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Development of standardised and integrated shape memory components in "one-module"-design

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Abstract. Actuator systems based on shape memory alloys are nowadays mainly characterized by the alignment to specific applications. However, there is a considerable interest in shape memory actuator systems with complex and variable functions. One way to represent the realisation of such a system is a modular system. Modular systems do not only enable the adoption of the solutions for other applications, but also lead to a reduction of the diversity of variants and to a reduction of the development risk. An unsolved problem of modular systems is the increasing system complexity. Responsible are additional functions, like the mechanical and electronic coupling of the modules. Beyond the conventional form of a modular system there is the possibility to create a variable shape memory actuator system only by using the material configuration of one single SMA-component ("one module" modular system). Apart from the conventional point of view there is a new perspective with extreme integral and standardised set up. Therefore, the SMA-component can be programmed functionally for the scheduled utilisation. The purpose of the present study is to show options and the creation of such a universal SMA-component. Thus, an object of investigation is the analysis of designs, properties and capabilities. Structuring modular systems differently and re-arranging the production process represents a new way of thinking in the field of mechanical engineering.

1. Introduction

For the functional programming it is important that the SMA-structures are locally heated or heat treated in order to perform superior movements. To use the two-way effect you also need to provide a resetting. The movements must be reproducible and the actuator must perform the required number of cycles. Most of the SMA-structures can be partially activated or locally configured. The so-called smart SMA-structures based on partial activation or local configuration can contain resetting elements or required hinges if combined clever. Direction changes, increase of forces or adjustment travels of the real SMA-element are also possible. The technical feasibility of such components are demonstrated in [1,2,3]. The features of partial activation or local configuration are summed up in ***Table 1.***

Table 1. Features of partial activation and local configuration.

	partial activation	**local-configuration**
Features and possibilities	• Temporary effect generation • Locally limited activation of regions • Gradual movement possible • Realisation of actuator and reset elements in integral design • Possible variation of damping behaviour and elastic characteristics	• Permanent effect generation by heat-treatment • Activation of the entire system • Gradual movement possible • Realisation of actuator and reset elements in integral design • Possible variation of damping behaviour and elastic characteristics
Requirements for SMA-structures	• Heating must be locally limited • Heating mechanism must be installed locally • Consideration of pseudo plastic deformation of non-activated regions • Reproducibility of movements	• Heat-treatment must be locally limited • Necessity of thermo mechanical pre-treatment • Effects and effect variants must be clearly definable • Reproducibility of movements
combination: partial activation and local configuration	• Temporary and constant effect generation to realise a more subtle effect diversification • Unique control or partial activation of locally configured region possible • Utilisation of activation mechanisms for local configuration • Summary of features, requirements, problems and advantages of both methods	

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2. Features of SMA-actuators

For the development of smart SMA-structures it is necessary to get an overview of the features and possibilities of SMA-actuators. ***Fig. 1*** provides an overview of the features which characterise the SMA-actuators. Therefore it can be considered as a checklist for the identification of relevant requirements.

