

# UNTRADITIONAL ACTUATORS SMA TYPE -MODELING OF HYSTERESIS

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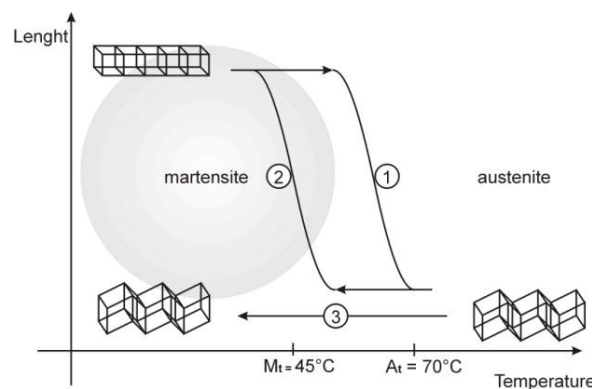
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**Abstract:** The shape memory materials are known since first half of the twentieth century. The example of these materials could be a Shape Memory Alloys (SMA). Because of their attributes, the engineers usually call them a „smart materials“. The SMA can be used in many static or dynamic applications for example in problem of actuators. Thanks to the SMA materials sophistication and associated shape memory effect, there are some issues (hysteresis, degradation etc.), which can complicate their prospective usage. The attributes of SMA classified these actuators to the category of non-linear system with hysteresis. This article deals with the SMA use and potential hysteresis modeling approaches. Several model examples are discussed.

**Keywords:** Shape memory, SMA, untraditional, actuator, modeling, valve, hysteresis

## 1 INTRODUCTION

The phenomenon of memory effect (SME) was discovered by the Swedish physicist named Arne Olander in 1932 [1]. He found a metallic compound (Au-Cd), which was able to simply model in „cold state“. The compound returned back to the original shape after its warm up. This effect was only the result of internal crystallography changing (Fig.1) between two states of SMA. These states are low-temperature (martensite) and high-temperature (austenite). The high-temperature state can be reached by electrical current flowing, the low-temperature state can be reached by surroundings temperature also the active cooling can be used. The result of mentioned transformation is changing of SMA elements dimensions (contraction). These elements can have a various basic shapes also they can be customized. The common shapes are wires, tubes, springs or strips. There are two basic areas of SMA use. The static (the SME is use only once), and the dynamic (the SME is use repeatedly) [2].

