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HIGH SPEED SHAPE MEMORY ALLOY ACTIVATION

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ABSTRACT

Due to their ability to change into a previously imprinted actual shape through the means of thermal and electrical activation, shape memory alloys (SMA) are suitable as actuators. To apply these smart materials to a wide range of high-speed applications like valves or safety systems, an analysis of the application potential is required. The detection of inner electrical resistance of SMA actuators allows gauging the actuator's stroke. By usage of a microcontroller a smart system without any hardware sensors can be realized which protects the system from overheating during high-current activation. The publication concentrates on different experimental data on high-speed actuation under 20ms and the potentials in the field of industrial applications. The paper gives an overview about different controlling methods for SMA-actuators, experiments concerning the resistance behavior of SMA and the development of systems using a resistance control feedback signal during high-speed activation.

INTRODUCTION

Shape memory actuators have certain characteristics which are unique in comparison to other actuating principles. These intelligent materials are able to change into a preciously imprinted shape after a macroscopic deformation by thermal or electrical activation. The small dimension and weight of a shape memory actuator allow realizing most compact and powerful drives for mechatronic systems. Today's competitiveness of micro- and mechatronic systems is determined by precision, cost, quality and simplifications. For example a shape memory actuator driven system generally consists of fewer parts than conventional ones. Furthermore the reduction of parts often enhances the reliability of the actuating components. A striking advantage of shape memory actuators is the significantly higher working capacity in comparison to conventional actuators. These advantages are beneficial, for example, in safety applications. Figure 1 shows a schematic overview over different application field for systems which are triggered either electrically (e.g. by crash sensor systems for automotive applications) or thermally (e.g. fire control shutter in building technology) during a critical incident. Within this publication, the focus is concentrated on electrically driven actuators and their fast activation behavior regarding electrical activation problems. The following experiments show the general characteristics of shape memory actuators during dynamic activation and their resistance after a brief conceptual approach.

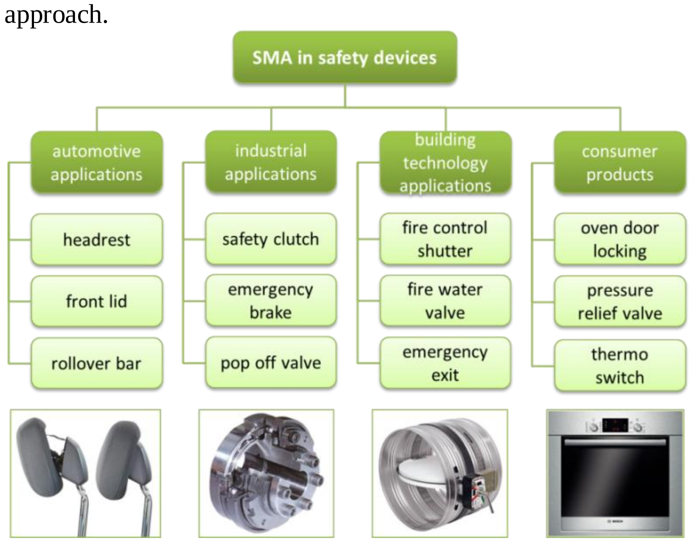

Figure 1: SMA actuators in safety devices

CONCEPTUAL

The opportunity of utilizing shape memory alloys in this application field enables security systems which can be checked part by part for functionality before the implementation in products. Such tests are possible in systems driven by solenoid drives, but they are heavy in comparison to SMA actuators. Pyrotechnic systems, also used in security systems, often cannot be tested before a critical incident at all. In SMA the functional test can be achieved by the detection of the intrinsic sensor function.

The electrical resistance of shape memory wires changes during the phase transformation, from deformed to the imprinted shape. As described in [1] the electrical activation of shape memory actuators is sensitive to ambient temperatures, which does not limit the activation, but affects the dynamic response of an SMA. On the other hand, a high speed actuation within less than 20 ms is sensitive to a SMA device. If the ambient temperature rises, a test may lead to an overheating of the systems at constant activation time and current level.