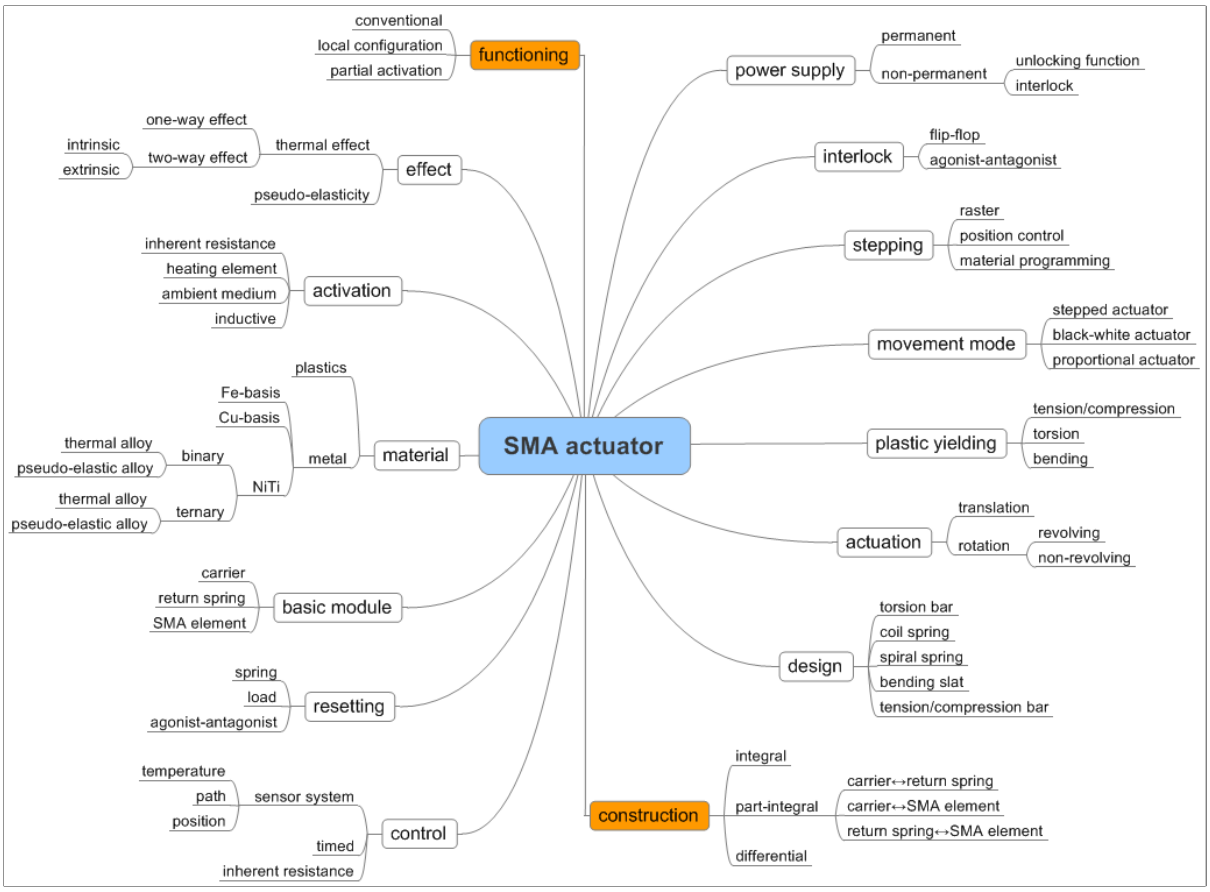


Fig. 1. Features of the SMA-actuator elements.

3. „One-Module"-modular system

The one-module modular system depicts the methodical perception on partially activated and/or locally configured smart SMA-structures. The possibilities for the realisation of one-module modular systems and their features are given schematically in ***Fig. 2***.

In contrast to conventional modular systems this approach proceeds even one step further as it reduces the modules to regions of one single component. The one module system can be specifically programmed for the allocated application. Here the SMA-structure can be modified by a local configuration of the SMA-effect, e.g. local heat-treatment, so that it can perform different activities in the actuator region as well as in the pseudoelastic region. Additionally it is possible to generate passive hinge-, damping- or structure functions and actuator functions with different transformation temperatures at the same time. This is done by local heat-treatment with different parameters (duration, intensity).

Another possibility for the creation of a one- module modular system is the partial activation of sub-regions of the component during operation. In this case diverse effect specifications are available. Moreover one-module systems can be based on the combination of both function allocation methods. The SMA-element itself can possess different passive regions as well as different active regions. The configured and/or activated regions can be combined arbitrary just like modules of a modular system [4].

From a methodical point of view, the one-module concept can be disputed by two approaches:

- Standardisation,
- Function integration.