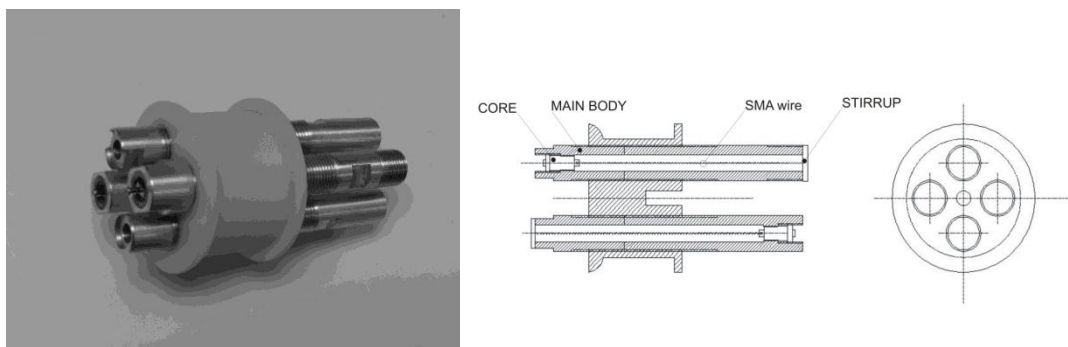


**Figure 1:** Crystallography changing during SME in SMA.

## 2 UNTRADITIONAL (SMA) ACTUATOR

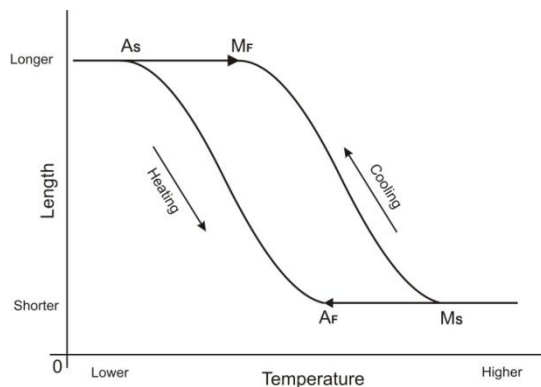
The described mechanism (SME) and a very good attributes such a ratio of power/ weight, silent run, chemical resistance, electrical conductivity etc. give a possibility to SMA be use as an untraditional actuators. One of the commercial products is an electrically controlled universal valve [3]. This valve is designed as a “universal one” nevertheless its purpose of use is pneumatic filed. The valve consists of a dielectric body, core, and SMA wire as an actuator. The SMA actuator is connected to the conductive metallic endcaps. Through this endcaps is the SMA actuator by the electrical current activated. The SMA compound used by the valve producer was compound of Ni (Nickel) and Ti (Titanium). This material is usually called NiTiNol and its parameters are possible to find in datasheet [7].

A few untraditional actuators can be integrated altogether. The particular solution is shown in the Fig.2. There is a new McKibbens pneumatic muscle endcap with SMA valves integrated. In this solution the SMA valves replaced the standard electrical valves, which are heavy and bulky.



**Figure 2:** McKibben’s pneumatic muscle endcap with SMA valves integrated.

The SMA’s attributes classified these types of untraditional actuators to the category of non-linear systems with hysteresis. The problem is shown in Fig.3.



**Figure 3:** Hysteresis curve in SMA materials.

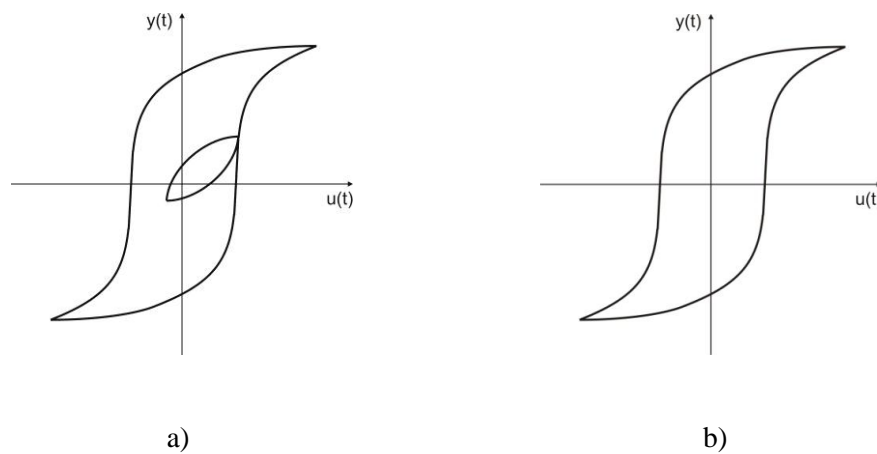
The hysteresis parameters are given by compound properties and the attributes of particular dynamic application. In a case of actuators the ability of a fast heating and a fast cooling are the main factors which form the hysteresis shape, even it can the hysteresis problem eliminate. There are some applications, where these factors can’t be use. The appropriate hysteresis model can helps to control the SMA actuators in this these cases. There are two methods [4] [5] [6] how to establish a proper model. The first method is to make the experiments with real system and the measured

characteristics use for building of the model. The second method is to analyze the theory about solved problem and establish the model on theoretical basics.

### 3 HYSTERESIS MODELING

The quality regulation of non-linear systems is usually more complicated than the linear systems. The model reference control systems (MRCS) appear to be the best solution for nonlinear systems control. The quality of control is in many cases given by precision of system's model. There are many methods, how to build the model, which is necessary for the effective and accuracy control of specific system.

The problem of hysteresis can be separate to the problem of hysteresis with internal curves (Non-local Memory hysteresis - NM) and hysteresis without internal curves (Local Memory hysteresis - LM). See Fig.4, where a variable  $u(t)$  and a variable  $y(t)$  represent an input, and an output of the general nonlinear system hysteresis type.



**Figure 4:** a) Non-local Memory hysteresis (NM), b) Local Memory hysteresis (LM).

The example of the nonlinearity hysteresis type modeling with application of mathematical functions is the Liang-Roger's approach, where the approximation by cosine function is used.