In order to achieve the compensation of thermal fields by a constant and fast activation, an electronical circuit as presented in figure 2 is necessary. The microcontroller unit can be triggered by external sensor information by a digital input. In this case, the system can activate the current supply unit, which is automatically adjusted to the ambient condition over a digital and an analog output. The digital output transmits the activation command (on / off) while the analog output is used as an adjustment signal for the gain element. The maintenance circuit (grey paths) allows the gain element to supply the SMA element with current in the full range of the power supply. In this concept, an additional power supply component for the microcontroller would be necessary. The gained current is then transformed in the SMA element into heat energy by Joule heating. The resistance signal is transmitted by another circuit (dotted paths) enabling the measurement of the reference voltage at the SMA element.

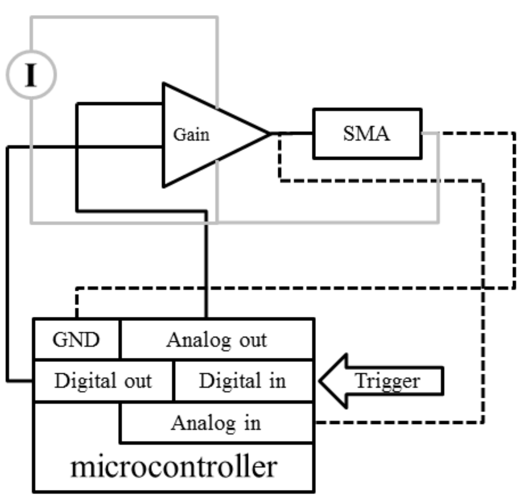

Figure 2: electrical control circuit for current gain and SMA resistance detection for overheating protection.

If the SMA element has to be tested, a minor current is needed to detect the functionality. The measuring unit is able to detect a beginning transformation of the SMA element, granting a conclusion on the functionality of the SMA device.

The mechanical hardware with the implemented SMA element can be designed as a multipurpose unit. A remarkable advantage due to simplification of product varieties can be achieved by mechanical design. Because of the thermal characteristic of SMA, a mechanical actuator design can be activated thermally, steered electrically or controlled by time or electrical current. This allows building one system which can be used for different safety applications (see figure 3). For example, a fire water valve can be triggered thermally, or by an electronic control unit as described before. Such concepts lead to a faster and more efficient product development process as presented in [2].

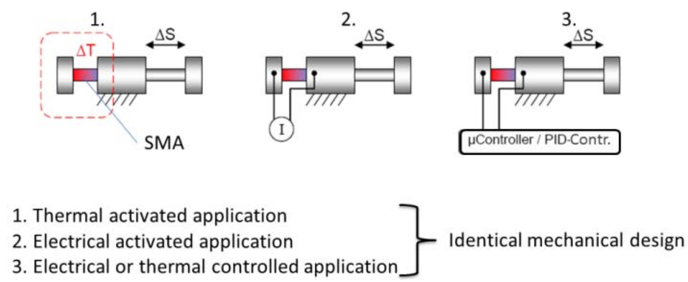

Figure 3: Conceptual design of application specific systems with a mulitpurpose SMA actuator.

EXPERIMENTAL

The test rig shown in figure 4 was used for experimental analysis of the SMA wires. The SMA specimen is mounted with two precision clamps to a fixed support and a linear spring. The spring is displaced to apply a pre-stress to the SMA specimen. The displacement of the clamping between SMA specimen and spring is measured using a laser vibrometer. The control and current supply unit is integrated in the test rig. With this equipment, the dynamic behavior of SMA wires was investigated.

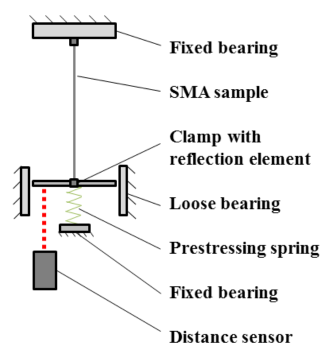

Figure 4: Schematic of vertical SMA Test rig

In figure 5 and 6 the time response of SMA wires at varying electrical current, as well as the corresponding reference voltage during heating are depicted. The experiment shows the possibility to vary the time response of SMA actuators and the dependence of the actuator voltage on the preset reference current. The extremal values of the voltages correspond to the start and completion of the phase transformation as published in [2, 5]. The austenite (activated) phase fraction is presented by ξ. For $\xi = 0$, the SMA contains only martensitic phases. The phase fraction can vary between 0 and 1.
These facts allow establishing a testing process within a production line of SMA safety systems, which will not destroy the element in cases of high speed actuation and varying ambient temperatures. The following experiment regards the dimensioning of SMA wires for high speed actuation, and represents the elctrical challenges and opportunities.

