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AN OVERVIEW OF SHAPE MEMORY ACTUATORS AS AN ENABLER FOR INDUSTRIAL SERVICES

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ABSTRACT
Shape memory alloys are smart materials with advantageous technical characteristics and can be used as actuators. Services are more and more a sales argument and can foster to increase the diffusion of technologies. In the case of shape memory actuators most companies focus on technical prop-erties, which often lead to cost pressure. Service is barley considered in todays' research. This paper made a contribution by systematically analyzing the service potential of shape memory actuators based on existing products and prototypes and evaluated the applicability of industrial services mainly emphasizing the field of mechanical engineering as well as these requirements. By considering services for shape memory actuators companies are able to generate new values for customers, which differentiate them from competition and additionally enables new innovative business models.
Keywords: shape memory alloys, services**,** actuators

1. INTRODUCTION
Actuators based on shape memory alloys (SMA) are very simple and have a high technical performance, which makes them attractive for intelligent systems, among other things. Regardless of this, the great application potential of SMA remains largely unused, and SMA actuators are almost invari-ably used in small and medium-sized series. Essential for this are often higher costs [1, 2]. Services are not a sole argument for purchasing a product. Nevertheless they can be an important buying crite-rion, if they are appropriately aligned and complement a product [3]. In this case services can generate additional or new benefits for customers. Often, however, the service is 'built around' a technical solu-tion. Nevertheless a systematic analysis of the service potentials of SMA products is missing. This paper makes a contribution by analyzing and evaluating systematically the service potentials of a wide range of SMA products. At the beginning, the SMA are briefly introduced and important characteristics are presented as well as industrial services. Based on an industrial structure analysis the current situation of SMA technology is summarized. After that, the services derived from technological trends will be assessed and the capability of SMA to provide such services are evaluated, which are the foundation to evaluate the service potentials of SMA products and be able to derive features to characterize a service. The procedure is summarized in Figure 1. Furthermore, the analysis and evalu-ation of service potentials generates a large number of ideas. For companies which are already in the field of shape memory technology, this can help to expand their business model or to develop completely new ones. Furthermore, companies from outside the industry can also use them to better eval-uate the use of SMA actuator systems as a substitute for established technologies.

2. CURRENT SITUATION OF SMA, SERVICE AND THE INDUSTRY STRUCTURE
The shape memory effect (SME) is based on a change in the microstructure, a reversible martensitic phase transformation, in which certain properties change. Among the shape memory alloys, by far the most widely used alloy systems are based on binary nickel-titanium, [2] because of their advantageous properties. These are: highest achievable actuator stroke and number of activation as well as corrosion resistance [4]. The most significant technical obstacle for applications is the low transformation tem-perature of about 100°C [5]. Shape memory alloys have a high potential for substitution of conven-tional actuators such as electric motors. Due to the usually very simple structure and the few system components, SMA are interesting for a wide range of applications for example as a stent, valve con-necting sleeve or locking device (see Figure 2).

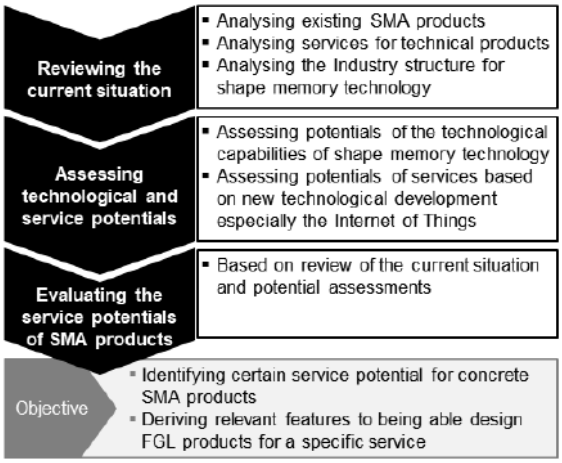

Figure 1. Procedure, and details for the analysis to determine service potential for SMA products

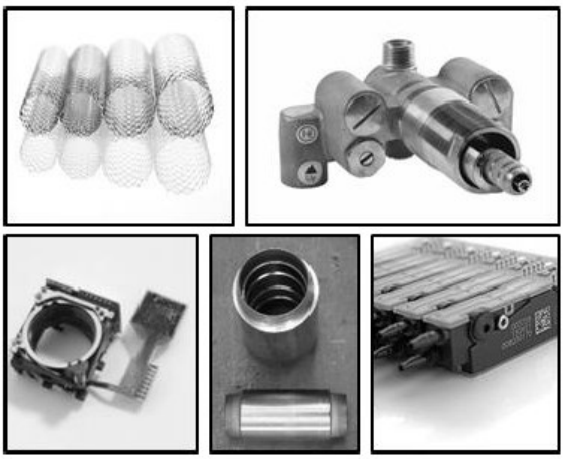

Figure 2. Overview of SMA based products. From left to right: stent [6], thermostatic mixing valve [7], autofocus and micro-camera image stabilizer [8], Cryofit connection sleeve [9], valve [10]

Simply put, services are intangible products. Often a service is added to a physical product [11] which is called value added services or product-related services. Industrial services often follow the phases in the product life cycle. Here, the use phase is crucial, which is also reflected in the number of deliverable services [12]. The consistent further development in product-related services are industrial product service systems (IPSS). For the further analysis, essential service features are: the phase of the life cycle, frequency, customers' willingness to pay, the type of service and the type of revenue stream. 84 industrial services were identified based on literature research.

