Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 55
ISSUE 2
December
2012

Shape memory actuators - potentials and specifics of their technical use and electrical activation

J. Strittmatter [a,b], P. Gümpel [a,b], V. Gheorghita [a,c]
[a] HTWG - Hochschule Konstanz University of Applied Sciences, Konstanz, Germany
[b] WITg - Institut für Werkstoffsystemtechnik Thurgau an der Hochschule Konstanz, Tägerwilen, Switzerland
[c] University Transilvania of Braşov, Braşov, Romania
* Corresponding e-mail address: joker1@htwg-konstanz.de

Received 12.10.2012; published in revised form 01.12.2012

Properties

ABSTRACT

Due to a martensitic phase change shape memory alloys can revert to their original shape by heating when they undergo an appropriate treatment. Actuator elements with this shape memory effect can show a significant design change combined with a considerable force. Therefore they can be used to solve many technical tasks in the field of actuating elements and mechatronics. These intelligent materials will play an increasing role in the next years, especially within the automotive technology, energy management, power and mechanical engineering as well as medical technology. In order to use the potential of these materials in an optimal way it is necessary to know and understand the extraordinary and unconventional properties of shape memory alloys.
This paper will present the commonly used systems of shape memory alloys of today including their performance characteristics and will explain the basics of the shape memory effect in a vivid way. A multitude of application possibilities of shape memory actuators will be presented, in particular the research and development projects that have been carried out at the Konstanz University of Applied Sciences during the last years. In this way a solid state heat engine and an intramedullary nail for bone elongation will be presented as well as various adaptive systems for automotive safety and comfort systems, driven by shape memory elements. Regarding the applications in the automotive field a special focus will be given to different electrical activations to enable very fast contraction times of the shape memory components.
Keywords: Shape memory actuators; Shape memory alloys; NiTi; Shape memory applications

Reference to this paper should be given in the following way:
J. Strittmatter, P. Gümpel, V. Gheorghita, Shape memory actuators - potentials and specifics of their technical use and electrical activation, Journal of Achievements in Materials and Manufacturing Engineering 55/2 (2012) 368-377.

1. Introduction

Shape memory alloys represent a very encouraging material to be used as active elements for actuator and/or sensor applications in numerous technical fields. Their advantages when using them as functional materials are undisputable and widely recognized, e.g.: they offer a high working performance per volume, are easily miniaturizable, allow noiseless and vibration-free motions in different movement types and do not show susceptibility to electromagnetic fields. The use of shape memory elements therefor enables the assembly of simple and compact systems that economize weight, volume and costs. But in spite of this huge potential their industrial use is still limited to very few applications in series or volume production.

The goals of this paper are the presentation of the specific properties of NiTi shape memory alloys with its particularities on the one hand and the demonstration of its application potentials on the other hand by showing some own research and development projects.

2. Shape memory alloys

2.1. The martensitic phase change

The shape memory effect is based on a reversible martensitic phase change of the high temperature phase 'austenite' into the low temperature phase 'martensite' and is also referred to as thermal shape memory effect. The superelasticity of shape memory alloys is also based on this reversible martensitic phase change, but in that case the austenite phase is changed into the martensite phase when mechanical stress is applied at constant temperature. This phase change is also referred to as mechanical shape memory effect. So, austenite and martensite are two different phases of crystalline structures, which appear according to the temperature or the external mechanical stress. Both effects are visualized in Fig. 1.

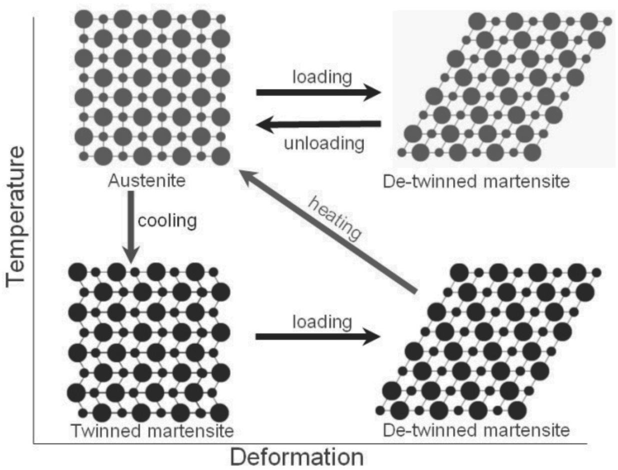

Fig. 1. Thermal and mechanical shape memory effect

According to this reversible martensitic phase change two different kinds of applications can be used: the mechanical shape memory effect at constant temperature is mainly used in medical applications, where, for example, different tools for endoscopic surgery take advantage of the high elongation properties of the superelastic shape memory materials. The thermal shape memory effect can be used in actuator elements, when, for example, a weight or spring deforms a shape memory element at low temperature and the contraction of this element is activated by heating. In that way shape memory materials find application as adjusting, combining, supporting or contacting elements in different technical areas. It is also possible to use them as sensor or damping elements. An extensive overview of different applications can be found in [1].

2.2. General properties of the main alloy systems

In metal science it is known that a lot of alloys exhibit a shape memory effect, e.g. Au-Cd or In-Ti, but in industry only some of them are presently used. Table 1 shows some general properties of these main alloy systems.

Table 1.
Functional properties of the main shape memory alloy systems [2,3]

Properties	NiTi	CuZnAl	CuAlNi	FeNiCoTi	FeMnSi
Data concerning the shape memory effect					
Phasen change temp.(°C) Austenite - Martensite	-50 ...+120	-200 ...+120	-200 ...+170	-200 400	0 ...+300
min. Hysteresis	15	10	15	40	80
Af-Ms (°K)					
max. overheating (°C)	400	200	300	500	450
max. OWSME (%)	8	5	6	1.5	2.1
max. TWSME (%)					
N=10	6	1	1.2	0.5	0.3
N=1000	2	0.8	0.8		
N=100000	0.5	0.5	0.5		
max. number of cycles	10^6	10^4	10^3	10^2	10
max. rev. elongation(%)	8	2	2	1.7	no
max. number of cycles	10^6	10^3	10^3	10^2	Data
Other material proprieties					
Damping capacity (%)	15	30	10	8	1
Biocompatibility	very good	bad	bad	bad	bad
Corosion resistance	very good	low	good	bad	bad

As NiTi shape memory alloys show excellent corrosion resistance and biocompatibility combined with the highest values concerning the shape memory effect they are chosen in the majority of applications. In the following only NiTi materials are considered when shape memory alloys are described. Table 2 gives an overview of some physical properties of NiTi alloys in comparison to stainless steel.

