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RESEARCH ACTIVITIES IN SMART MATERIALS AND STRUCTURES AND EXPECTATIONS TO FUTURE DEVELOPMENTS

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The paper starts with a brief introduction into the main ideas and concepts of smart materials and structures. Then, an overview about German research activities in this field is given. Some of the projects are summarized, including the main research ideas, some results, experiences, etc. Finally, a look into the future is ventured as a very important task to adjust research directions. The paper presents author's expectations, which are based upon his own research experiences and several discussions with colleagues in Europe, USA, Japan etc.

Key words: active materials, smart structures, intelligent structures, future trends

1. Introduction

In the United States a workshop on *Smart Materials, Structures, and Mathematical Issues* in 1988 at Virginia Polytechnic Institute in Blacksburg could be seen as an important milestone in the development of this field as well as a starting point of several new activities in research and development. But also future perspectives were discussed [23]. As definitions sentences occur such as "*The smart materials concept is based on integration of sensors with materials, so that the material has its own nervous system, able to both sense and communicate with outside intelligence...*" or "*...Looking at the macroscopic and possibly microscopic behaviour of organisms will lead us to developing goals and perhaps mechanisms for actuators, sensors, and intelligence for structures and materials...*" Even today such definitions describe visions and challenges of future developments.

In the United States mainly the military and aerospace applications act as driving forces [23, 34, 35, 46, 60, 61]. Japan is a main center of civil research and development in smart materials and smart structures technology [16, 25, 40, 56, 58, 68, 69]. The First Joint U.S.-Japan Conference on *Adaptive Structures* was held in 1990 followed by several other joint activities of Europe, U.S. and Japan such as the annual International Conferences on Adaptive Structures and Technologies (ICAST), the SPIE, etc. [60, 20, 18].

In Germany for this new area the term *adaptronics* (Adaptronik) was created and clearly defined during a meeting of experts in autumn 1991 [4], where such an adaptronics system is supposed to combine the greatest possible number of functions in one single element and, if appropriate, in one specific material system. Consequently, adaptability and multifunctionality are key issues of such an *adaptronics system* [17]. The first research activities in Germany were initiated and supported by the VDI Technology Center in Düsseldorf, established by the German Federal Ministry for Research and Technology, e.g. the *Materials Research* program. During the next years several studies about the future potentials of new technologies were published in Germany, such as *Technologies in the 21st Century* in 1993, were adaptronics was seen as one of eight key technologies of the 21st century. In early 1994 the first application oriented projects were started mainly focusing on vibration damping in measurement robots. In 1993 at the Otto-von-Guericke-University of Magdeburg the first interdisciplinary research initiative in adaptronics at a German university was undertaken – the project ADAME*S* – *Adaptive Mechanical Systems*, which has been financially supported by the German Research Society (DFG) since 1996. In the German aerospace industry, mainly in close relation and cooperation with European partners, several projects were established during the past years to develop new technologies by applying adaptronics concepts (see Fig. 5) [31, 32, 38, 39, 49, 52, 54, 64]. But also in mechanical engineering, civil engineering, automation technologies, medical technologies etc. the development and application of new adaptronics concepts are in progress [9, 21, 27, 29, 39, 53, 55, 62]. Several activities from the basic research to applications are concentrated in the project *ADAPTRONICS – Adaptive Composites for Lightweight Structures by a Structural Conform Integration of Piezoelectric Foils and Fibers* [50], which starts in 1997.

But also in other European countries, especially in Great Britain, France, Italy and Spain at the same time research and development activities were initiated [17, 18].

Over the past ten years increasing attention has been paid to smart structure concepts in many branches of engineering and several new approaches and technologies have been developed. In the international community this emerging new field is now usually being regarded as *smart materials and structures*. But instead of *smart structures*, it is recommended to use the more precise name *structronic systems* (structure + electronic) [10, 13, 14], which more clearly points out the main characteristics of such a structural system consisting in a synergistic integration of active materials into a passive structure connected by a control system to enable an automatic adaptation to changing environmental conditions (see Fig. 1).

