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An Innovative Shape Memory Actuator

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Abstract. The work describes a NiTi linear actuator. This material is able to realize a contraction with heating produced through Joule effect. Then a cooling of the active device is realized with forced air. Finally the lengthening is realized with another active element. The particular structure of the geometry allows for an increment of reliability, because the electrical connections are mechanically stabilized and the active elements are compelled to avoid undesired electrical contacts through an insulated cylindrical core.

1 Introduction

One of the main requirements that an actuator needs to satisfy is to guarantee high mechanical performances in a limited space. In this way, SMA actuators play an important role to provide the highest power-to-weight ratio among light-weight technologies [1-3]. They have become a very attractive option for uses in actuators and they are implemented in a broad range of commercial applications (consumer electronics, fashion, fasteners, …). SMA actuators can be actuated remotely with a low actuation voltage [4-6] guaranteeing reliable performances and ease in installation.
SMA actuators are widely used in wire or spring configurations, but upcoming applications (e.g. medical instrumentations or microsystems) also demand more complex shapes [7-12]. Designing a SMA actuator is a challenging task due to the complexity of the material selection and behavior. In this manner, the electrical, thermal and mechanical aspects have to be considered simultaneously [13].
SMAs are intermetallic compounds able to recover, in a continuous and reversible way, a previously defined shape when subjected to an appropriate thermomechanical load [14-16]. From a microscopic point of view, this transformation consists in a transition from a crystallographic stable phase at low temperature (e.g.. martensite) to a different crystallographic stable phase at high temperature (e.g. austenite). When the SMA is deformed by an external force, instead of breaking crystallographic bonds and damaging its structure, it starts a progressively arrangement of planes which closes the deformation without achieving significant atomic displacements. During this process, atoms have moved only slightly from original positions. When an imposed stimulus occurs, atoms move to restore the previous crystal structure before the deformation and then the recovery of macroscopic original shape.

2 SMAs application to linear motors

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This paper presents the study and realization of a SMA actuator able to achieve linear movements in a coil spring configuration. SMA material has an high electrical resistance, it can be heated to its transition temperature simply by passing current through it. This approach opens up many possibilities for providing mechanical actuation (movement) without any moving parts. The purpose of this research is the realization of SMA actuators which perform in defined operating temperature a specified movement. Temperatures have to meet limits due to actuator structure and application. The duty cycle for current application should be in agreement with user's needs, so as to allow a movement in a short time. For these reasons, authors have as primary objective the shortest working cycle with imposed temperature constraint, especially during the cooling phase. A robust approach (Design of Experiment) is accepted for performing tests in order to achieve a required output for thermal [17], voltages, stroke and time point of view [18, 19]. The developed experimental tests permitted a performance comparison between different operating conditions.

This paper focuses on two main issues in SMAs assessment and selection. The first one is the characterization of the thermo-mechanical behavior of SMA materials [20-22] and the other is the actuator application of one-way shape memory effect (SME). The selection of the operative temperature range is a crucial point in SMA selection [23]. All memory alloys have temperatures that characterize the internal structure [24]. In this study, the main temperatures of phase transformations for the adopted alloy (NiTiCu5) include the temperature at end of martensitic transformation (MF) 26°C, the martensitic transformation start temperature (MS) 37°C, the austenite transformation start temperature (AS) 48°C and the end temperature austenitic transformation (AF) 59°C (Hysteresis 24°C) [25-28]. The temperature of 59°C indicates the maximum operative temperature for SMA material, in fact for higher temperature no transformation phase are pointed out. The SMA element remains in the same position and all exceeded power is dissipated. Temperature of 26°C indicates the lower limit of the resting phase of SMA element and internal structure of alloy is all in the martensitic phase.

Generally, the one-way effect does not provide suitable mechanism of SMA actuator due to the host structure that is not able to return to initial shape after cooling process. However, different researches [29] proposed some designs of SMAs applied to muscles of robot hands demonstrating that it is possible to realize a hand actuated by SMAs. In this case, a model based controller does not perform in a satisfying way due to the open loop configuration. The control problem (e.g. hysteresis) can be partially solved restricting the displacements to a specific range simplifying the problem to a linear one. This behavior is linearized using two counteracting shape memory elements. This solution is further improved by a temperature sensor on the shape memory element. Electrical resistance position feedback is also used in common practice [30, 31]. An example of this application has been developed in the proposed actuator system.