Table 2.
Physical properties of NiTi alloys in compairison to stainless steel [3]

Property	NiTi-nol martensite (M)/ austenite (A)	Stainless Steel
Melting point [°C]	1310	1450
Density [g/cc]	6.5	8
Electrical Resistivity [μΩ/cm]	76(M)/ 82(A)	72
Thermal Expansion [10^{-6}/°C]	6.6(M)/11(A)	17.3
Thermal Conductivity [W/m-°C]	18	16.3
Elastic Modulus [GPa]	40(M)/ 75(A)	193

2.3. Summary of the advantages using NiTi

As already mentioned in the introduction of this paper, shape memory alloys can be used as actuators, sensors, elastic elements, dampers or structural materials. In some cases they even can fulfil several of these functions in one single element. So the advantages using NiTi alloys can be given in the potential of function integration and therefor in the possibility to realize a new system with fewer parts, less weight and less installation size. NiTi elements offer a high work performance per volume and allow noiseless and vibration-free motions in different movement types. They do not show susceptibility to electromagnetic fields, they can be used in cleanrooms and explosion-protected areas and they exhibit good corrosion resistance and resistance against environmental influences like dust or moisture. Finally, they are predestined for applications in the human body not only because of their excellent biocompatibility but also because of their specific properties which can be adjusted very close to the properties of bone material.

3. Particularities of NiTi actuator elements

For a successful use of NiTi actuator elements it has to be taken into account, that a lot of electrical and physical values of these materials in parts dramatically change during the phase change and that the shape memory effect is influenced by a multitude of other parameters. It can be stated that almost all parameters are networked with each other and are influencing each other. This is one of the reasons, why computer based authoring tools are still missing until this day and only little reliable information and data concerning the behaviour of a given NiTi actuator element is available.

3.1. Influences upon the shape memory effect

Fig. 2 gives an overview on the networking of some characteristic parameters concerning the design of an electrical activated shape memory actuator.

While the basic functional properties of the shape memory elements are adjusted by the supplier - mainly through the chemical composition, the degree of cold work and the thermo-mechanical treatment - a lot of the desired functional properties are influenced by the user. As a demonstration that some of the parameters have a strong influence upon other parameters, the following diagram shows the effect of the stress increase upon the phase change temperatures (Fig. 3).

In Fig. 4 it is shown how the parameter stress, contraction (effect amount) and attainable number of cycles are linked together and influencing one another.

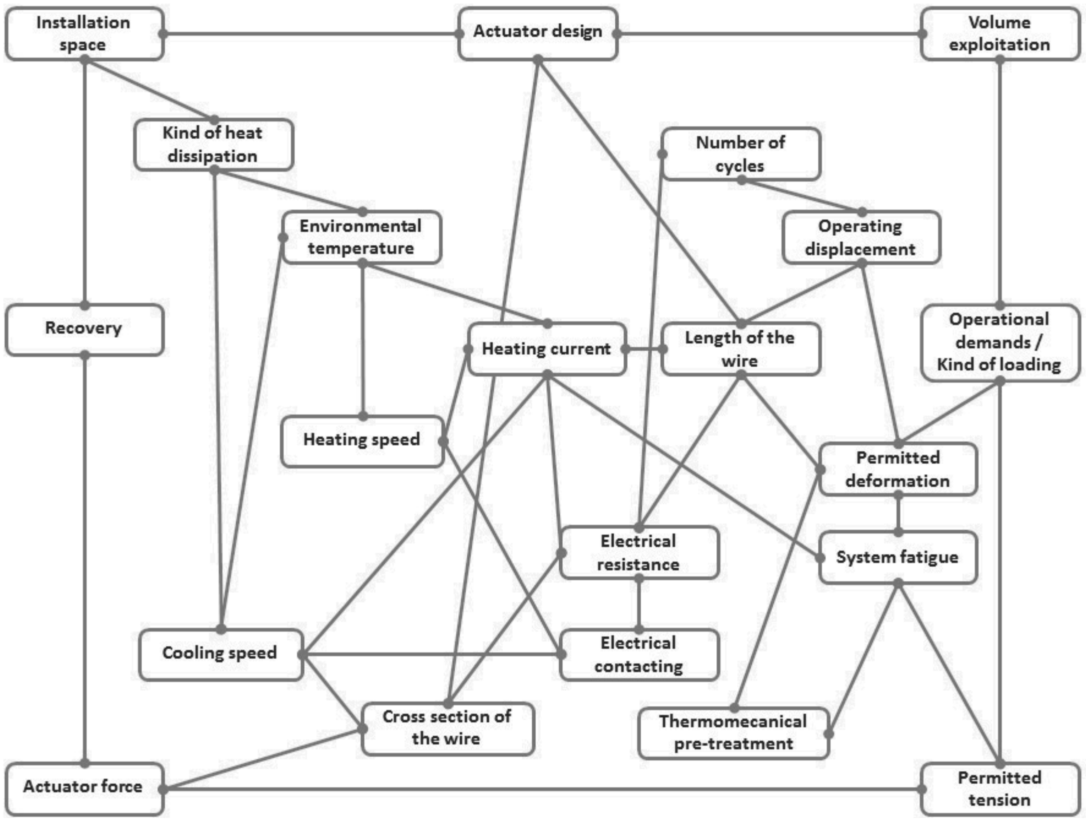

Fig. 2. Parameter networking of an electrical activated shape memory actuator wire [4]