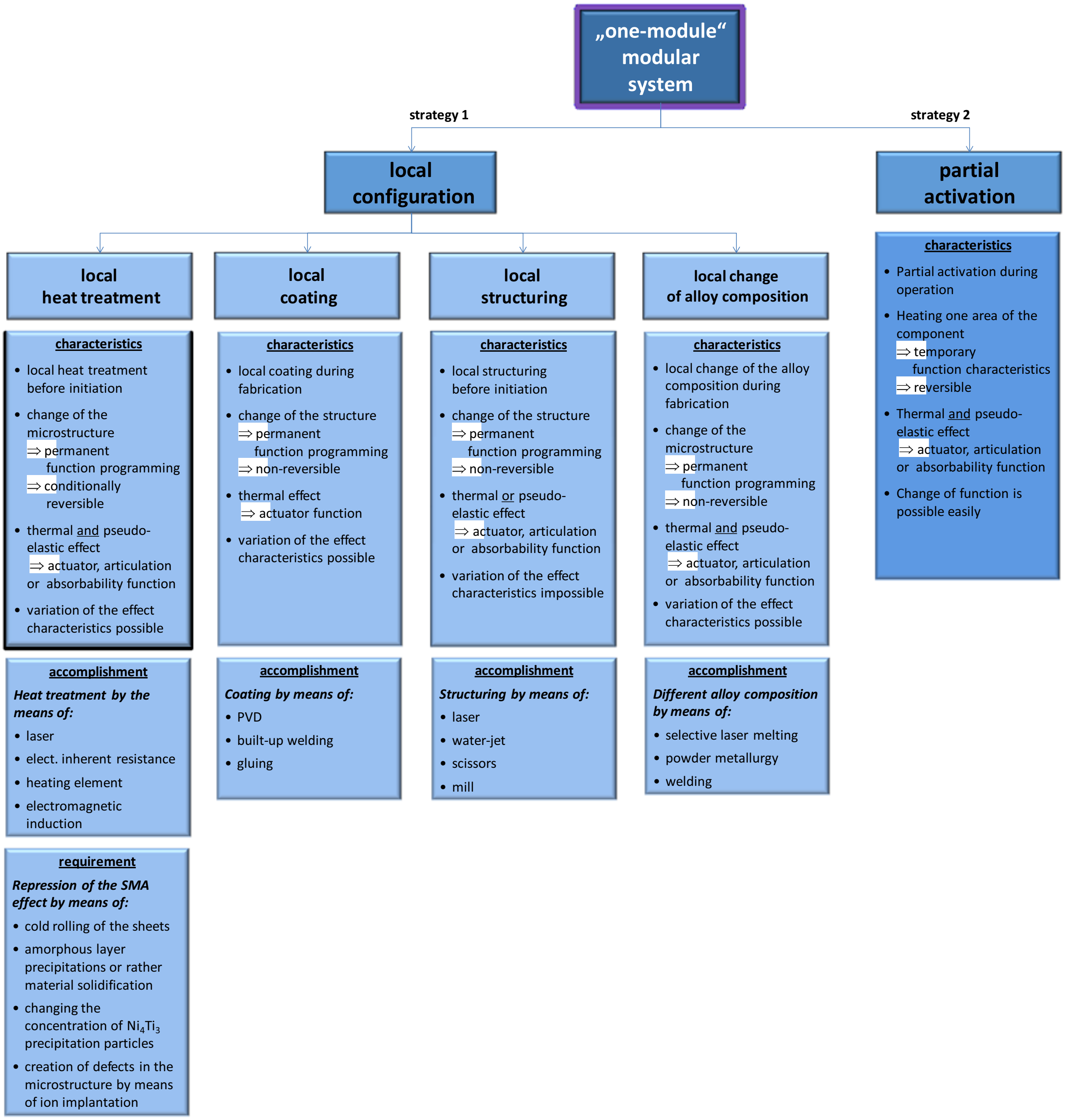
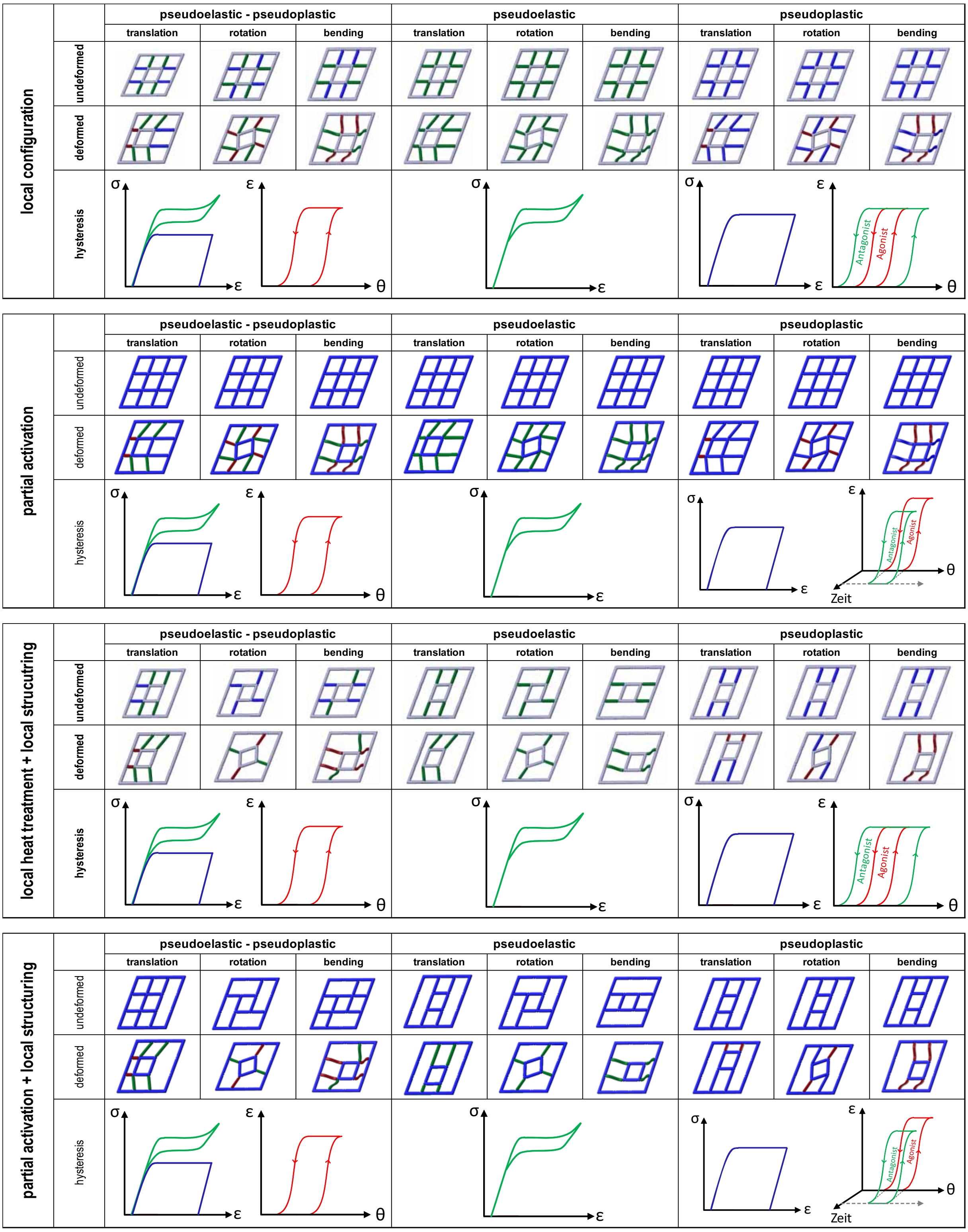