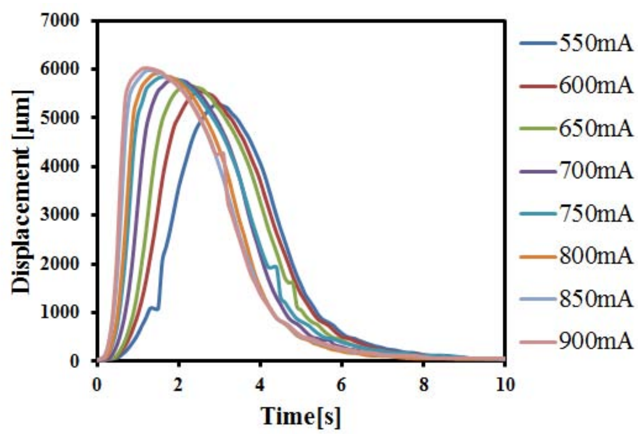

Figure 5: Displacement response of SMA actuators in dependance of electrical current.

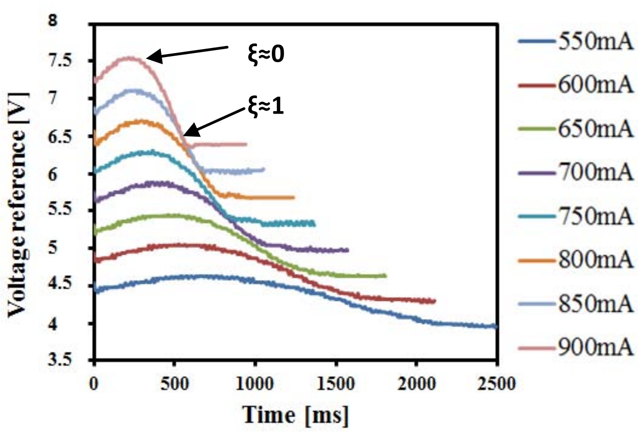

Figure 6: Resistance feedback expressed as voltage reference during SMA activation corresponding to figure 4.

In another experiment SMA wires with two different dimensions were investigated by measuring the voltage and calculating the electrical resistance for a preset electircal current (figure 7). The used specimens were 50 mm long SMA wires with diameters of 0.05 and 0.1 mm. The preset currents were activated for 1.2 ms for unloaded specimens. As the absolute resistance of the 0.05 mm SMA wire is higher than for the 0.1 mm wire, the measured wire voltages differ repsectivly. The current difference between the two wires is due to the different cross section area.