The previous analysis of the industry structure of electrically activated SMA products shows that companies are currently limiting themselves to offering SMA products [13]. Services, are not relevant and at best offered sporadically. This already shows that service potentials are largely unused.

3. ASSESSING THE POTENTIALS OF SMA PRODUCTS AND SERVICES

The most important current technological trend, which is influencing services is the Internet of Things (IoT). IoT leads to a 'smartization' of mechatronic systems through connectivity, analytics and data availability which creates new data and knowledge-based services. Essential for this are continuous availability and automatically trackable information about the product and its actual condition [11]. These services are barely considered as well as offered, but nevertheless will be increasingly important in the future [14]. For companies these services are particularly promising in view of custom-ers' willingness to pay and potential for differentiation by competition. Through a literature review 26 new services were identified.

A detailed analysis of the current research as well as performed experiments about SMA reveals two key characteristics, which makes SMA relevant within the context of IoT. These are the integrated sensor function and the thermal sensitivity. Due to the integrated sensor effect, various operating states of SMA actuator systems can be detected, which are position and thus control of a SMA actua-tor system [15], some system conditions [16] and even fluid velocity within a system [17] as well as lifetime prediction [18]. Among other things, these features allow SMA elements to help increasing system security or system availability and information quality about a system. The sensor function gives SMA actuators the chance to play a key role within IoT. Besides that the thermal sensibility allows regeneration of actuator properties to some extend which was proven by [19; 20]. Especially in the case of electrical heat treatment this can save costs and material, if maintenance is necessary. Also thereof potentials in deriving services at the end of product lifecycle and maintenance related services occur. In combination with the condition monitoring ability of SMA actuator the automation degree of automation can be increased.

4. EVALUATING SERVICE POTENTIALS FOR SMA PRODUCTS

With the previously captured situation and existing potentials, the SMA products and their respective service potentials with regards to certain services were evaluating. In particular, close-to-production prototypes and purchasable SMA products were taken into account, for example SMA valves or release mechanisms for tank flaps as well as well-known SMA products, such as stents or eyeglass frames. In sum, all major areas such as medical, automotive, aerospace, consumer goods and house hold appliances, mechanical and plant engineering, heating and air conditioning and also universally usable applications were considered.

In total, the database used included 23 SMA products and 110 services, of which 26 were knowledge based services. As a result, a total of 2.530 reviews were made. The selected SMA products were also briefly defined. The following examples in *Table 1* illustrate these.

Table 1: Illustrative description of two SMA products

Category	Product/ service	Comment
SMA product	Serial SMA actua-tor for locking/ un-locking applications or valves	The electrically activated series actuator uses several SMA wire actuators for stroke addition and can be used for a variety of applications. Due to its diverse range of application, even more complex systems are possible. The assumed sales volume is high and the seri-al actuator is already available on the market. Furthermore, a microcontroller can be used which allows data acquisition and transmission.
	Self-expanding stents	The self-expanding stents are made of flexible wire mesh or springs. Activation is mechanical. The field of application is limited exclusively to medical technology. Customers from a provider's perspective are hospitals and thus doctors. Since the system is very simple and works independently, there are no components for data acquisition and transmission.

The evaluation of the SMA products took place one after another for each service, based on expert knowledge. Randomization was used to avoid the influence of trends during evaluation. There were intentional deviations from randomization, when a service was evaluated and similar services existed. This allowed to work out existing differences in a direct, pairwise comparison. It also ensured consistency and comparability of the services among each other. During the evaluation, remarks were made regarding the preconditions to be able to provide this service for SMA products as well as providing this service with SMA products. Therefore the view of service provision was divided also a criteria and in 'for' and 'with' or 'both' of a SMA product. The scale of evaluation ranged from one (unlimited possible) to five (not possible). *Table 2* gives an overview of the structure.

Table 2: Scheme for evaluating the service potentials of SMA products

Service	RN	SMA product							Comment
		1	2	3	…	9	…	23	
General consultancy	32	0	0	0	…		…		
…	…	…	…	…	…	…	…	…	
Adaptive production	102	3	3	3	…	4	…	3	
Operational security	50	5	5	5	…	2	…	5	
Self-protection of products	93	5	5	5	…	1	…	5	
Operating data acquisition	69	5	5	5	…	4	…	5	
Continuous status tracking and traceability	99	5	5	5	…	5	…	5	
…	…	…	…	…	…	…	…	…	

Legend: 0 Available 1 Unrestricted possible 2 Slightly restricted possible RN Random number
3 Limited possible 4 Very limited possible 5 Not possible

Every criteria was analyzed separately. The criteria for SMA products were view of service provision, type of activation, area of application and SME and for services were frequency, willingness to pay, type of service and phase in the product lifecycle. Furthermore, the arithmetic mean for each service, service feature and SMA product was calculated, to compare the criteria's.