Fig. 2. Features of the „one-Module“-modular system.

3.1 Standardisation

In case of standardisation the common approach of variant construction is turned upside down and the variety of variants in terms of SMA-actuating elements is reduced dramatically. This new view regarding variant generation of components is comparable to the production of circuits in information technology (IT). The final function definition is applied during the design phase on the principle of base structures as well. ***Table 2*** depicts such a standardised component. The potential of such standardised structures can be schematically determined by this component. With adequate pre-treatments different movements (translation-, rotation- or bending movements) can be realised and the reset function can also be integrated. In addition to the type of movement there is a classification dividing SMA-effects and function definition. In this context the combination of the allocated functions is also investigated.

Table 2. Standardised „One-Module“-structure with different configurations.



3.2 Function integration

In addition to the standardisation potential the integration potential of SMA-structures can be completely utilised by the “one-module”-design. That means, all required mechanical functions for the actuator system can be realised by one SMA-component. As a result, the following central functions can be combined in one component:

- Actuator functions
- Reset functions
- Hinge functions,
- Forming functions,
- Structure- and carrier function

Two different views are provided in relation to the design of such a component. One can realise a spatial structured SMA-component in form of fundamental structure elements like rod- or wire structures and the configurable actuator component can be realised by complex structures. Disc- or thin layer structures represent such component structures [4].

3.3. Analytic examination of the integration potential

The following paragraph disputes the systematic development of SMA-actuator structures by means of their integration potential. Three different types of design can be distinguished, i.e. the differential design, the semi-integral design and the full-integral design. If the full-integral design and hence, a one-module element, can be realised without using the agonist-antagonist-design, it is wise to combine the partial activation with the local configuration. Using local configuration, pseudo elastic hinge regions or reset elements, if needed, can be easily integrated into the structure.

