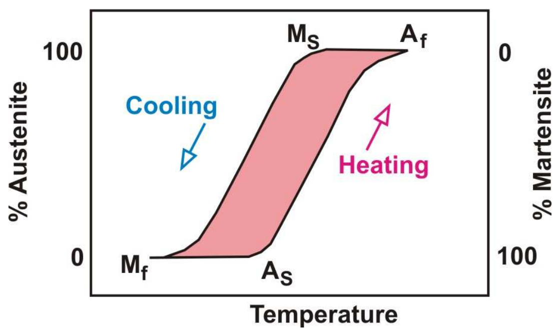

Figure 1 The SMA hysteresis and nonlinearities [1, 2]

A shape-memory alloy (SMA, smart metal, memory metal, memory alloy, muscle wire, smart alloy) is an alloy that "remembers" its original shape and that when deformed returns to its pre-deformed shape when heated. This material is a lightweight, solid-state alternative to conventional actuators such as hydraulic, pneumatic, and motor-based systems. Shape-memory alloys have applications in robotics and automotive, aerospace and biomedical industries.

SMAs also display superelasticity, which is characterized by recovery of unusually large strains. Instead of transforming between the martensite and austenite phases in response to temperature, this phase transformation can be induced in response to mechanical stress. When SMAs are loaded in the austenite phase, the material will transform to the martensite phase above a critical stress, proportional to the transformation temperatures. Upon continued loading, the twinned martensite will begin to detwin, allowing the material to undergo large deformations. Once the stress is released, the martensite transforms back to austenite, and the material recovers its original shape.

SMA actuators are typically actuated electrically, where an electric current results in Joule heating. Deactivation typically occurs by free convective heat transfer to the ambient environment. Consequently, SMA actuation is typically asymmetric, with a relatively fast actuation time and a slow deactuation time. A number of methods have been proposed to reduce SMA deactivation time, including forced convection, and lagging the SMA with a conductive material in order to manipulate the heat transfer rate [1-3].

2 SMA wire actuator activity

Heating and cooling of the SMA wire actuator causes change of the wire free end position. Fig. 2 shows this dependence of free end SMA wire position on value of electric current, which shows highly nonlinearity and hysteresis behavior. The characteristic shown on fig. 2 has been measured with bias weight 1 kg, which corresponds to maximum pull stress.

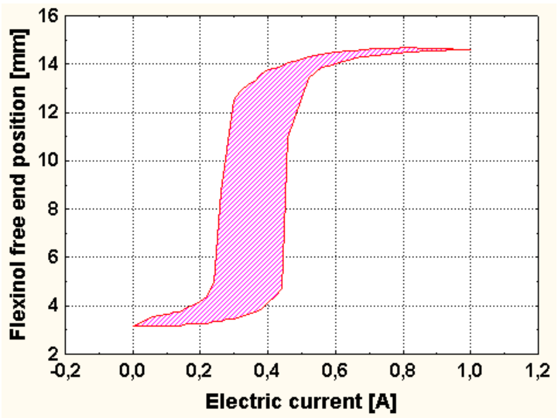

Figure 2 Dependence of the free end Flexinol position on the value of electric current

The pull stress overload of the SMA wire actuator has been also tested. SMA actuator works correctly and without damaging. Results of this testing (Figure 3) shows decreasing of the relative deformation with increased value of additional bias weight. Activation value of electric current has been 1000 mA for this testing.

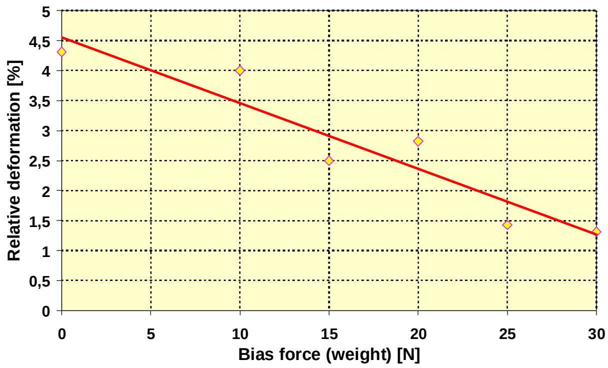

Figure 3 Dependence of the free end SMA wire actuator position on the value of electric current

Dynamic characteristic has been tested through the step response testing. Excitation electric current is shown on fig. 4 and it has been controlled via microcontroller. Step response has been measured via measuring adapter with personal computer. Mathematic model obtained from calibration process has been used for obtaining of the step response as time dependence of the free end SMA wire actuator position.

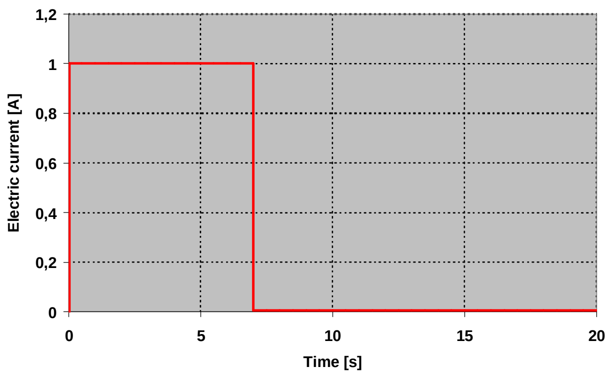

Figure 4 Activation electric current for step response testing

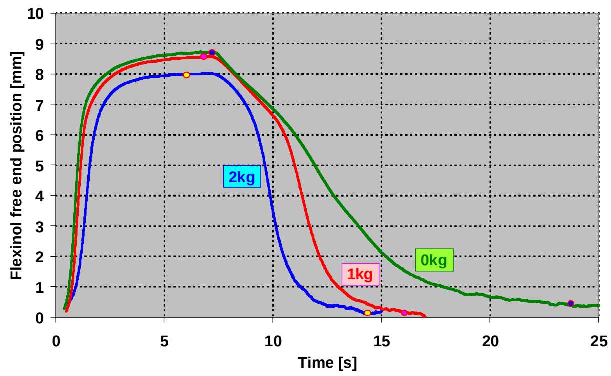

Figure 5 SMA wire actuator Step response for various bias weight

It is possible to determine activation and deactivation time for SMA wire actuator which are corresponds with heating and cooling time. Figure 5 shows that cooling is slower then heating. Step response is tested for overloaded mode and it is possible to say that overloading causes a decreasing of the heating and cooling time.

3 Conclusion

Shape memory alloy has a lot of advantages as clean, silent and spark free operation, high biocompatibility and excellent corrosion resistance. They are also free of parts such as reduction gears and do not produce dust particles. Actuators based on this principle are very often used in robotic and mechatronic application [4-30].

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