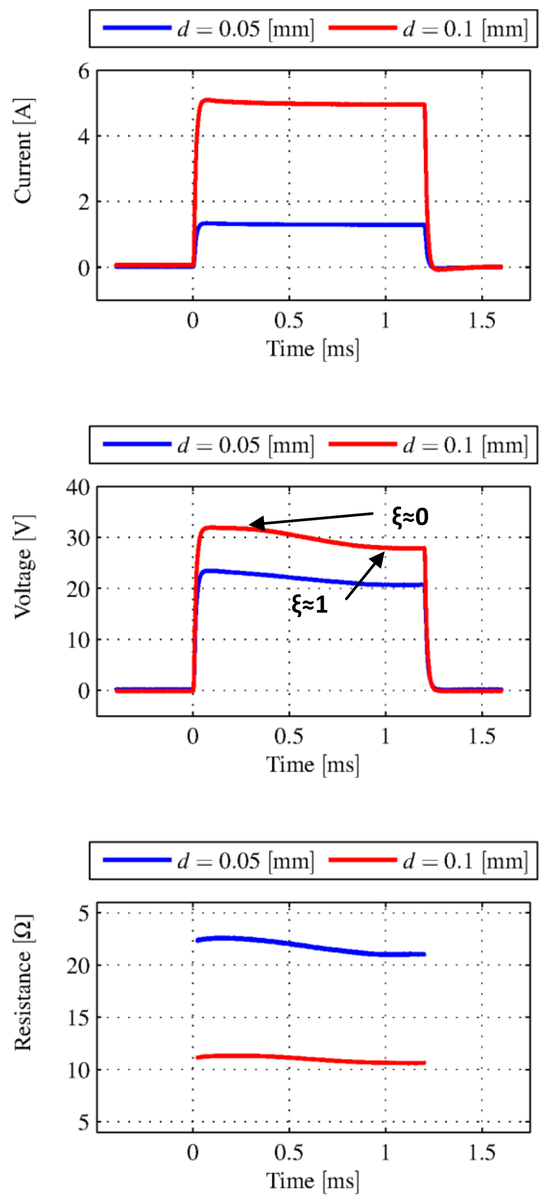

Figure 7: SMA high-speed activation test with a maximal time range of 1.2 milliseconds. The voltage reference can be used for detection of the phase transformation state.

As presented in figure 5, it is possible to localize the maximal and minimal extreme points of the voltage reference in order to cut off the activation current for overheating protection within the high speed activation. This method is described in detail in [5] where an algorithm and electical circuitry for appropriate displacement control is presented. Moreover, the experiment was repeated with pre-stressed SMA wires. Additionally the wire's total displacement was measured using a laser vibrometer.

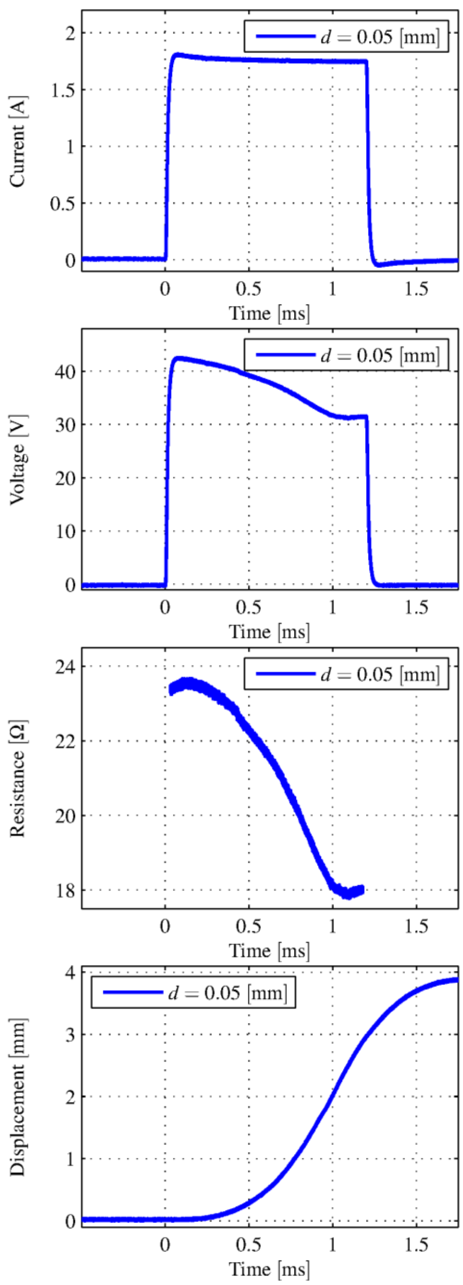

Figure 8: Shape memory actuator high-speed activation with displacement measurement and sensor feedback in a time range of 1.2 milliseconds.

The results for a 70 mm long wire under a load of 200 MPa are shown in figure 8. The transformation of the SMA wire is induced by thermal heating where the limiting factor for the transformation is the speed of sound in the material. A sufficiently high current is applied to the wire in order to ensure transformation within the desired time (1.2 ms activation time). From the resitance and displacement graphs in figure 8, it follows that the mechanical displacement of the wire is delayed. This is due to the inertia of the accelerated mass of the pre-stressing spring and the SMA wire. Therefore the time delay between start of transformation and displacement will be higher for loads with larger inertia.

CONCLUSION AND OUTLOOK

As presented in this publication, it is possible to use shape memory alloys as actuators for high-speed activation. This dynamic behavior can be used in a wide range of safety systems, which can be used several times. The challenge in this topic is not only to develop an operable SMA system, but also to develop a sufficient electronic circuit which protects the SMA wire during high-speed activation. Further works will concentrate on high-speed activation at varying ambient temperatures and the experimental validation of the concept.

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