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SYSTEMATIZATION OF ACTIVE BENDING SHAPE MEMORY ALLOY ACTUATORS

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Abstract: *In this paper is presented a systematization of the active bending shape memory alloy actuators by complexity. Each example is treated according to the specific movement characteristics where it can be used, from the fundamental execution element to more complex systems that use various connections of active elements. Present technology is in a search for new solutions for miniature systems improvement. Because of their properties, shape memory alloys are an answer for the development and redesign of the mechanical systems that are constraint by their dimensional parameters.*

Key words: *shape memory alloy, actuators, active bending, systematization.*

1. INTRODUCTION

Shape memory alloys (SMA) are smart materials that can be "educated" to memorize a defined shape through thermomechanical processes. This entire procedure takes place under certain temperature conditions by following reversible martensite-austenite transformations, [1]. The "shape memory effect" (SME) gives these SMART materials a set of special properties and applications such as: superelasticity, returning to the memorized shape (under a constraint or without any load) and the capacity of producing mechanical work.

An SMA actuator (SMAA) is an element of execution that consists of one or more SMA active elements, an associated mechanical structure and the control, cooling and powering systems, as seen in fig.1.

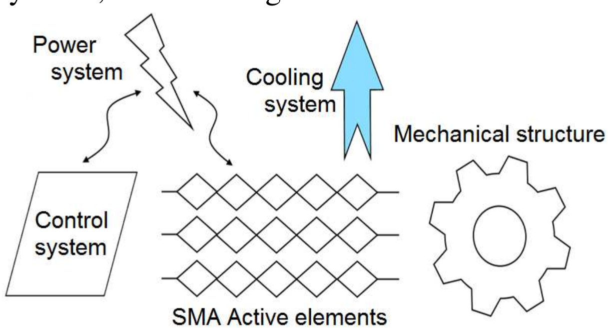

Fig. 1. The SMAA components.

For an execution element at activation the exerted force is a few times higher than the force necessary to deform the element at normal temperature. The source of heating for the SMA can be provided by the surrounding environment (for sensors) or electrically, by passing a current through SMA. In combination with an efficient cooling system the electrical heating method has the advantage of offering a high frequency of operation and maintains the minimal dimensions feature of the execution part of the entire structure.

Active bending represents the capacity of a structure, determined by the action of one or more execution elements, to have controlled bending deformations. This concept has various applications such as: biomedical engineering (cardiovascular devices, endoscopes etc.), robotics (grippers, underwater and pipes walking robots etc.), in sensors, industrial applications, military and more, [5].

In paper [2] an actuator composed by a flexible parallelepiped in which are incorporated four SMA wires is presented. Each wire goes diagonally from a corner to another under a small eccentricity angle. The structure can bend in two directions by activating the wires A-B or C-D. To produce a torsion, the pairs A-D or B-C are activated simultaneously. The system is capable to bend itself a range 160° both in bending and torsion mode. The research is further developed in work [4].

An example of a complex combination of active elements are presented in paper [6]. In figure 2 is illustrated a flexible articulated arm formed by a series of modules with legs with SMA wires, that act as a muscle. Each module presents three principal motion: vertical translations, inclination and deviation angle. Through the entire series of modules, the arm is able to perform elaborated motions by using the two SMA wires in each leg that act against each other.

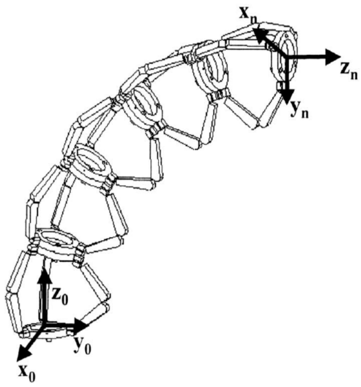

Fig. 2. Flexible arm based on SMA wires, [6].

In paper [6] are presented two types of endoscopes that have a flexible end of a certain length. The first one uses four SMA wires that depending on their variation in length at activation determine the controlled bending of the flexible structure. The second one uses SMA plate springs linked between articulations that can be activated independently. The series of modules composed by the SMA springs and articulation allow the endoscope to follow more elaborated movement patterns and offer them a better dexterity.