5. RESULTS

The result of two services are presented in *Table 3* to exemplify the results, because the analyzed SMA products and services covered a wide range, The comments shows companies the conditions for a specific services related to SMA products. This can help them to assess, whether these are fulfilled or what is required to offer a specific services for a SMA product.

Table 3: Illustrative results for a service based on evaluated SMA products

Category	Product/ service	Comment
Service	Marketing and sales support	Possible if the SMA product is a component in a more complex system and leads to addi-tional sales arguments. Especially meaningful, the larger the more potential buyers the cus-tomer's products have. Also, the number of potential customers has a positive effect as well as the competence of the customer in the field of marketing, which is high in the consumer goods sector and usually lower for industrial products. There is also a positive impact if the variety of possible applications of customer products is high. Furthermore, a higher degree of innovation and technical advantages over the current customer solution are advantageous.
	One-time maintenance	This service requires data that allows a conclusion on the state of the actuator system. For this reason, data acquisition and transmission is required. Consequently, this service is al-most exclusively useful for electrically activated SMA actuators. For thermally and mechan-ically activated SMA actuators, this is conceivable, but less useful due to the additional components required. Furthermore, the need for maintenance is a prerequisite for the possi-bility of service provision.

The analysis of the arithmetic means reveals (see *Table 4*), that *overall* the potentials of SMA to provide services is heterogeneous. In case of the SMA *products* the capability for offering services is im-pacted

depending on the SME and type of activation. Electrical activated SMA (EA-SMA) actuator systems using the extrinsic two-way effect are best, due to commonly used micro controller for con-trol purposes. Also these systems also wear out and requires maintenance. Areas of application with high service potential are especially the mechanical and plant engineering as well as automotive. Compared to this consumer products and medical devices are limited suitable with regards to services. Furthermore, the more universally an SMA product can be used, the more services are possible. Above all, with regard to the *service* features, the overall slightly better service is made possible by SMA products. Furthermore SMA products tend to make regularly deliverable services possible. With regards to type of services SMA products are especially suitable for advisory and training services due to the fact that barely standards exists and therefore there are knowledge intense. On the other hand due to the lower complexity planning and coordinating services are hard to offer. In mechanical engi-neering, electrically activated SMA products which realize a crucial function within the production process can be an imaginable case for this.

Table 4: Overview of the results of the evaluation with services criteria's left and SMA products right

Service criteria			
Frequency		**Phase in the product lifecycle**	
Continuously	3,98	Planning	3,72
Regularly	3,14	Development	3,14
Individually	3,43	Production/assembly	2,93
Once	3,52	Usage	4,19
Type of service (excerpt)		Service	3,27
Advising	2,96	Termination	3,35
Function preserving	3,47	**Willingness to pay**	
Function creating	3,80	High	3,73
Coordinating	4,39	Medium	3,62
Training	2,18	Low	2,85

Product criteria			
View of service provision		**Area of application (excerpt**	
For	3,23	Telecommunication	3,60
With	3,79	Aerospace	3,60
Type of activation		Automotive	3,38
Electrically	2,91	Consumer goods	4,09
Thermally	4,02	Heating & air conditioning	3,80
Mechanically	3,88	Medical	4,08
Shape memory effect		Mechanical engineering	3,11
One-way effect	3,90	Various	3,21
Pseudoelastic effect	4,02		
Two-way effect	3,23		

General	
Overall for services & SMA products	3,53

Selected combinations (excerpt)	
EA-SMA actuators with two-way effect within mechanical engineering	2,20
EA-SMA SMA actuators with two-way effect with regularly frequency and high willingness to pay for a service	2,82
Maintenance related services	3,07

Finally, based on the results it was possible to identify important features for SMA products, which affect service for products. These are type of activation, complexity of a product, wear characteristic of a product, area of application, connectivity and view of service provision. These features are useful in brief evaluating the potential service offering for a SMA products.

6. CONCLUSION

The paper has shown that by considering services for SMA products new value can be generated for customers and thus the possible applications of these can be greatly expanded. It was highlighted that especially electrically activated SMA actuator systems have a high service potential. Furthermore, SMA products can enable new services up to an industrial product-service system, if they fulfill a main function in a more complex system. Nevertheless further research is necessary. Service-oriented SMA products require a rethinking al-ready during product development. For this developing a guideline to evaluate service potential within this phase would be helpful for companies. Furthermore developing a SMA and service-oriented business model framework, can help companies to utilize the service potential of SMA products and is crucial for commercialization of this technology. Besides this, transferring the presented procedures to products based on other smart materials, especially piezoelectric actuators, is interesting as well.

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