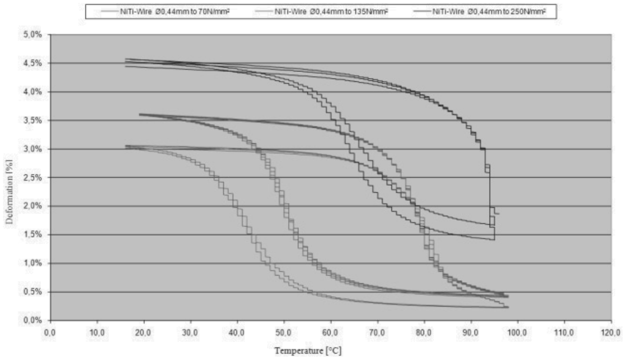

Fig. 3. Stress dependency of the phase change temperatures of a 0.44 mm NiTi wire cycled at different constant stress levels [5]

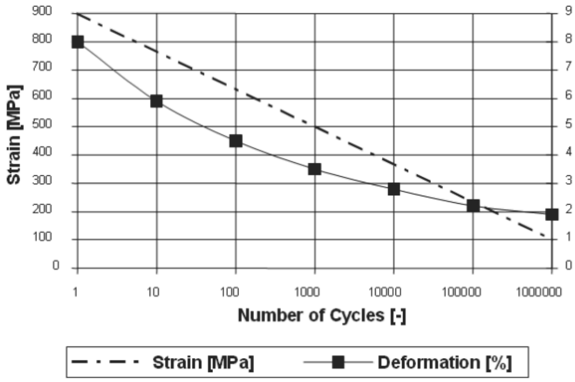

Fig. 4. Dependency of achievable cycle numbers according to applied stress and effect amount [6]

Another important particularity of shape memory elements is their dependency on the elongation speed. Especially when actuator elements are used in combination with a bias element such as weight or spring, the dynamic of the whole actuation process is very important. For thicker actuator geometries the relaxation behaviour of NiTi elements can be of importance, especially when the cycles have long non-operating periods.

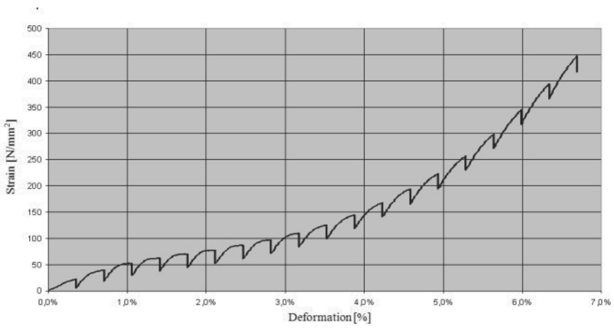

Fig. 5. Stress-strain graph at slow strain rate (0.25 mm/s) and long holding times after every 0.25 mm of a NiTi tube with 3.9 mm outer and 3.1 mm inner diameter with an active length of 71 mm, trained with one way effect [7]

Fig. 5 shows the stress-strain diagram of a NiTi tube at constant temperature of 37°C that was strained during one second with a strain speed of 0.25 mm per second and then stopped at this point during 10 minutes before the next strain step of another second was realized. Considerable stress decay can be observed during the holing times of this relatively thick actuator element. Tests without holding times at this testing speed resulted in a line through the superior values while tests at slower speeds resulted in lines closer to the inferior values. And test data at higher dynamics resulted in graphs at much higher stress levels [8]. According to the application of the actuator element this relaxation behaviour and the dependency of the elongation speed has to be taken into account for a successful operation of the shape memory elements especially for bigger actuator elements that are seldom activated.

3.2. Training

For a successful application of NiTi actuator elements training has an important role. Normally the suppliers of the shape memory material do not inform the user about the details of the thermo mechanical treatment and therefor the parameters during the adjustment of the shape memory effect of the actuator wires are unknown. But only under the same conditions the phase change temperatures and the working capacity would be equal. Against this background it is necessary to train the actuator material under exactly the same stress collective of the desired application to guarantee reproducible results. Corresponding to the authors' experience this training designed to user specifications has to be carried out between 50 and 80 activation cycles.

3.3. Electrical activation

A lot of shape memory actuators are operated with electrical energy. They offer the possibility to heat up the elements in very short times and therefor facilitate short activation times. The drawbacks of these applications often are the long cooling times, especially in devices without external cooling possibilities. But when the actuator task mainly is given in single use activations like in fire protection requirements or automotive crash applications it is even possible to realize activation times far under one second even for shape memory elements with geometries in the range of 0.2 mm [9]. In applications where a lot of energy for the heating of the actuator elements is necessary or this energy has to be economized, respectively, the composition of the electrical circuit can be of great importance. In general it is advantageous to use parallel activation of several NiTi elements if one cannot use high electrical tensions but the electrical source disposes over enough intensity of current. Some detailed guidelines concerning parallel or serial connections can be found in [10].

The most important aspect of any electrical driven actuator consists in the most appropriate way of the electrical activation. On the one hand, the insertion of electrical energy should be fast enough to heat up the shape memory element in the desired activation time, but on the other hand it has to be assured that no overheating occurs in order to avoid possible damages of the actuator function. As the temperature of small dimensioned actuator elements can hardly be measured within short activation times, nowadays the measuring of the electrical resistance of the shape memory element is applied. For NiTi shape memory elements the electrical resistance of the austenite is about 8% higher than the electrical resistance of martensite (see Table 2) and thus represents a good instrument to avoid overheating of the actuator elements. It is also possible to activate defined positions between the operating displacements by controlling the electrical energy submitted to the NiTi element. Such a sensor-actor device using a self-developed microcontroller can be found in [11].

3.4. Aging of the shape memory effect

Especially in single use applications, for example, in fire protection requirements or automotive crash systems possible aging effects and the effect of the first activation has to be taken into account. These special influences upon the shape memory effect due to diffusion processes and segregation of atoms were studied in details and are reported in [12].