Table 3 and ***Table 4*** show the systematic development of actuator structures, which are suitable for partial activation or local configuration. Moreover, the conceptions also consider the combination with local configurations. For the development selected basic structures were divided into proper classification criteria and organised in a classification scheme. The displayed structures are only an extract of an optional and extendable number of solutions. Alternative solutions also result from the variation of the position of the actuator elements or the reset areas. Due to this variation other transformation-, actuator forces or adjustment travels can be implemented. Another possibility is to connect similar or different structures or structural elements to a complex possibly spatial structure. The classification schemes to display the structure synthesis are applied as follows: the structures are divided into gripper structures and movement structures. Two different basic structures are shown at a time.

Table 3. Classification scheme of smart SMA-structures with reset function.

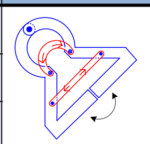
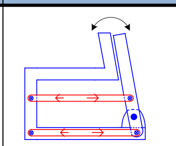
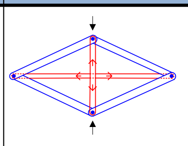
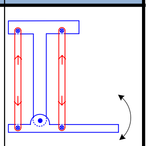
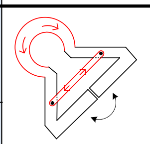
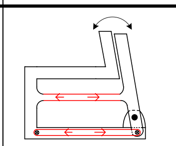
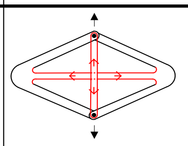
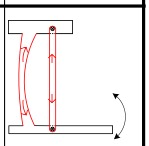
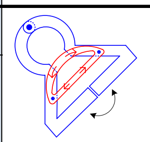
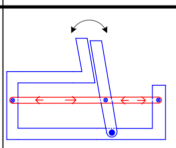
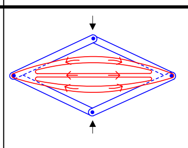
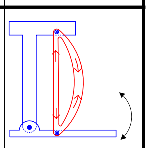
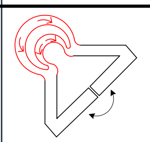
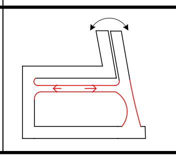
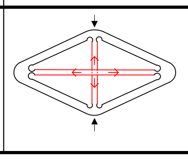
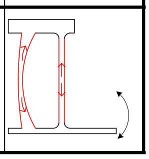
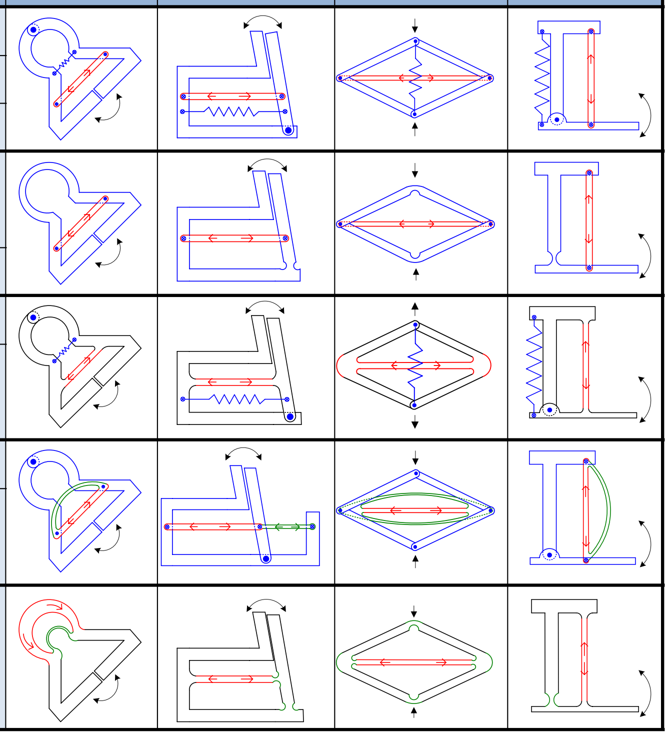
SMA-structures with integration potential (agonist-antagonist design)										
design	parts	material		integrated parts	allocated function		gripper-structures		actuator-structures	
		FGL	kein FGL		PA	LK	1	2	1	2
differential	carrier		X	-						
	SMA-component1	X		-						
	SMA-component2	X		-						
partial integrated	carrier	X		X	X	X				
	SMA-component 1	X		X						
	SMA-component 2	X		-						
	carrier		X	-						
	SMA-component 1	X		X	X	X				
	SMA-component 2	X		X						
integrated	carrier	X		X	X	X				
	SMA-component1	X		X						
	SMA-component 2	X		X						

Table 4. Classification scheme of smart SMA-structures with agonist-antagonist-principle.