2. SYSTEMATIZATION OF ACTIVE BENDING SMAA

In this paper is presented a systematization of the active elements and structures that could be generally used in SMAA with active bending capabilities. The classification is made by complexity, from simple to more elaborated systems.

The fundamental active element is a SMA wire or lamella (section S and length L), represented in figure 3, educated as follows: from the low temperature phase M_f (only martensitic crystalline structure), the element (1) reaches, in this case, the maximum bending when it is heated over the transformation temperature from martensite to austenite, A_f.

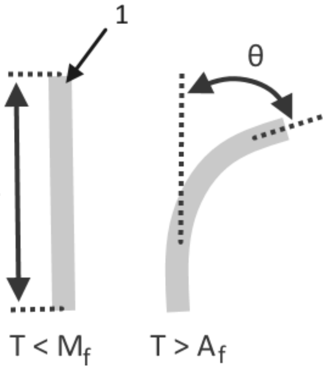

Fig. 3. Fundamental wire or lamella SMA active element.

After the transformation the free end of the SMA moved with angle θ. Another very common case of deformation, when heating the element to the educated shape, is a shortening in length (mostly used at SMA wires, springs).

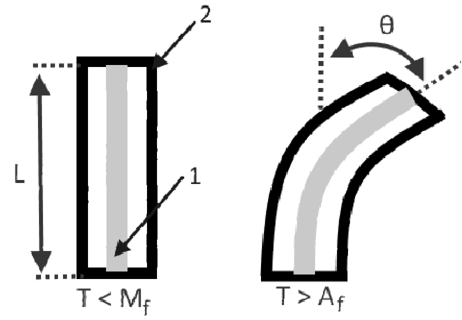

Fig. 4. SMA active element enclosed in a compliant structure.

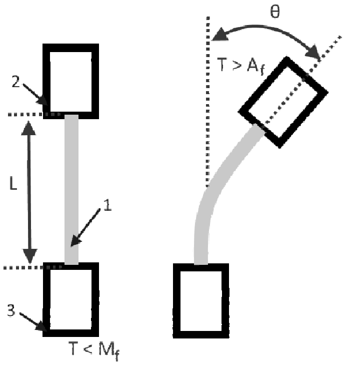

Fig. 5. SMA active element connected to two mechanical structures.

The wire/lamella (1) can be enclosed in a compliant structure (2), as in figure 4, or it can be connected between to solid structures (2 and 3) that amplify the free end motion and use the work developed by the SMA's motion, as in figure 5. The compliant structure acts on the active element with an elastic force that returns the active element in the initial position after lowering the temperature.

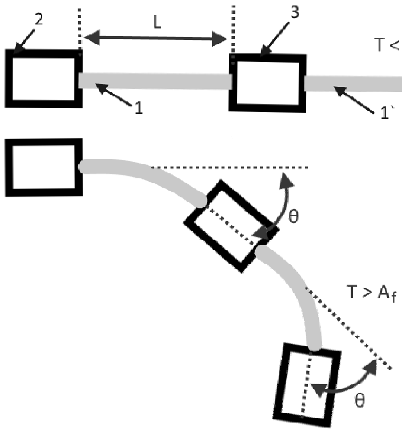

Fig. 6. Two SMA elements connected in series with a movement of 2θ

In the case where two (or more) active elements are connected in series the total movement is multiplied by the number of elements. In figure 6 is presented a series of two elements connected to three structures (2, 3 and 4). In the austenite phase, when heated, the free structure rotates around the fixed base (2), from the initial horizontal position, with a doubled angle θ.

