

DESIGN OF ACTUATING ELEMENTS MADE OF SHAPE MEMORY ALLOYS**P. SCHMIDT-MENDE and H.-G. REISS***Krupp Industrietechnik GmbH, Systems engineering division, D-4300 Essen 1, Germany*

Abstract - Actuating elements made of shape memory alloys can be used in many sectors of industry. Examples include aerospace, auto manufacture, household appliances, medical equipment, heating, ventilation and air conditioning, fire protection, electrical equipment and model construction. Requirements to be taken into account for the selection of the suitable alloy, the component design and the effect stability for a particular application are explained.

Design begins with selection of a suitable alloy. Important requirements to be considered include transformation temperature, size of memory effect, hysteresis width, number of cycles, material strength, corrosion resistance and not least price (Fig. 1).

The most important memory alloys used today are nickel-titanium and copper-aluminium-zinc alloys. They offer high work per unit volume, complete work performance in a small temperature range, the capability of performing different types of motion (tension, compression, bending, torsion) and thus wide scope for component design.

Component design is influenced by the forces and paths required, the speed of transformation and the possibility of heating (Fig. 2). Often the design scope is limited by available space. The materials can be formed, machined and welded, resulting in a wide range of possibilities of tailoring the component to the requirements of the application. By using suitable components, e.g. in the form of tension wires, torsion wires or spring elements, specially tailored force effects can be produced, maintained and cancelled out again.

The number of cycles required determines the requirements made on effect stability, which is dependent not only on the alloy but also on its pretreatment, the forces acting and the ambient temperature (Fig. 3).

For application requiring high numbers of cycles, nickel-titanium alloys are most suitable. As a rule mechanical stresses should not exceed 130 N/mm^2 when nickel-titanium components are used. The ambient temperature should not be more than $100 \text{ }^\circ\text{C}$ higher than the A_g -temperature. In addition, a restoring force of around 25 % of the maximum force to be exerted by the nickel-titanium component should be provided.

Provided the component is properly designed, the probability of memory component failure is extremely low. However, this calls for very close cooperation between user and manufacturer.

In selecting a suitable component the method of heat transfer plays an important role (Fig. 4). The speed of shape change is determined by the heating and cooling rate of the component. It is preferable for the memory component to be surrounded by a liquid or gaseous medium, heating of which will cause the component to change shape and do the required work. In such a case the component combines the functions of a sensor and an actuator. Ohmic heat in a current-carrying component can also be used to trigger the memory effect. Possible contact heating methods include resistance heating wires either braided or embedded in silicone rubber, sheathed heating conductors and heating foils. The use of PTC thermistors offers the advantage of temperature limitation and thus protection against overheating.

When estimating and assessing the costs of using memory components it is necessary to consider overall system costs, i.e. the cost of the memory component (as a function of quantity), plus costs for heat, force coupling, housing and assembly. In terms of the memory component alone tension wire offers the best price-performance ratio, followed by torsion wire, compression springs, sheet metal, tubing and special shapes.

For a preliminary estimate of forces, paths, moments and angles the following formulas can be used.

Tension wire

$$\text{Tensile force } F_D = A \cdot \sigma \text{ [N]}$$

$$\text{Path } S = L \cdot \epsilon_M \text{ [mm]}$$

Torsion wire (straight)

$$\text{Moment } M_t = \frac{\pi \cdot d^3 \cdot \tau}{16} \text{ [Nmm]} \quad \text{Torsion angle } \varphi = \frac{2 \cdot L \cdot Y_M}{d} \text{ [degree]}$$

Helical spring

$$\text{Spring force } F_s = \frac{\pi \cdot d^3 \cdot \tau}{8 D_m} \text{ [N]} \quad \text{Spring path } f = \frac{4\pi r_m^2 \cdot i \cdot Y_M}{d} \text{ [mm]}$$

where

- A = cross sectional area of wire [mm²]
- σ = maximum admissible tensile stress ~ 130 N/mm²
- L = length of wire [mm]
- ϵ_M = size of memory effect (in tension)
~ 0.035 (3.5 %) für the repeatable effect
- d = diameter of the wire [mm]
- τ = maximum admissible torsional stress ~ 100 N/mm²
- Y_M = size of memory effect (in torsion)
~ 0.02 (2 %) for the repeatable effect
- D_m = mean turn diameter [mm]
- r_m = mean turn radius [mm]
- i = number of turns

Fig. 5 shows characteristic data for thin wires stressed in tension.

In a simple example Fig. 6 shows different design possibilities for an actuator with force, path and heating given. If there are other givens, e.g. space or transformation speed, the designer will be further limited in his optimization possibilities. The best solution from a technical and economic point of view arises when memory actuator and environment can be matched to one another, i.e. when the memory element is integrated in the product at an early stage of the development process.