4. Application potentials and own projects

4.1. Energy management

One of the most effective mechanisms to converse thermal into mechanical energy is given through a phase change. Water can be mentioned as such an example, where already very small temperature changes cause a very high work performance by means of the volume change during congelation, e.g. used for rock braking. With shape memory alloys it is also possible to do such a work according to a nearly loss-free lattice change during slight temperature changes. Shape memory engines with this function principle are called solid state heat engines and exist till the 70ths of the last century [13]. The tilted disk heat engine of the HTWG Konstanz is such a kind of heat engine using shape memory metals to convert low temperature heat into mechanical energy [14] (Fig. 6).

Its active principle is based on two coupled disks between which pulling wires made of NiTiCu are stretched. They are cooled on one side by air, heated on the other side by hot water. On the cold side the wires are mechanically extended along their circular path due to the tilt of the disk. A subsequent immersion in heated water triggers the phase transformation: the wires attempt to recover their original shorter shape. As the tensile stresses in the wires are considerably higher on the heated side than on the cold one, a rotary movement is generated via the tilted disk and results in tangential forces.

This tilted disk heat engine described here has been further developed and optimized, but even in the last development stage in the year 2003 the highest output of mechanical energy was no more than 63 Watts (achieved with 120 shape memory wires with an active length of 1000 mm, tested in warm water at 85°C and cold air at 22°C) [1]. The efficiency of the whole tilted disk heat engine was too small because the working force results in direction of the rotation axle and according to the design of this engine only some percent of the obtained energy is converted into rotation energy.

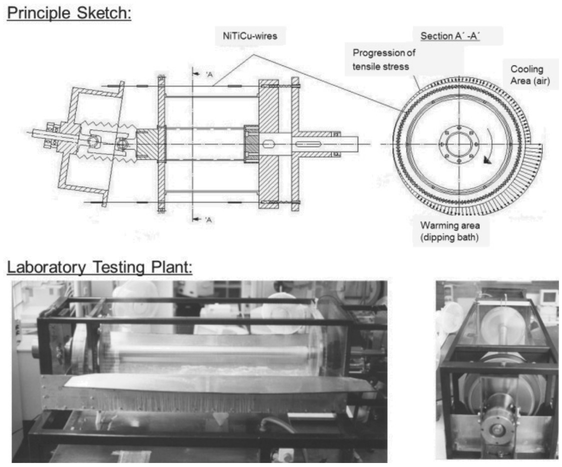

Fig. 6. Principle of the tilted disk heat engine (above) with progression of tensile stress on shape memory wires (above on the right) and two corresponding views of the laboratory testing plant (below)

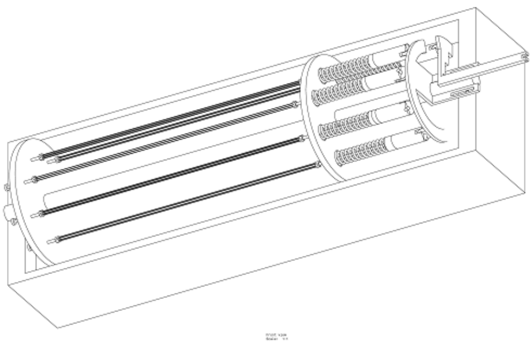

Fig. 7. Possible design of the novel heat engine [15]

In the last years other shape memory heat engines with different function principles were being developed at the HTWG and led 2009 to a new idea based on the described tilted heat engine, see Fig. 7 [15]. The main difference of the new heat engine is based in the function principle that will facilitate the conversion of the complete phase change energy into mechanical energy. One of the approaches consists in a revolving energy storage that could be realized in form of springs that are blocked after the contraction of the shape memory wires in the water bath. In the air the springs will be guided in their compressed form along a ring that enables the springs to release their complete energy just in the moment before the wires will dive again in the warm water bath. For sure, in this case the whole system has to be tracked over an outside force (and not by the wires themselves during their contraction). But with this new idea a considerable increase in the efficiency of the energy conversion is expected that shall facilitate an effective energy recovery of low-temperature waste energy of industrial processes.

4.2. Medical applications

Besides the already mentioned medical application of shape memory elements as endoscopic devices or stents it is also possible to use shape memory elements as thermally driven actuators in active implants. The development of an intramedullary nail for bone extension is such a research project in the medical field. The application of this active implant containing a shape memory element is based on the following medical facts: normally, any tissue reacts to an injury with repair and healing processes through multiplication of cells. If after a transverse osteotomy a strain stimulus is activated, for example by tensile stress, this multiplication of cells and new formation of tissue may be continued for any length of time. In this way even considerable loss of bone caused by fractures or congenital defective positions, e.g. shortening of legs, as well as defective positions on account of infections, e.g. poliomyelitis, may be compensated without bone grafts. The technique of callus distraction by means of fixation or intramedullary nail stimulates the formation of callus in the bone gap. Callus is the repair tissue of the bone generated in the fracture gap in case of bone fracture or osteotomy. The gap to be bridged should not be wider than 1 mm. The process starts with the exudation of callus around the ends of the broken bone. At first, callus is more like a fibrous tissue. Later on it becomes harder due to deposition of calcium and eventually it is converted into true bone. Three weeks after severance the vascular system is formed [16].

External systems are normally used for the extension of bones, the bone fragments being fixed on rings by wires. The decisive disadvantages of those external systems are primarily the considerable risk of infection due to protruding wires, noticeable discomfort for the patient because of the external rings, a coarse cosmetic result because of scarring, as well as rather long hospitalization. Therefore internal bone extension systems are of great interest to orthopedic surgery.