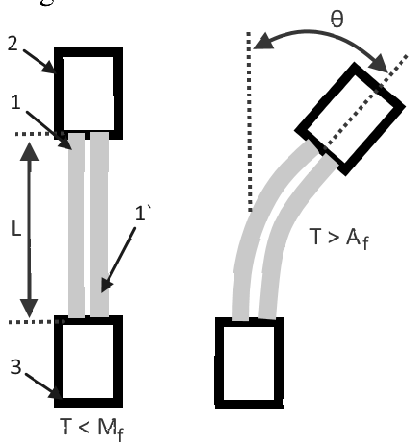

Fig. 7. Two SMA elements connected in parallel

If the active elements are in parallel the movement is the same, but the force developed by the SMA is multiplied by the number of used elements. In figure 7, the parallel connection moves the free end with the same angle θ. The force/torque at activation is doubled compared to a single SMA active element system. Thus, if the system evolves under a constraint it will develop a double work.

By activating independently the active elements in series and parallel connections, the motion becomes more complex and reaches a higher number of degrees of freedom.

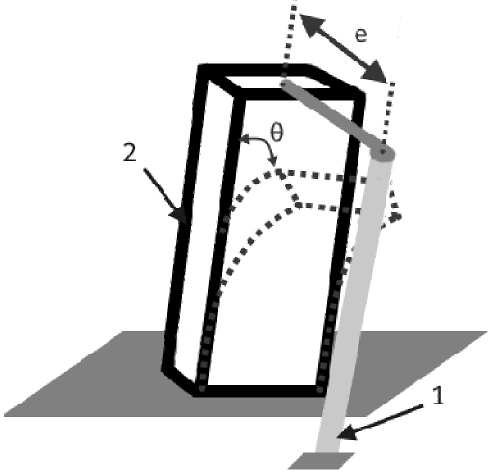

Fig. 8. SMA element connected with an eccentricity to a flexible structure

If the SMA active element is connected in parallel (by an eccentricity e) with a compliant structure, the antagonist force necessary to bring the active element back to the initial shape is developed by the elastic forces of the structure. In figure 8 is presented a structure (2) that bends with angle θ when the element 1 is activated and shortens with a portion of its length. The system may have various construction possibilities, depending on the expected bending effect. The active element could have different shapes: wire, spring, lamella, torus, helix or other profile.

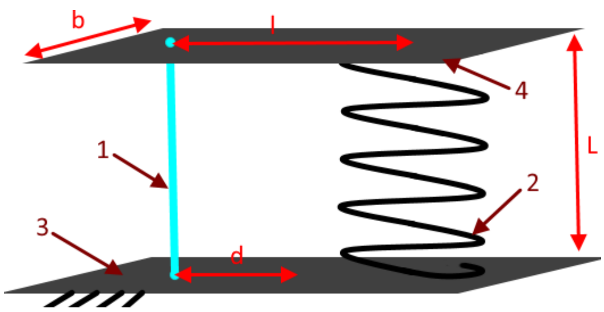

Fig. 9. SMAA system where the antagonist element is played by a spring

In figure 9 is presented a SMAA system where the role of the antagonist element is played by a spring (2), connected in parallel with the active element (1). When activated the SMA wire shortens and the planes 3 and 4 approach. After cooling the wire is brought to the initial length by the spring.

The SMAA systems have various mechanical structures according to the requirements of each problem it solves. In figure 10 is presented a more complex SMAA system where a set of active elements connected in parallel with various inclinations (1c, 1d, 1e) are in series with another module with SMA vertical wires (1, 1a, 1b). The planes (4, 5, 6) approach in various positions and inclinations when the active elements are activated (independently or simultaneously) and shorten with a certain length. The tension that appears in the springs are the antagonist forces that elongates each of the SMA elements to the initial length.

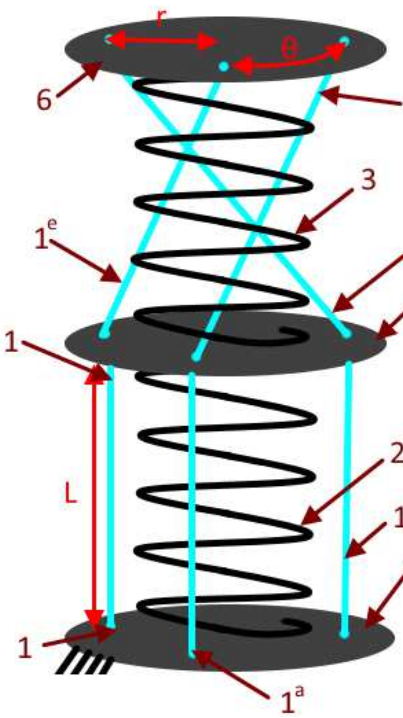

Fig. 10. Complex SMAA system with active wires that can action independently or simultaneously