3 Design of SMA actuator module

The actuator is designed to obtain a linear movement along horizontal axis of SMA elements. The shortest duty cycle was the primary objective in designing the device. This assumption highlights that the importance to meet specific functional requirements, severely affected the designers' choices [32, 33] regarding the shapes and configuration that actuators should possess in order to produce predefined strokes and output forces [34-41]. Cartesian geometry (Fig. 1) develops electrical and mechanical function on several layers [42, 43]. This configuration is a result of movement optimization as shown in the followings.

The actuator needs to moves along an horizontal axis or a plane to perform a linear movement. The intuitive geometry for this type of movement is the cylinder, where all the components are positioned around the main axis of movement. In this case functional axes (mechanical constraints, electrical contacts, movements, thermal heating and cooling) are coincident with the movement axis and the model is very compact [44-46]. A cylindrical geometry does not permit the geometrical diversification of the contact points that characterize the different functions.

These functions need of different materials and physical connections. In order to design properly the single elements of the actuator, it is useful to separate functions with Concentric cylinder geometry (separate elements, on concentric surfaces) or Cartesian geometry (different functions on different parallel plans). The physical model is more complex, but the design phase and maintenance activities are simplified by isolating geometrical features, with independent functional behaviors.

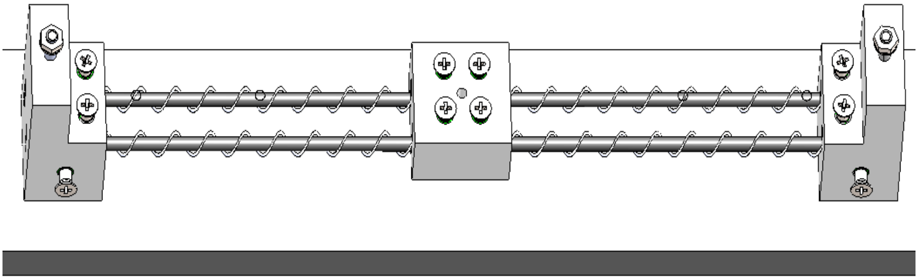

Figure 1. The modular actuation system.

From a Cartesian geometry is possible to develop a modular model (Fig. 2). SMA model is designed to have more actuator elements in parallel without changing the conformation of the individual components, but increasing overall dimensions, developed force and energy consumption [47, 48]. This approach represents an important benefit compared with concentric cylinder geometry. In particular, this configuration permits an increment of the nominal force of the actuator as shown in Fig.1 [49-51].

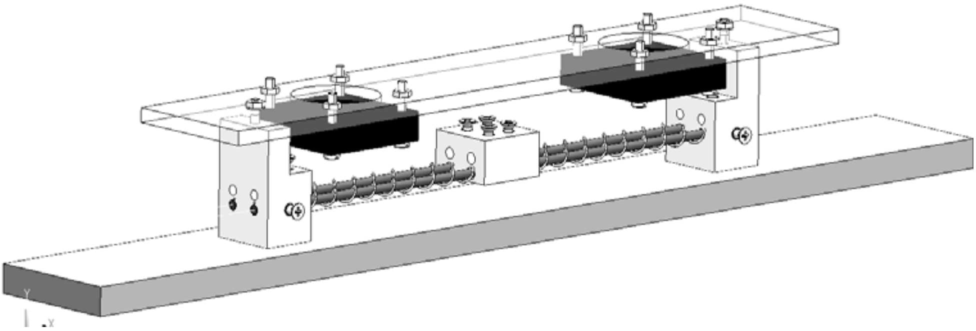

Figure 2. The SMA prototype based on two modules.

Fig. 2 describes the developed prototype, electrical and mechanical functional plans are separate. Electrical function is located in the upper part of the SMA actuator (Fig. 2) while the plane of the mechanical function is located on the axis of SMA elements. The number of springs has been chosen in order to obtain the best control and stability in the movement. In this study four SMA elements are used, positioned on each side between central slider and wall. The spiral diameter is equal to 4.00 mm and the wire thickness is 0.40 mm.

4 Conclusions

This paper presents the development of a modular actuator based on shape memory alloy material. Starting from theoretical observations, this study wants to highlight the main relations between the functional and geometrical properties of this device. The next steps include to improve some theoretical aspects and develop new prototypes to optimize the required perfomances.

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