If variable  $X$  [%] is martensite fraction,  $X_0$  [%] is starting fraction of martensite,  $T$  [°C] is temperature and  $K$  [-] is constant representing slope of curves in Fig. 3, then

For the increasing temperature we use the relation:

$$\begin{aligned}
 X &= X_0 & \text{pro } T &\leq A_s \\
 X &= 0.5X_0 [\cos K_M (T - A_s) + 1] & \text{pro } A_s < T < A_F \\
 X &= 0 & \text{pro } T &\geq A_F
 \end{aligned} \tag{1}$$

For decreasing temperature we use another relation:

$$X = X_0 \quad \text{pro } T \leq M_F$$

$$X = 0.5X_0 [\cos K_M(T - M_f) + 1] \quad \text{pro } M_S \geq T \geq M_F \quad (2)$$

$$X = 0 \quad \text{pro } M_S < T$$

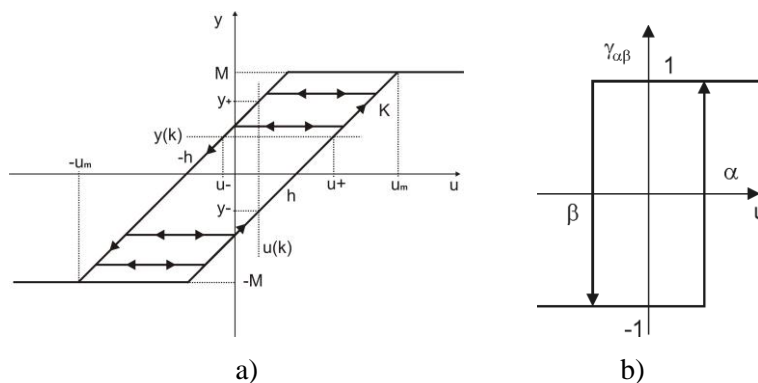
And  $K$  is given by:

$$K_A = \frac{\pi}{(A_F - A_S)}, \quad K_M = \frac{\pi}{(M_S - M_F)} \quad (3)$$

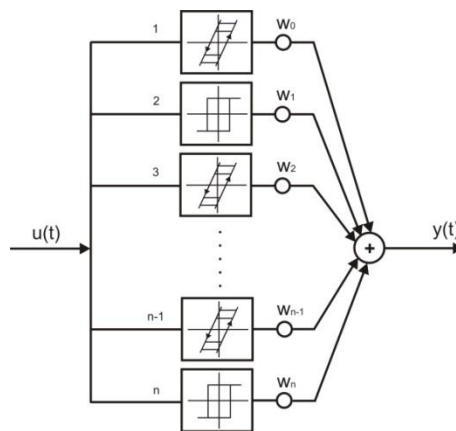
The similar method of hysteresis modeling is Tanaka's approach, where the exponential function is used.

These two methods mentioned above can be used in problem of hysteresis modeling, but they are not able to model the problem of internal curves, which is shown in Fig.4. The problem of NM hysteresis modeling can be solved by use of more the more sophisticated methods. These methods can be use in a case of LM hysteresis too [5].

A many of these methods are based on "main block" idea, where the model output is given by the summation of the all blocks outputs. The particular blocks can be defined as simple nonlinearities (Fig.5). The Preisach's method use relay type (Fig.5a), Prandtl-Ishlinskii method use backlash or saturated backlash type (Fig.5b).



**Figure 5:** a) Elementary hysteresis type saturated backlash b) Elementary hysteresis type relay.



**Figure 6:** The combined model scheme.

The mathematical relations, which belong to the models mentioned above, are thanks to the use of simple non-linearities, relatively undemanding. The “weight function”  $w_0-w_n$  (Fig.6), can be also implemented to the model mathematical basis. This can make a model more complicated but also more accurate. The “tuning” of the particular system model can be probably done by the using of different “basic blocks” (Fig.6).

#### 4 CONCLUSION

There are still some application such an untraditional actuators SMA based, where we can find a problem of non-linear systems with hysteresis nonlinearities type. There are some existing solutions mentioned this article, which can be used. The Liang-Roger’s have a simple basics and it is easy to make. Their disadvantage is inability to describe the hysteresis with the Non-local memory. To the contrary of it, there are more sophisticated methods based on the “main block” idea (Preisach’s, Prandtl-Ishlinskii’s). These methods are more suitable for the modeling of the hysteresis nonlinearity, but its use can be complicated. The function, used in main blocks, can be replaced by the preferable one, which more precisely represents the particular physical model. Also the different “main block” combination is possible.

#### ACKNOWLEDGEMENT

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