In figure 11 the structures 3 and 4 are linked together with the antagonist spring 2. Between the two structures are connected the active elements 1, 1`, 1`` and 1```, at various angles θ and lengths L. When one active element passed by a current I it shortens with Δl and develops a force along its length that determines a certain inclination of the plane 4. In this system by activating independently at different contractions each of the SMA wires participates at the broad range of movements of the mobile structure 4.

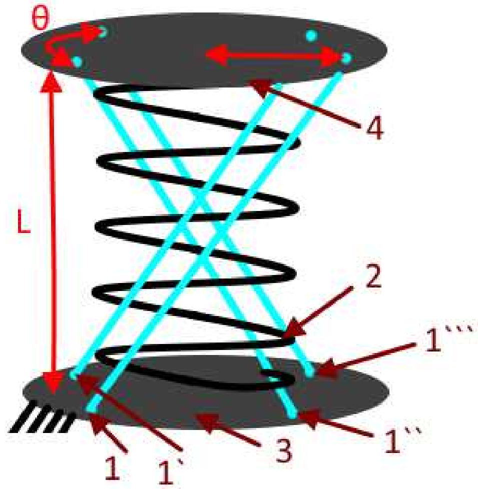

Fig. 11. Complex SMAA system with active wires that can be acted independently or simultaneosly

The associated mechanical structure is an essential part of the SMA actuator. It sustains the active elements in the system and transforms the energy of the SME in output work. Also, the associated mechanical structure protects the SMA from overheating/overload and excessive deformations. In practical experiences the cooling time limits the frequency of activations of the SMA element. Thus, the structure must provide a capable cooling environment. If the structure does not provide strong enough antagonist forces for the relaxation tension of the SMA, there can be added more antagonist factors such as: magnets, weights, springs, hydraulics and other.

To reduce the dimensions of a SMAA and for an optimal miniaturization the active element of the complex SMA wires system can be partially or fully enclosed in a compliant structure. In figure 12 is illustrated the case where an SMAA uses a compliant tube incorporated with one wire (a) and three wires at 120° each (b). In case a, the tube can bend in a single direction to a limit angle θ. In case b, by changing the shortening at different currents in each of the wires independently the tube bends in any vertical plane that contains the axis of the tube to the limit angle θ. The case with two wires antagonistically disposed is also possible.

In the case of using four wires (fig. 13), each at a distance d from the axis of the tube, in the wall of the tube, the system can produce the same bending movement, previously described. In the four wires case or a larger number n, the difference is that the system can be controlled more accurately and the frequency of the executions increases. Moreover, the total maximum force that can be developed increases and the number of independent directions (in which one wire bends the tube) is higher. Thus, the errors of a mathematic controlling system reduce.

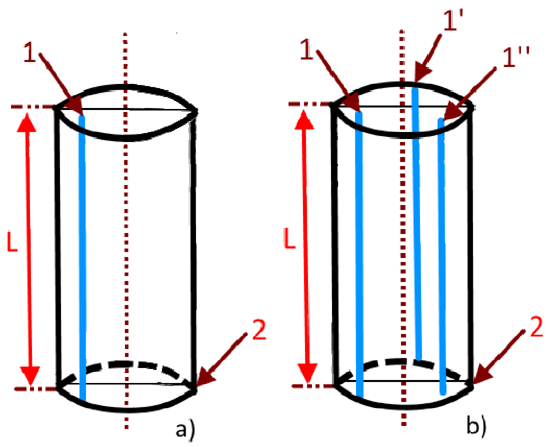

Fig. 12. Compliant tubes with SMA wires: a) one wire; b) three wires at 120° angles.