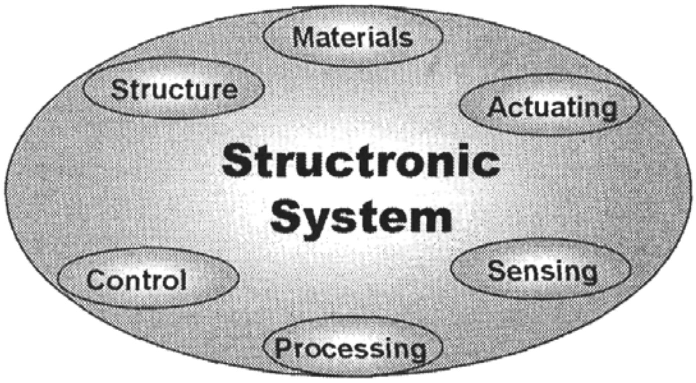

Fig. 1. Inherent parts of a *structronic system*

Consequently, smartness implies an inherent ability of a structure to sense and to actuate, but also to self-diagnose the environment, to self repair, to store the processes in a memory, to learn and to initiate appropriate actions in advance in order to fulfill its objectives (close-loop smartness) [6]. Piezoelectric materials (e.g. PZT, PVDF) and shape memory alloys are widely used as distributed sensors and actuators in structronics systems, where especially hybrid composites – a combination of fiber-reinforced angle-ply and active lamina – are very powerful smart material systems. Such hybrid composites are characterised by a high structural conformity preventing major disturbances of the mechanical behaviour as a result of the integration of actuator and sensor materials into the structure. An active material in general forms an integral part of the load-bearing structure itself and does not cause significant changes in the passive behaviour of the structure. Active materials or material systems build an inherent component of a structronic system, which is able to convert and to store different types of energy. But a material itself can never be smart and, consequently, one should avoid to use this term in relation with materials. Some of the most popular active materials are summarized in Fig. 2.

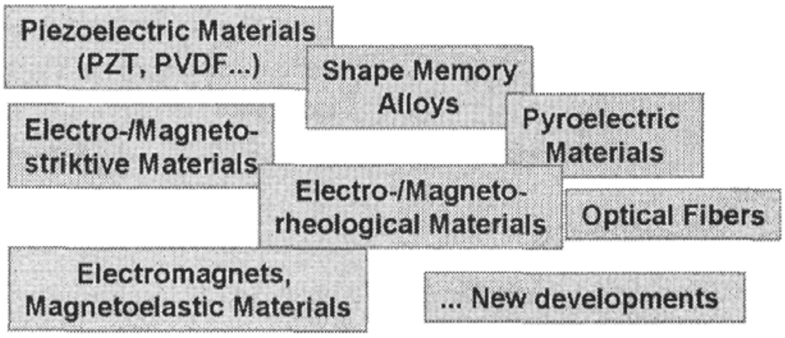

Fig. 2. Active materials condidates

2. German research and development activities

The main fields of industrial activities to develop and to apply smart structures concepts are summarized in Fig. 3, and the main objectives of such developments are given in Fig. 4.

- Aeronautics and Space Craft, Satellite Antenna
- Military Aircraft
- Civil Aircraft, Rotorcraft, Helicopters
- Automobiles
- Trains, Ground Transportation Systems
- Marine Transportation
- Optics, Electronics
- Machines and Plants, Mechanical Engineering
- Civil Engineering

Fig. 3. Main fields of industrial applications

- Shape Control
- Vibration Control
- Noise/Acoustic Control
- Flow Control
- Precision Systems
- Monitoring and Diagnosis

Fig. 4. Objectives of smart structures applications

The main driving force in Europe and also in Germany are without any doubt the aerospace and the military aircraft industry (EADS), which involves the governmentally supported institutions working in these fields, such as the German Aerospace Research Center (DLR), the Italian Aerospace Research center (CIRA), the Defense Evaluation and Research Agency of the United Kingdom (DERA), the National Spain Aerospace Research Institute (INTES), the National Aerospace Laboratory of the Netherlands (NLR), etc. But also leading European concerns such as DaimlerChrysler, Volkswagen, Siemens, ABB, SAAB, Fokker, etc. are involved in several activities, where also smart structures technologies and active materials play a major role. Some of the projects are summarized in Fig. 5. An interesting example of a typical low budget European collaboration based on a GARTEUR action group is presented in Section 2.1.

- The **Adaptive Wing (ADIF)** Program: DaimlerChrysler, DLR, DASA Airbus
- The **Adaptive Rotor (AROSA)** Program: Eurocopter, DLR, DaimlerChrysler
- The **Advanced Aircraft Structures (FFS)** Program: DASA Airbus, DLR, DaimlerChrysler
- The **MONITORE** Program (EU): Determination of potential reduction in operating costs of aerospace structures, e.g. by damage monitoring systems, increasing structural health and integrity, etc.
- The **GARTEUR** AG 23 on **Active Equipment Isolation and Structural Damoing:** Aerospatial Matra CCR, ONERA, UNI Magdeburg, SAAB, NLR, DERA

Fig. 5. Some of the European Aerospace R&D programs

Without going into details it should be mentioned that numerous investigations have been carried out in the field of enhancing aircraft structures [17, 64], adaptive wing control [38, 52, 54], adaptive helicopter rotor blades [31, 32, 35, 38, 49], health monitoring, damage detection, etc. (see also Fig. 5, and the paper of Ch. Boller for more details [17]).