FACTORS WITH A BEARING ON CHOICE OF ALLOY

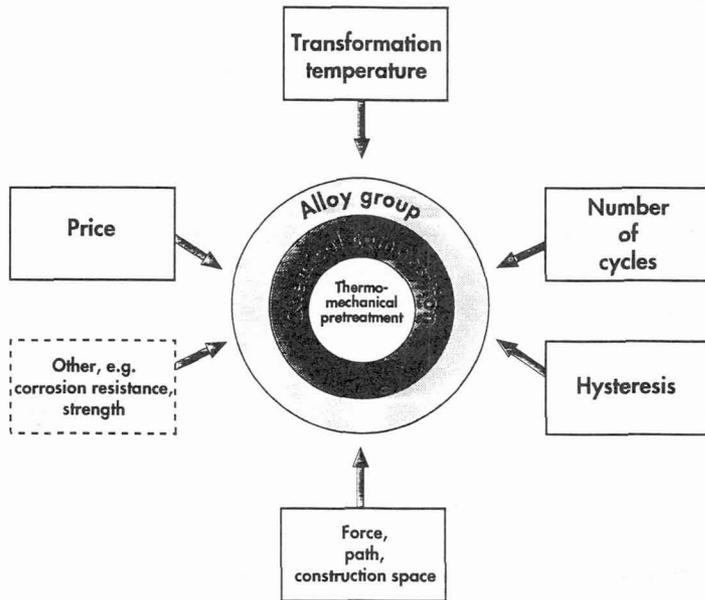


Fig. 1

FACTORS WITH A BEARING ON COMPONENT SHAPE

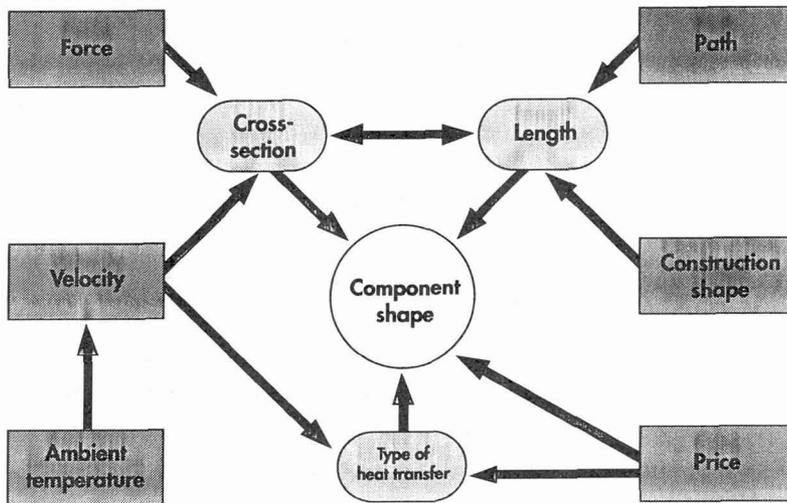


Fig. 2

FACTORS WITH A BEARING ON LONG-TIME STABILITY

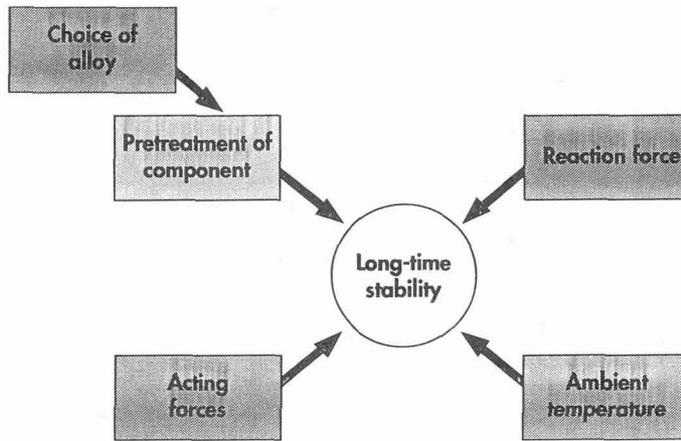


Fig. 3

HEATING POSSIBILITIES FOR VARIOUS CONSTRUCTIONAL SHAPES

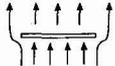
Constructional shape	Surrounding medium (radiation)	Source resistance	Cold conductor (PTC) conductive plastics	Heating wire
Wire, rod (tension, torsion) 				
Spring 				
Sheet and plate 				
Pipe 				
Ring 				
Clasp 				

Fig. 4

Memory - 'tension wire' of NiTiCu
 Heating by ohmic resistance
 Transformation temperature A_S approx. 65 °C

Wire Diameter	0,12 mm	0,20 mm	
Memory effect (shortening) on heating to 95 °C	3.5 %	3.5 %	
Tensile force on heating	1.4 N	3.7 N	
Minimum restoring force on cooling	0.4 N	1.1 N	
Spezific ohmic resistance	at 20 °C at 95 °C	95·10 ⁻⁶ Ω·cm 80·10 ⁻⁶ Ω·cm	95·10 ⁻⁶ Ω·cm 80·10 ⁻⁶ Ω·cm
Ohmic resistance	at 20 °C at 95 °C	84.0 Ω/m 66.5 Ω/m	30.0 Ω/m 23.4 Ω/m
Max. current capacity, long-term	250 mA	470 mA	
Heating voltage per m wire length, long-term	16.6 V	11.0 V	
Heating time with above voltage and current	3 sec.	7 sec.	
cooling time in air at room temperature	4.5 sec.	7 sec.	

Fig. 5

Design example

Given: Actuator for function 'Open - Close'; Force 3.5 N;
 Path: 10 mm; heating: surrounding medium; alloy: NiTi; A_S : ≈ 65 °C

Design	Tension wire I	Tension wire II	Spring
Diameter	0.2 mm	0.4 mm	6 mm
Length	150 mm	40 mm	Block length 10 mm
Restraint	End sleeves	End sleeves	-
Restoring spring	1 N	4 N	1 N
Leverage	-	1:4	-
Space	5·5·160 mm	5·5·50 mm	6·6·10 mm
Response speed	7 s heat 7 s cool	18 s heat 25 s cool	20 s heat 25 s cool
Prices approx. Memory element	DM 2.50	DM 0.80	DM 2.50
Peripheral costs	DM 1.80	DM 3.70	DM 1.50
Total Price	DM 4.30	DM 4.50	DM 4.00

Fig. 6