SMA-structures with integration potential (return spring design)										
design	parts	material		integrated parts	allocated function		gripper-structures		actuator-structures	
		SMA	no SMA		PA	LK	1	2	1	2
differential	carrier		X	-						
	return spring		X	-						
	SMA-component	X		-						
partial integrated	carrier		X	X	-	-				
	return spring		X	X						
	SMA-component	X		-						
	return spring		X	-						
	carrier	X		X	X	X				
	SMA-component	X		X						
	carrier		X	-						
	return spring	X		X	(X)	X				
	SMA-component	X		X						
integrated	carrier	X		X						
	return spring	X		X	-	X				
	SMA-component	X		X						



PA: partial activation LK: local configuration

legend

SMA-element, pseudoplastic	SMA-element pseudoelastic	SMA without effect
steel	steelspring	hinge

The rows in *Table 3* and *4* show, from top to bottom, the development of the integration potential. In row one the structure is arranged differential, i.e. the beam consists of metal or plastics and the resetting results from a steel spring. The SMA-element simply assumes the actuator function. Such a construction can be discovered in today's SMA based applications. Rows 2, 3 and 4 show partially integrated structures, where the function integration is designed by different features. In row 2 carrier and reset springs and in row 3 carrier and actuator element are put together to become one component. Row 4 shows the construction from a non-SMA-carrier and a local configured SMA-structure, which integrates actuator elements and resetting. The solutions given in row 5 (***Table 3***) and row 4 (***Table 4***) have a completely integrated monolithic construction and fulfil the criteria of a "one-module" modular system. All functional and structural allocated characteristics are combined in a single component. The solutions in row 5 consist of an SMA-component with a local configured actuator region and a pseudoelastic all-solid hinge that perform the deformation of the structure and the resetting. The solutions in row 4 (*Table 4*) have a similar construction, the only difference is that the resetting is performed by the agonist-antagonist principle.

4. Generation of a defined SMA-structure

Having acquired a range of possible solutions in the previous paragraph it is now essential to select and implement a suitable actuator. The creation of a completely integral, locally configured SMA-actuator structure requires important features with regards to the production process and the functionality. Therefore the implementation of such structure still takes some time. The mentioned concepts or integral structures show however what such a structure could look like.

So the first step to a completely integrative SMA-structure is a partially integrated structure. The partial integration can be achieved by the integration of the non-SMA-components. This agreement is a possibility to generate a functional structure with a maintainable complexity. The bent lever actuator in ***Fig. 3*** depicts the results of this development [5].

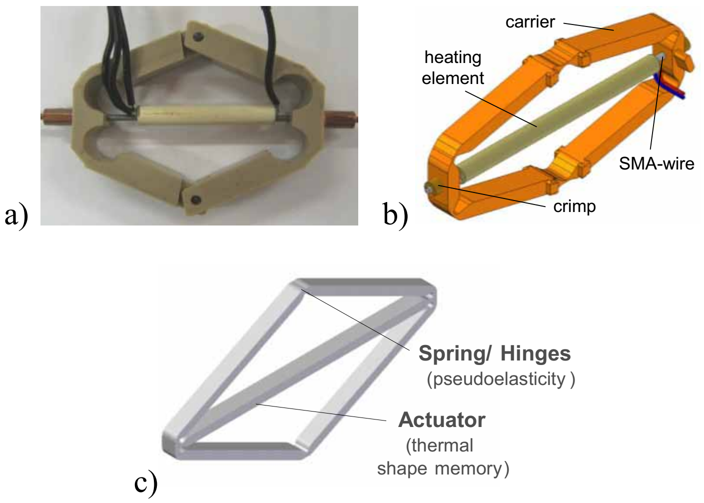


Fig. 3. Bent lever actuator with SMA-element, a) implemented actuator, b) CAD-view of the actuator, c) monolithic designed bent lever actuator.