2.1. The GARTEUR action group on "Active Equipment Isolation and Structural Damping"

The objective of GARTEUR (Group for Aeronautical Research and Technology in EURope) is to mobilise, for mutual benefit of the GARTEUR member countries, their scientific and technical skills, human resources and facilities in the field of aeronautical research and technology. GARTEUR was founded in 1973 and has as member countries France, Germany, Netherlands, Sweden, United Kingdom, Italy and Spain. In the Action Group 23 the application of smart structures concepts has been investigated in order to isolate high sensitive electronic boxes against vibration caused by impacts as well as acoustic waves. The active participants in this GARTEUR group were France (Aerospatial Matra and ONERA), Germany (University of Magdeburg and DLR), Sweden (SAAB), Netherlands (NLR and Fokker Space B.V.) and United Kingdom (DERA and BAE Systems). The group has established a detailed research program, defined joint activities based on the expertise and the capabilities of the participants. In contrast to usual projects, nearly no financial support is provided for such a GARTEUR activity. But nevertheless it operates quite well due to the interest of the participants to learn from each other and to increase their own abilities and experiences. This cooperation is often an excellent basis to apply later on to R&D projects of the European Union. In the case of the GARTEUR project 23 two different demonstrator types were built (see Fig. 6) and distributed to the participants for several investigations such as vibration and acoustic measurements, testing of different actuator concepts, active/passive damping behaviour etc. In our group at the University of Magdeburg computer models of Demonstrator I were established and several active vibration damping concepts including different positions of piezoelectric stack actuators and control algorithm were investigated [19, 29].

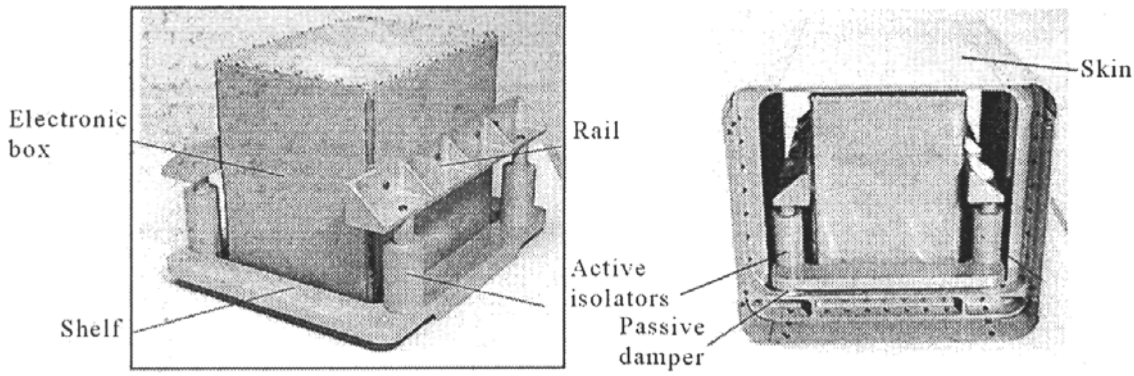

Fig. 6. GARTEUR Demonstrator I – active damping of noise and vibrations

In the following sections two interdisciplinary German research projects in the smart structures area are briefly summarized. The first one is the project ADAMES – *Adaptive Mechanical Systems* of the Otto-von-Guericke-University of Magdeburg. This is a typical basic research project financially supported by the German Research Foundation (DFG) since 1996. The second one is the project ADAPTRONICS – *Adaptive Composite Lightweight Structures with Integrated Piezoelectric Wafers and Fibres*, which aims to close the bridge between basic research and industrial applications. This project is financially supported by the German Federal Ministry of Technology (BMBF) since 1997.

2.2. ADAMES – Adaptive Mechanical Systems

The project ADAMES was the first interdisciplinary research project at a German university. In the project seven institutes of the Otto-von-Guericke-University of Magdeburg consisting of several working groups are involved in the fields such as: materials research, materials testing, mechatronics, computational mechanics, experimental mechanics, control, process engineering and image processing. Also the first chair of adaptronics in Germany was established based on the financial support of the German Research Foundation (DFG).

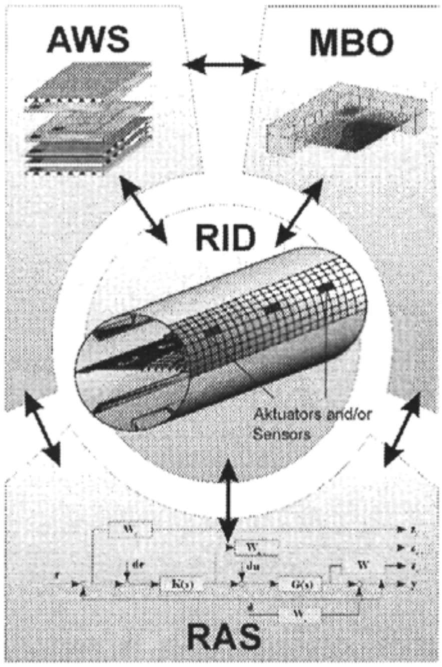

Fig. 7. The ADAMES project structure

The ADAMES project is focused on the following four close related working projects (see Fig. 7): Project 1: *Adaptive Material Systems (AWS)*; Project 2: *Modelling, Analysis and Optimization (MBO)*; Project 3: *Control and Signal Processing (RAS)*; Project 4: *Realisation, Identification and Demonstration (RID)*. The project AWS aims to create multifunctional fiber composites by