The objective of this project is the development of an active intramedullary nail using shape memory alloys for bone extension and defect bridging according to the Betz and Baumgart method. After the osteotomy the nail is to be inserted into the medullary cavity of a long bone and fixed to the two bone fragments, see Fig. 8. Upon heating by high-frequency energy coupling, the shape memory element is strained and consequently causes an extension of the bone. After insertion of the nail the surgical incision is completely closed, thus the risk of infection is minimized by this application. While the bone fragments move apart - about 1 mm a day - new bone material is formed, which will have the extraordinary mechanical properties of a cylindrical bone later on. The excellent performance of the shape memory elements requiring minimal space allows large forces to be transferred with this new type of shape memory intramedullary nail. Because of the large stroke of the active element, a linear movement is generated with a minimum of moving parts and without any rotation. The simple mechanical principle and the compactness of the shape memory intramedullary nail are of particular advantage when used in the lower leg or in the upper extremities. It has the additional benefits of cost savings and operational reliability. The original and innovative solution may, under certain circumstances, allow the application of this method of bone extension in smaller circular bones, which cannot be extended as yet.

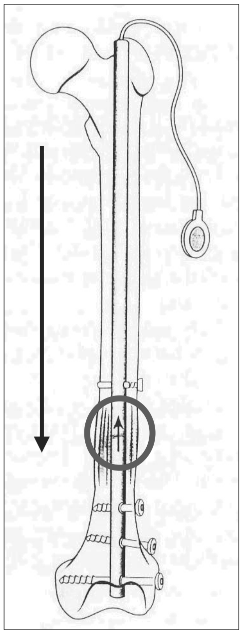

Fig. 8. Implanted intramedullary bone, fracture gap is marked with a red ring; the outer flash shows the direction of the implantation direction, the inner flesh the direction of the progressive feed [17]

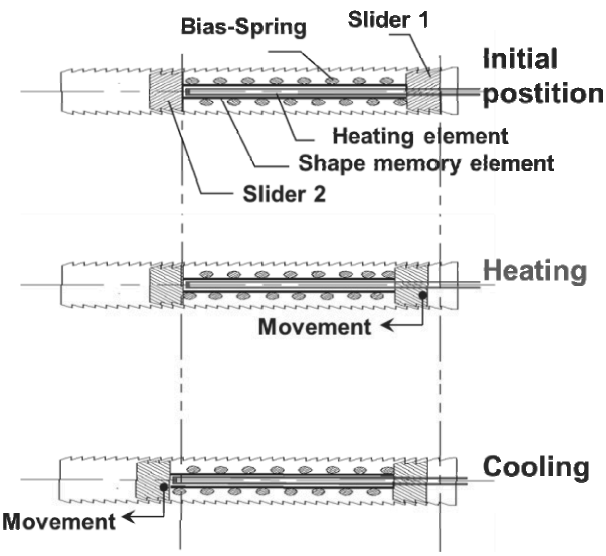

Fig. 9. Driving principle - heating causes contraction of the shape memory element, cooling causes elongation of the device and progressive feed

The functional principle shown in Fig. 9 of the shape memory linear driver is protected by patent [18-20] and has been proven by a first prototype with direct connection to a power supply [21]. A miniature prototype for preclinical functional tests and later animal tests fitted with a receiver and high-frequency coupling is at present being developed in cooperation with a medical company.

4.3. Automotive applications

The automotive field is a very special area concerning the introduction of new products, material or devices on the market. On the one hand most of the car manufacturers and suppliers are looking for new solutions with obvious advantages in comparison to the competitors. And by the majority they want to take part in a new technology when - or even before - it is launched into production. But on the other hand the automotive industry shows a lot of reservations concerning new ideas and innovations because of their large-scale production and the risk of failures in their cars and the associated recalls. So the automotive requirements towards new materials and system solutions are extremely high.

In the last years, the here described situation was one of the main reasons that shape memory actuators have not been introduced into large-scale automobile production, despite of their obvious advantages. Combined with the disadvantages that the phase change temperatures were not as high as required, the quality of the actuator material was not guaranteed in large production scales and the potential material manufacturers could not completely satisfy the needs of the automobile producers, there were developed only a few applications with shape memory alloys that overcome the prototype status.

But especially in the last years the situation has severely changed: today, shape memory producers are existing that are able to produce shape memory actuators at high quality in great quantities, even with material certification and higher phase change temperatures. The awareness level of shape memory technology also increased little by little, especially in the research and development departments of the innovative companies and last but not least a couple of institutes and companies are developing standardized shape memory actuators and are working on simulation tools and calculation programs for shape memory elements. As a logical consequence first applications of shape memory driven devices in larger quantities are reported, for example the self-called "first serial application of shape memory actuators in quantities of several millions per year" of the Actuator Solution company, an international joint venture between SAES Getters (Italy) and Alfmeier Präzision AG (Germany). In this first application shape memory actuator elements are used in 3/3 way valves in pneumatically adjusted seat application for comfort purposes [22].

A lot of other automotive research projects could be reported at this point, if no non-disclosure contracts would exist between the car manufacturer and the research facilities. Therefor the huge potential for applications of shape memory actuators in automotive systems is generally shown in Fig. 10.

At the end of this article the authors like to present a research and development project that is currently in execution in cooperation between the ThyssenKrupp Presta company (Liechtenstein), the HTWG in Konstanz (Germany) and the WITg (Switzerland) [24].