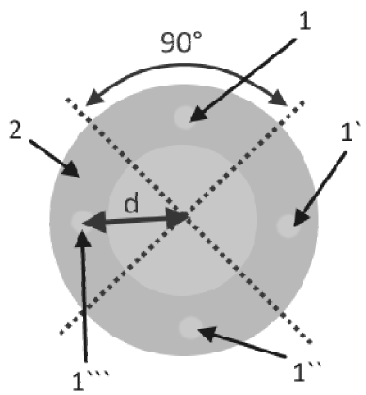

Fig. 13. Compliant SMAA with four wires.

Figure 14 shows the calculus scheme for the general case of a compliant tubular structure with an enclosed SMAA active element (for example, a SMAA wire) based on which, a mathematical model will be developed in our future work.

The advantages of the SMAA consist from simple construction, high ration work/mass, reduced weight and volume to biocompatibility, mechanical and corrosive resistance and no need of lubrication. However, the drawbacks that limit the applications spectrum come from the low frequency (slow cooling of the SMA), the influence of the environment temperature, relatively high activation currents, complexity of the accurate control and the need of thermal resistant materials that provide insulation, [1].

The shapes of the SMAA from this point evolve to varied examples according to their elaborated applications. SMA construction spectrum goes from large combinations of simple elements to membranes, special shaped SMA and soft or composite SMA.

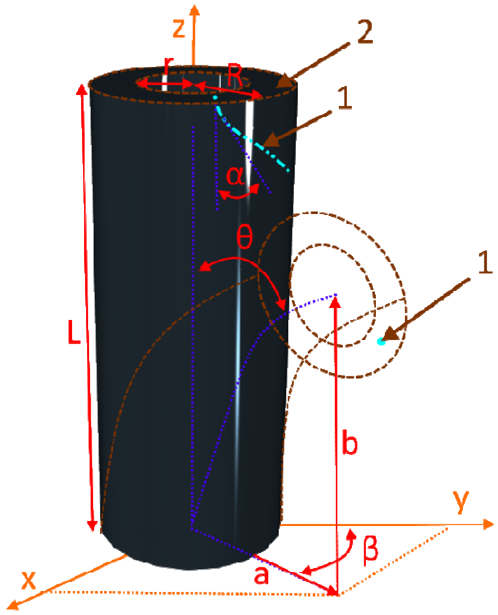

Fig. 14. Example of an active bending structure.

4. CONCLUSIONS

The systematization of the active bending SMA actuators classifies a small part of the movements that the SMA actuators are able to develop. An element of execution based on SMA has the capacity to produce a considerable work, considering its dimensions. SMAA present a high flexibility in the range of movements that they can develop in a suitable mechanism. Modern technologies search for new ways of miniaturizing the mechanical systems in order to increase their efficiency. In this search for increasing the dexterity of actuators at small scales the shape memory alloys actuators are an important alternative, having a bright future in the upcoming technological developments.

In future work, we will consider developing a tube shaped SMAA with one wire, as in figure 12, and study its motion. Furthermore, as we obtain more results from the experiments we plan to increase the number of wires and analyse the range of deformations (linear, bending, torsion). From the results gathered we intend to propose and test a series of applications of the SMAA prototype.

5. ACKNOWLEDGEMENT

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SISTEMATIZAREA ACTUATORILOR PE BAZĂ DE ALIAJE CU MEMORIA FORMEI CU CAPACITATE DE ÎNCOVOIERE ACTIVĂ

În această lucrare este prezentată o sistematizare a actuatorilor de tip "active bending" pe bază de aliaje cu memoria formei în funcție de natura elementelor active și de complexitate. Fiecare exemplu este tratat după caracteristicile structurale specifice, având în comun mișcarea de încovoiere controlată, plecând de la elementul fundamental de execuție (cu efect de memorare de încovoiere), până la sistemele mai complexe ce utilizează diverse conexiuni de elemente active. Aceste cercetări se încadrează în eforturile actuale de a propune noi soluții privind acționarea sistemelor miniaturale. Datorită proprietăților lor, aliajele cu memoria formei reprezintă opțiuni de îmbunătățire și reproiectare a sistemelor mecanice, ce sunt constrânse în funcționarea lor de parametri dimensionali.

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