This actuator is equipped with a wire-actuator. The thermal activation is caused by a heating element. There are two reasons, the dimensioning of the actuating force to 90N and the resulting wire cross section of 1,3mm. This cross section can no longer be activated directly by its inherent resistance with the applied maximum intensity of current of 1A. Another advantage of such a resistance heating element is the optional integration of a temperature sensor. As a result the adjustment travel of the actuator can be controlled on the basis of path-temperature proportionality. This is shown in ***Fig. 4.*** The beam made of special plastics serves as reset element and it also transforms the adjustment travel of the taut wire. The beams and the heating element are functional integrated components of the system. ***Fig. 3c*** shows a similar principle. Here the actuator is carried out integral and is a one-module system. The actuator function of the actuator can be programmed by local configuration, heat-treatment or partial activation of the central bar. The produced thermal effect allows the operation method as a pull actuator. The hinges function as reset elements and can be configured by adjustment of the pseudo elasticity due to heat treatment or a temporary differential activation can lead to pseudo elastic hinge functions.

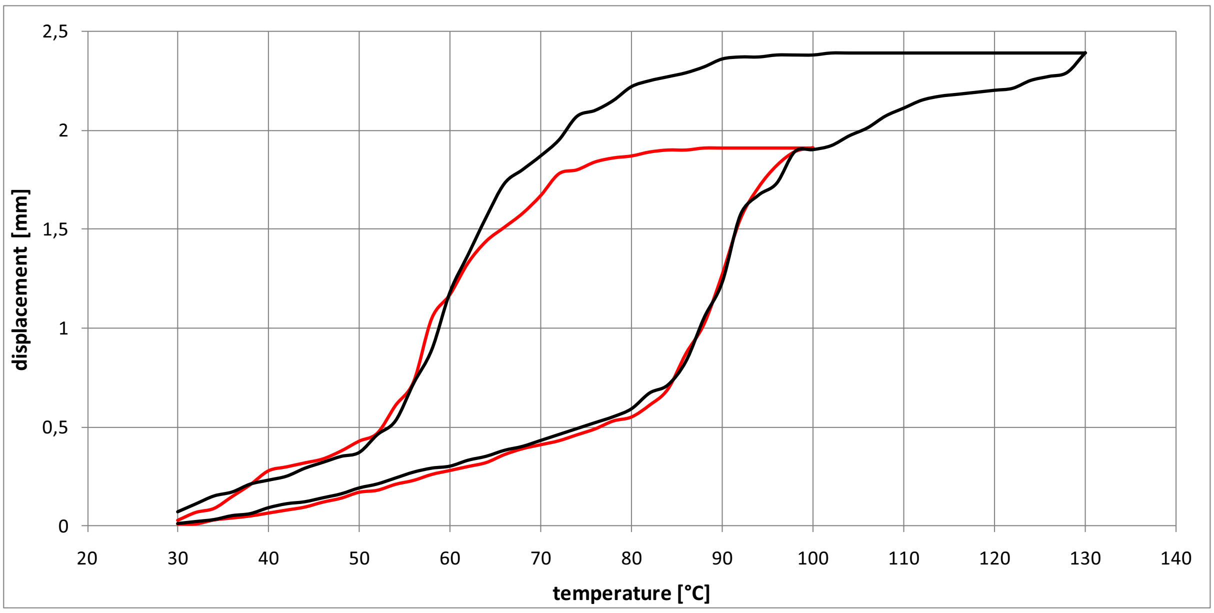


Fig. 4. Displacement-temperature-curve of the bent lever actuator.

As a result there are different strategies for the operating mode of the actuator; implying the agonist-antagonist design (***Fig. 5)***. If a sensor function that collects the adjustment travel and the displacement of the bent lever actuator is required, this can be achieved by a local coating with suitable sensor materials or by registration and evaluation of the resistance characteristic of the SMA-element.

The thermal activation by inherent resistance can cause problems concerning partial activation. The huge cross sections cause high electrical power and/or unwanted parallel circuits, conditional upon structure forms, lead to a dissipation loss. Nevertheless, there is the possibility to activate the actuator region by a resistance heating element as it is the case for the partially integrated system. Two-dimensional heating elements or the local coating of the actuator regions with a heating conductor material are possible.