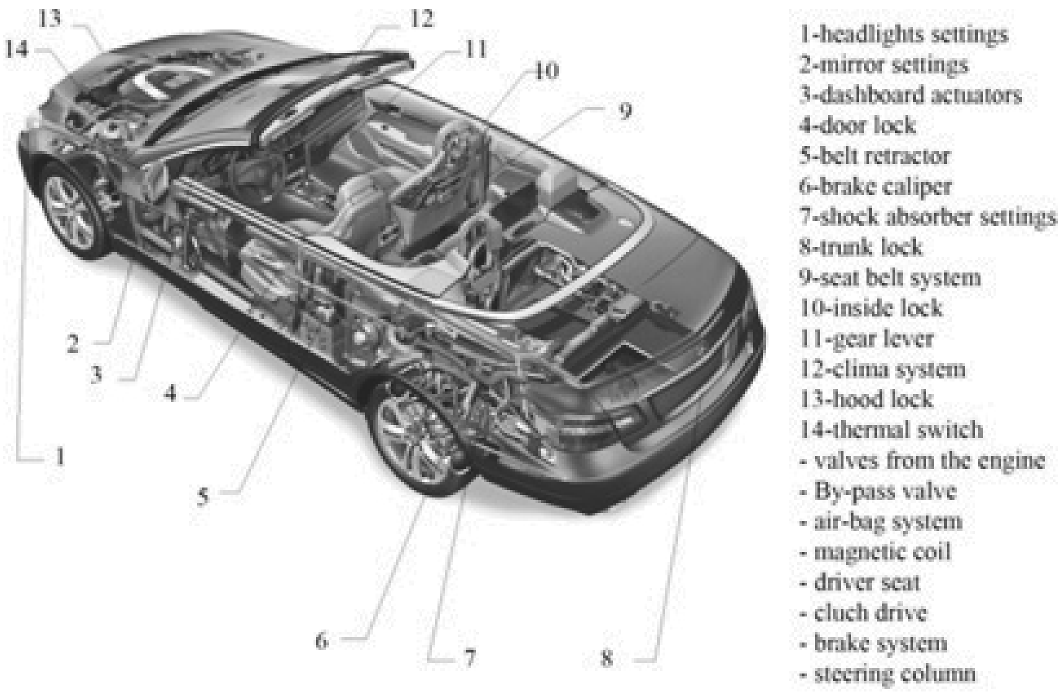

Fig. 10. Possible automotive applications of shape memory driven devices shown upon a model of the Mercedes Benz company [23]

The main function of a steering column is to transfer the torque applied to the steering wheel by the driver via the steering shaft to the steering gear. Another important function is for crash safety. The steering column can collapse and absorb energy during the crash phase. Therefor a crash element as well as a clamping system is required. The clamping system (see number 3 in Fig. 11) is holding the steering wheel for a reach and rake adjustable steering column in position with a clamping force between 3000 to 5000 N - depending on the steering column design respectively system. The clamping system can be opened manually by the lever. But the lever has a big disadvantage because its position could damage the driver's knee during the crash. Currently, there is only one crash force set up due to the manually clamping system. That also can cover more or less only one specific crash situation. All the other crash situations, e.g. at different speeds, different drivers weight, are compromises.

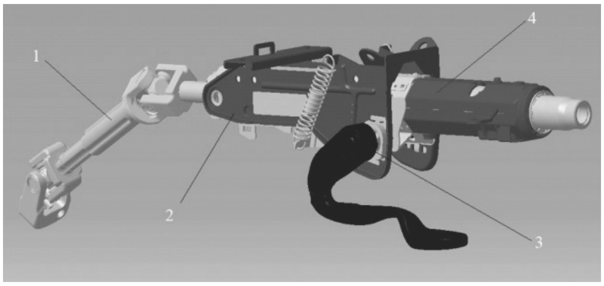

Fig. 11. Steering column with steering shaft: 1-steering shaft, 2-bracked, 3-clamping system, 4-column jacket [25]

This leads now to two important reasons to implement a shape memory driven system into the clamping systems of steering columns: first, the removing of the lever arm can reduce knee accidents and second, an adjustable clamping force can lead to many different crash absorbing forces. The third reason for the development of such a new clamping system can be found in comfort purposes, because it enhances the convenience of the driver.

The task of this application is to open the clamping system in less than 1 s. Actuator wires are used which can react in 1 second at 3000 to 5000 N. In order to guarantee 5000 cycles the chosen NiTi wires are loaded with 400 N/mm^2. The NiTi wires with a diameter of 0.40 mm show an A_S-temperature higher than 80°C.

Fig. 12 shows the design of one of the first approaches, the drum prototype. Between the drums the disc spring is contracted at 5000 N. The two drums are made from a special isolating material. Shape memory actuator wires are attached in 100 parallel loops between the drums. By applying the system with electrical energy (e.g.: by pushing a button from the steering wheel), the shape memory actuator wires (1) are contracted and the drum (3) will be pulled towards drum (2) and thereby the spring will be compressed.

The bracket part (blue one) will be free and the driver can adjust the position of the steering wheel (steering column). During the whole adjusting process the energy for the shape memory wires is controlled; otherwise the wires would be overheated. In order to contract within one second the NiTi wires need a lot of energy. When the electrical source is off the actuator wires will cool down, change into its martensitic phase and reset the whole system into the first position, because the disc spring will push drum (3) and also part of the bracket. In this case the steering column will be blocked in the desired position. So the clamping system is opened (or activated) with shape memory actuators activated by electrical energy and closed via disc springs when the stored mechanical energy is released.

The last prototype test was made with 16 NiTi wires, where each wire developed a pulling force higher than 50 N. In this set up the disc springs were pretensioned at 800 N. After electrical activation the final force was raised up to 1200 N. The tests are made to 16 V electrical tension and 56 A current intensity. To get this mechanical output (force, displacement vs. time) at least 3.5 A/wire is necessary. So, for the required 100 wires in this prototype design about 350 A would be necessary. Till this day the vehicle voltages of the cars are limited and the drum prototype could not be assembled in this design. Therefor in the next approach a reduction of the electrical energy was pursued.

