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# Magnetic shape memory actuator performance

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**Abstract**

Magnetic shape memory (MSM) is a newly developed actuator material. The MSM material changes its shape when exposed to an external magnetic field. Accordingly, motion generation applications such as actuators can be made. Coupling factor, temperature range, acceleration, speed, rise time, stroke and force of different MSM actuators are presented in this paper. Different types of dependencies of MSM actuators performance on their structure are also discussed.


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*Keywords:* Magnetic shape memory material; Actuators

Magnetic shape memory (MSM) material is a new material type, which changes its shape when exposed to an external magnetic field or to a mechanical force [1,2]. The material's magnetic-field-induced strain has been measured to be up to 10% [3]. Due to the link between the mechanical and magnetic energy, it is possible to make motion generation applications from the material. Moreover, it is possible to use also the reverse effect of the material to sense position, speed or acceleration. The generated motion of the material can be of many different types, such as linear or bending motion [4]. So far, the most common application are the linear motion actuators. Since the material motion depends on the magnetic field, these actuators are made to control the magnetic field in the MSM element. Usually, actuators consist of coils, a ferromagnetic core and an MSM element. Permanent magnets can be used to generate DC magnetic field, and spring load to make repeated motion. By controlling the current of the coils, one can control the magnetic field in the material and, thereby, its straining [5]. Several of these types of actuators have been built and tested.

The MSM actuator performance is strongly dependent on the MSM material properties. The most important material parameters are the internal friction or twinning stress, the magnetic field induced stress and the operating temperature range. One important property that these material parameters define is the coupling factor between magnetic field energy and mechanical work of the MSM element. So far measured values of coupling factor have been as high as 70%. The operating temperature of the MSM material is solely a function of its composition, i.e. the ratio of alloying elements. For the time being, the maximum temperature measured 70°C [6]. Study is in progress to increase the operating temperature to 150°C.

Besides, the material parameters are also the dimensions of the MSM element influence the actuator performance. The length of the element determines the stroke of the actuator and the cross-section area determines the output force. Accordingly, an actuator with a large cross-section generates high force, while a long one gives a large stroke. So far actuators with a stroke of 5 mm and a force of 2 kN have been built. Actuators with larger force or stroke can be made.

The strain output depends also on the opposing force the actuator is working against. There is an optimal load under which the actuator is beneficial to operate. This is generally an MSM material property [7].

A typical strain curve of the MSM element in actuator operation can be seen in Fig. 1 as a function of current. Due to small air-gap between the MSM element and the

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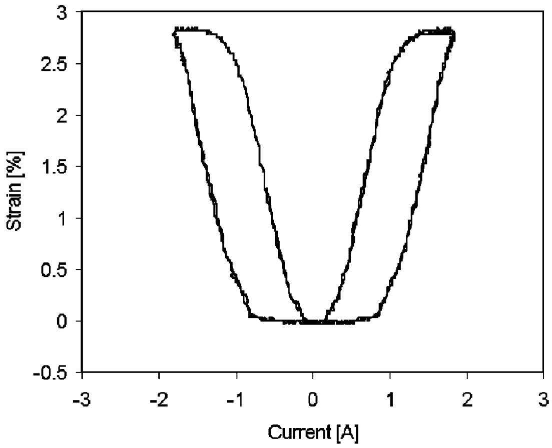


Fig. 1. Strain of an MSM element in the studied actuator, when the actuator is run with sinusoidal voltage.

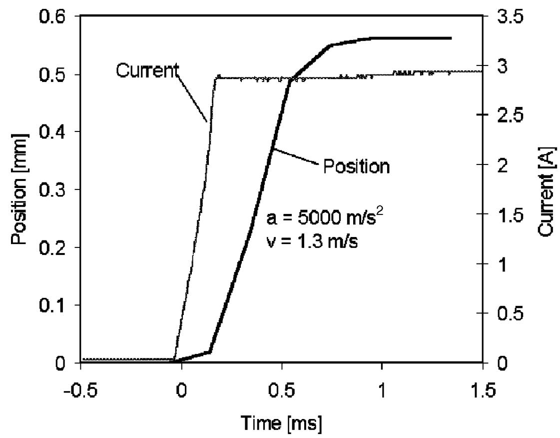


Fig. 2. Position- and current-waveform measured from the studied MSM actuator.

actuator core the corresponding magnetic field in the MSM material is hard to measure, but it can be estimated. In this actuator with 2 A current in coils the magnetic field strength inside the element is about 420 kA/m. The MSM material usually reaches its saturation magnetic field induced stress when the field inside the element reaches 500 kA/m, though most of the stress is generated with lower magnetic field.

The used element was non-stoichiometric $Ni_2MnGa$ alloy, consisting of 5-layered martensite. The MSM material element in the actuator was cut with spark cutting machine, mechanically wet polished and finally electro polished. After the treatment the element was put into the air-gap of the actuator. The element was rectangular with dimensions $1\,mm \times 2\,mm \times 10\,mm$. The actuator had two coils symmetrically around the element with 200 rounds of wire in each. The core of the actuator was made from laminated iron. All the tests with the actuator were performed at room temperature (20°C).

As can be seen in Fig. 1 the MSM material has hysteresis between the control current and the motion. This is a general MSM material property. Hysteresis generates damping abilities, which reduce the vibrations caused by the mechanical system as well as the current higher harmonics.

The dynamic behavior is an important factor in the actuator performance. Actuator's acceleration depends on the quotient of generated force and the moving mass. Largest accelerations are achieved when the moving mass is at minimum. Fig. 2 presents one sample run in the test actuator, where accelerations up to $5000\,m/s^2$ have been measured. The eddy currents of the magnetic core cause damping, which reduces the maximum acceleration and speed. Also there is some friction in the moving mechanical parts of the actuator. In high acceleration actuators the core shall be of high-frequency material and the friction minimized.

The maximum acceleration of the MSM element affects the maximum operating frequency and the rise-time of the MSM actuators. In Fig. 2 the rise time measured 0.6 ms, however rise times down to 0.2 ms have been measured. MSM actuators have been used up to 5000 Hz, higher frequencies can also be reached. Limiting factor is often the voltage supplies ability to change current in the actuator, as well as the inertia and the eddy currents.

Beside the acceleration also the speed of an MSM actuator is an important parameter. In the case of Fig. 2 the maximum speed measured 1.3 m/s. In MSM material the theoretical limit of the speed is considered to be a fraction of the speed of sound. Actuator eddy currents are likely to limit the maximum speed.

The fatigue of the MSM actuators has also been studied. The tests have shown that the material performed up to 200 million cycles without reduction in the strain [5].

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