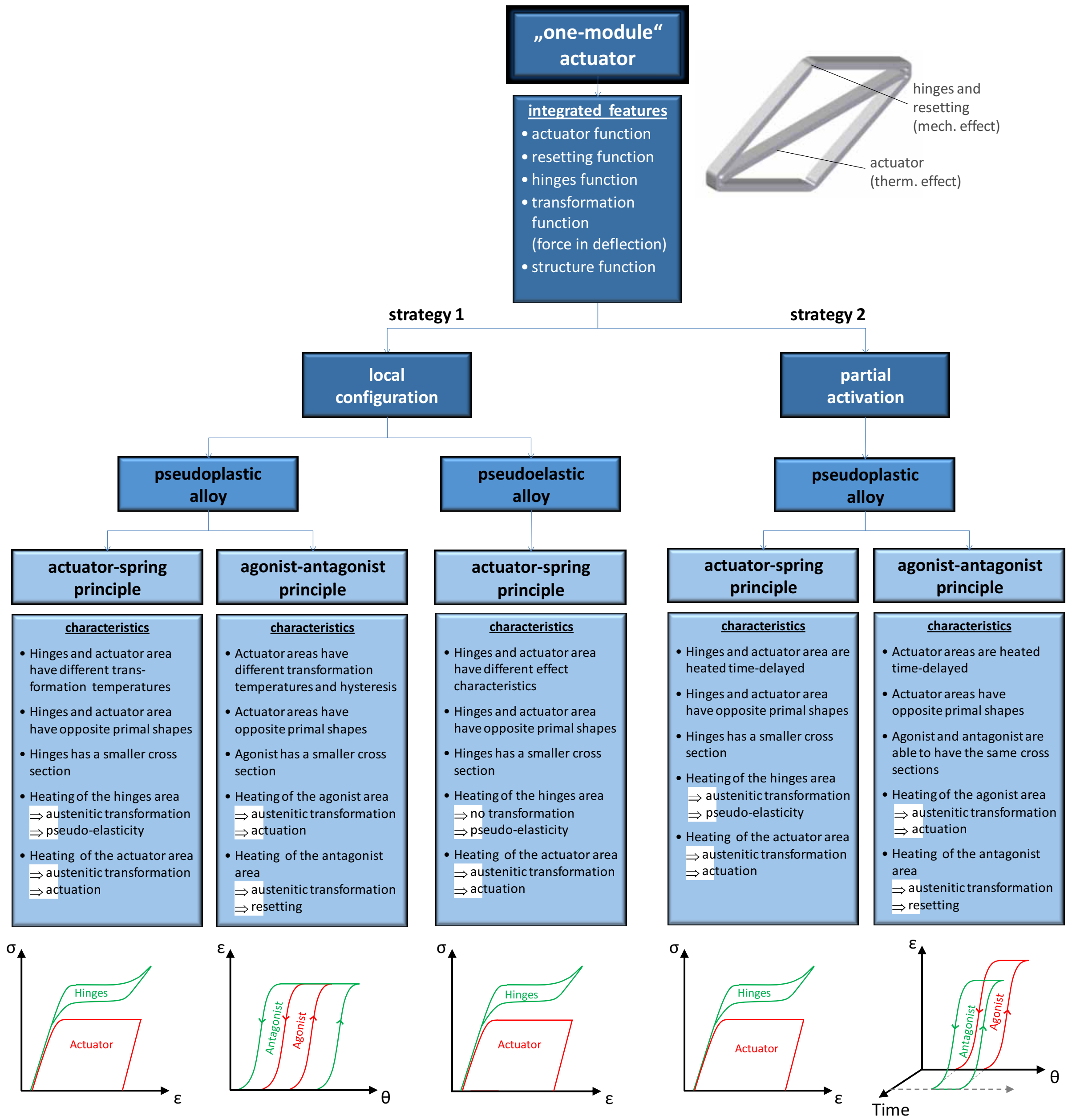


Fig. 5. Strategies regarding function of the bent lever actuator.

5. Conclusions

The research papers show the potential of “one-module” modular systems generated by partial activation and local configuration. This unique potential of SMAs allows influencing the modification of component functions in an advanced phase of the product design, simply by changing the characteristics of the material. The practicable smart SMA-structures provide the possibility of standardisation in order to reduce the number of components and increase the reliability of complex movement structures. Additionally, these structures have the potential for a profoundly function integration. In this context the basic aim of this research paper was to design basic actuator structures and analyse the different steps of the development of the functional component integration. A selected, partially integrated actuator was exemplary developed and tested to become a prototype. Because of plastic components, the partial integration was limited to the integration of non-SMA-components. The development of a completely integrated actuator system by integration of multifunctional plastic components with the SMA-actuator element will be the subject of further research activities.

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