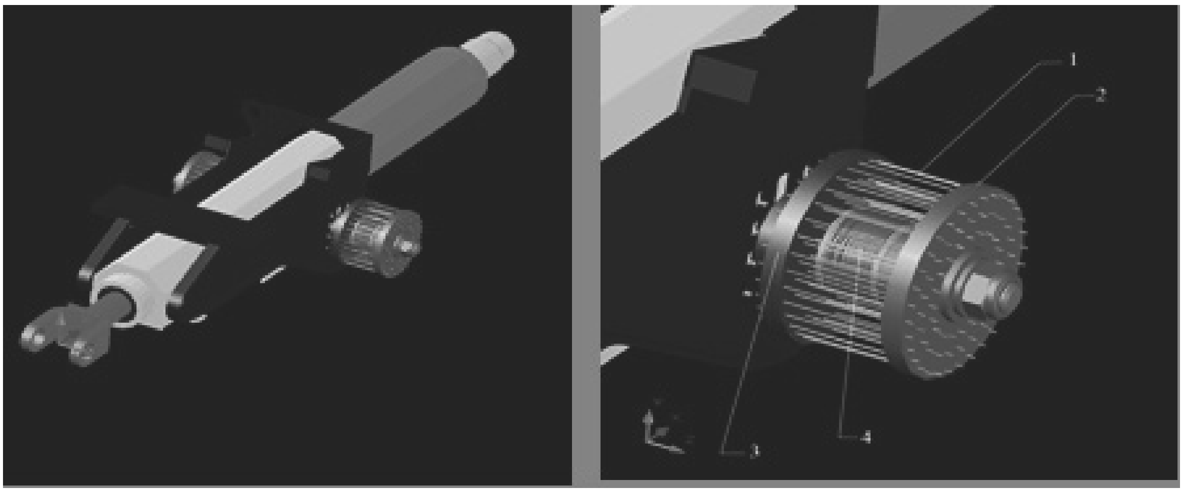

Fig. 12. Drum prototype: 1-shape memory wires, 2, 3-drum plates, 4-disc springs

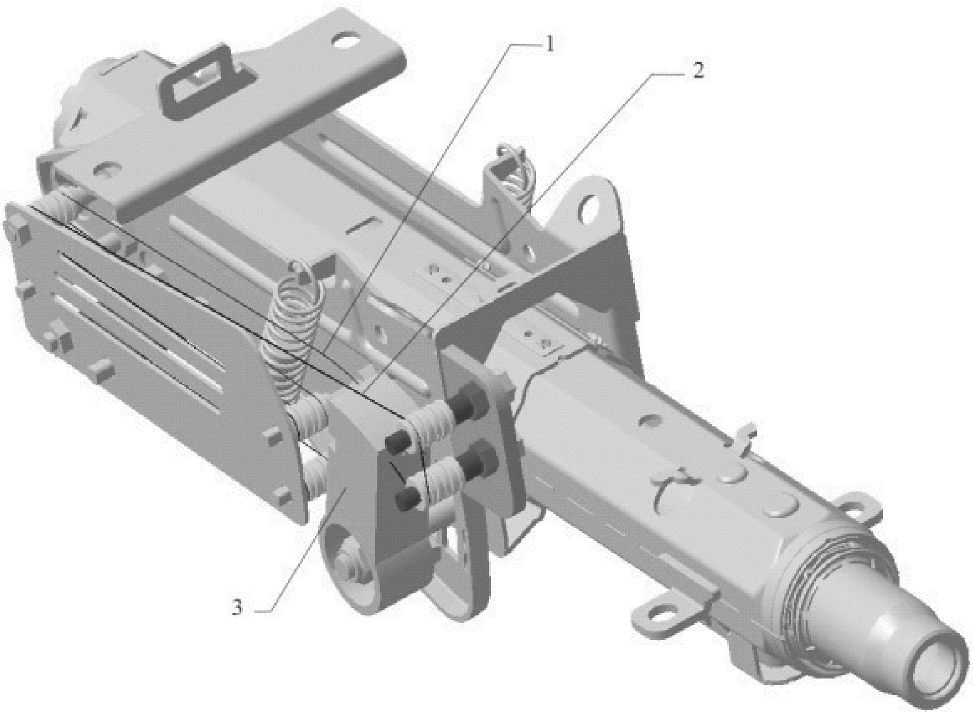

Fig. 13. Lateral wire actuator: 1-pulling shape memory wire (open), 2-pulling shape memory wire (close), 3-lever arm of the clamping system

In that so-called lateral wire actuator prototype (Fig. 13) the releasing arm of the steering column is slightly modified and shape memory actuators wires are fixed directly to the arm of the clamping system. Like in the original steering column system with the manual lever arm the pressing force of 5000 N is achieved over the bracket part when the lever is moved. In this case NiTi wires are used to open and also to close the clamping system. Electrical energy is used instead of manual energy. The system is more comfortable by pressing a button and then adjusting the steering column. When the source is "on" because of the activation of the button the wire (1 - red one) in Fig. 13 pulls the arm until the clamping system will be opened. And when the button is released ("off") a microcontroller will send electrical energy to the other wire (2 - black one, in Fig. 13) in order to pull the arm into the other direction. In that way the clamping system is closed again. Electrical energy is used to open and close the clamping system.

For the closing function only a torque of 8 Nm is necessary over an angle of 30 degree. Therefor NiTi alloys with a diameter of 0.44 mm can be used with an active length of 650 mm for these prototypes. Because of this length of the actuator wires they are conducted over different deflection pulleys on the lateral side of the bracket. In order to contract within one second the wire needs a considerable amount of energy. Last tests are made with 0.5 mm NiTi wires; two wires for opening and four wires for closing the system. In this configuration an electrical current of only 3.5 A is necessary for each wire.

Even though a lot of development work has to be done in this project it could already be demonstrated, that shape memory actuator wires can do a good job in this new automotive system, that not only will have its benefits for comfort reasons, but also for new functions in safety systems.

5. Conclusions

Shape memory alloys represent a very encouraging material to be used as active elements for actuator and/or sensor applications in numerous technical fields. Their advantages when using them as functional materials are undisputable and widely recognized, e.g.: they offer a high working performance per volume, are easily miniaturizable, allow noiseless and vibration-free motions in different movement types and do not show susceptibility to electromagnetic fields. The use of shape memory elements therefor enables the assembly of simple and compact systems that economize weight, volume and costs. But in spite of this huge potential their industrial use is still limited to very few applications in series or volume production.

This paper presents some specific properties of shape memory alloys with its particularities and shows its application potentials by means of the description of own research and development projects.

References

[1] J. Strittmatter, Formgedächtnis-legierungen und ihre Einsatzmöglichkeiten in der Praxis - Allgemeine Anwendungsbeispiele in der Technik und ausgewählte

Forschungsprojekte der FH-Konstanz, P. Gümpel (Ed.), Formgedächtnislegierungen - Einsatzmöglich-keiten in Maschinenbau, Medizintechnik und Aktuatorik, expert-verlag Renningen, Kontakt&Studium, 2004 (in German).
[2] D. Stöckel, Formgedächtnis-legierungen, D. Stöckel (Ed.), E. Hornbogen, Legierungen mit Formgedächtnis, expert-verlag, Ehningen, 1988 (in German).
[3] M. Mertmann, The physical properties of nitinol, http://www.memry.com/ nitinol-iq/ nitinol-fundamentals/physical-properties, 31.07.2012.
[4] S. Langbein, Potential von standardisierten Formgedächtniskomponenten, Expertenforum des FGL-Netzwerks, Einblicke in die Formgedächtnistechnologie, Dresden, 2012 (in German).
[5] P. Gümpel, J. Strittmatter, A. Walter, Prüfanlage für Bauelemente aus Formgedächtnislegierungen (FGL), Proceedings of the „DGM-Tagung Werkstoffprüfung“, Neu-Ulm, 2007, 305-310 (in German).
[6] Memry Corporation, http://www.memry.com/ nitinol-iq/nitinol-fundamentals, 31.07.2012.
[7] T. Boes, P. Gümpel, J. Strittmatter, A. Walter, Entwicklung einer Prüfanlage zur Prüfung von Bauelementen aus Formgedächtnismetallen (FGL), Hochschule Konstanz Technik Wirtschaft und Gestaltung Forum (2006/2007) 24-31 (in German).
[8] S. Gläser, P. Gümpel, H. Kilpert, J. Strittmatter, Investigation of the mechanism of the stress-induced martensitic phase transformation of superelastic shape memory alloys, Proceedings of the International Conference on “Shape Memory and Superelastic Technologies” SMST’2004, Baden-Baden, 2004, American Society for Metals ASM International, Materials Park, Ohio, 2006, 57-68.
[9] J. Strittmatter, P. Gümpel, Investigation of long-time aged ni-ti shape memory actuator wires for future use in automotive safety systems, Proceedings of the 12th International Conference “New Actuators and Drive Systems” ACTUATOR’2010, Bremen, 2010, 921-924.
[10] J. Strittmatter, V. Gheorghita, P. Guempel, Shape memory wires with activation times less than one second, Proceedings of the XXVI International Scientific Conference “microCAD”, University of Miskolc, Hungary, 2012.
[11] V. Gheorghita, P. Guempel, A.E. Ceron, J. Strittmatter, Controlling the stroke of shape memory actuator wires, B. Katalinic (Ed.), Danube Adria Association For Automation & Manufacturing International Scientific Book, Vienna, 2011, 563-572.
[12] J. Strittmatter, P. Gümpel, Long-time stability of Ni-Ti-shape memory alloys for automotive safety systems, Journal of Materials Engineering and Performance 20/4 (2011) 506-510.
[13] T. Kotitschke, Experimentelle Untersuchung eines NiTiCu-Drahtes zur thermodynamischen Betrachtung einer Wärmekraftmaschine mit Formgedächtnis-metallen, Diploma thesis at the Hochschule für Technik, Wirtschaft und Gestaltung, 1998 (in German).
[14] U. Berg, Weiterentwicklung des Schrägscheiben-Formgedächtnismotors, Diploma thesis at the Hochschule für Technik, Wirtschaft und Gestaltung, 1999 (in German).
[15] P. Gümpel, J. Strittmatter, A. Walcher, Wärmekraftmaschine und System, Patent application 10 2009 040 523.2, 2009 (in German).
[16] A. Rüter, D. Kohn, J. Corell, R. Brutscher, Kallusdistraktion, Urban und Schwarzenberg-Verlag, 1998 (in German).
[17] A. Betz, Voll implantierbarer aktiver Marknagel, A. Rüter (Ed.) Kallusdistraktion, Urban und Schwarzenberg-Verlag, 1998 (in German).
[18] P. Gümpel, H. Hütterer, H. Kühn, J. Strittmattter, Antriebseinrichtung mit einem aus einer Formgedächtnislegierung geformten Element sowie deren Verwendung, patent application DE 198 10 640 C 2, 2000 (in German).
[19] T. Boes, P. Gümpel, J. Strittmatter, Implantatvorrichtung zur Gewebe- und/oder Knochendistraktion sowie Verfahren zum Betreiben einer solchen, patent application 10 2007 036 359.3, 2007 (in German).
[20] P. Gümpel, R. Storz-Irion, J. Strittmatter, Marknagel zur Knochenverlängerung mit intelligenter Sensorik, patent application 10 2008 035 517.8, 2008 (in German).
[21] R. Storz-Irion, P. Gümpel, J. Strittmatter, I. Irion, J. Keller, F. Schiedel, Aktives Marknagelimplantat mit intelligenter Sensorik zur Knochendistraktion, Proceedings of the Internationales Forum Mechatronik ifm, Stuttgart, Tagungsband, 2008, 116-125 (in German).
[22] K. Pagel, Einsatz von Formgedächtnislegierungen im Automobil, Proceedings of the Expertenforum des FGL-Netzwerks, Einblicke in die Formgedächtnistechnologie, Dresden, 2012 (in German).
[23] http://mercedes-benz-blog.blogspot.de/2010/03/ new-mercedes-benz-e-class-cabriolet_ 6980.html, accessed on 31.07.2012.
[24] V. Gheorghita, P. Gümpel, T. Heitz, M. Senn, J. Strittmatter, Shape memory alloys open new possibilities in automotive safety systems, Proceedings of the 13th “European Automotive Congress” EAEC’2011, Valencia, 2011.
[25] T. Heitz, Analysis of using CFK-Material for steering column components in passenger vehicles, Proceedings of Conferences on “Automotive and Transport Engineering” CONAT’2010, Braşov, 2010, 245-253.