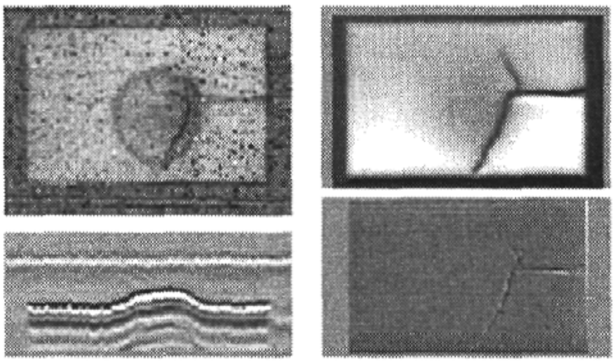

Fig. 8. Fracture identification by nondestructive testing (us-c-scan, eddy current scan, us-b-scan; radiation scan

integration of piezoelectric foils (PVDF) as sensors and thin piezoceramic patches (PZT) as actuators into a fiber composite and to investigate the interaction between structures and sensors/actuators, including non destructive testing of the microstructure and development of damage-tolerant-concepts of smart structures (Fig. 8) [9, 26]. The objectives of the project MBO are the development of efficient numerical methods and finite element approaches for simulation and analysis of thermo-electro-mechanically coupled multi-physics field problems [48], modelling and analysis of global and local behaviours of adaptive materials and structures, as well as design and optimisation of active materials, structures and systems including the optimal position and distribution of sensors and actuators [26, 28, 41-45, 63]. The project RAS aims to develop, simulate and realise algorithms for control and signal processing of discrete sensors and actuators including the use of neural networks [26]. Adaptive mechanical systems are in many cases either time-variant and/or non-linear, and the control algorithms have to cope with these features [9, 10]. The aim of the project RID is to develop and to optimise piezoelectric elements for creation of adaptive systems with distributed actuators. Several prototypes of adaptive systems have been investigated to verify the concept design including material behaviour under actuation, control algorithms and computational models (see e.g. Fig. 9 und Fig. 10). The goal of the demonstrator *smart cylinder* (Fig. 10) is to actively influence the vibration characteristics of the structure, e.g. to reduce the noise level inside the cylinder [26].

2.3. ADAPTRONICS – Adaptive Lightweight Structures with Integrated Piezoelectric Wafers and Fibres

This industry oriented project consists of a network of groups from the following research institutions, small size companies and industrial concerns:

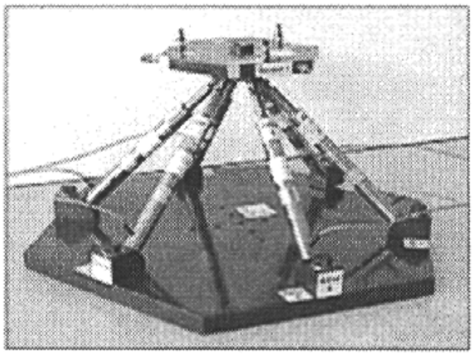

Fig. 9. Hexapod test structure

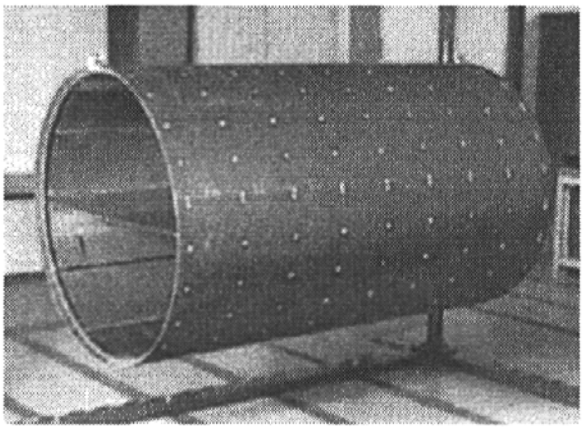

Fig. 10. Carbon reiforced cylinder structure: demonstrator for smart structures applications

research institutions: DLR – German Aerospace Research Center (2 institutes), FhG: Fraunhofer Society (5 institutes), Otto-von-Guericke-University of Magdeburg (2 institutes); *small size companies:* ERAS, INVENT, FEMCOS, HTM, Kayser-Threde, Panacol, Qnet; *industrial concerns*: DaimlerChrysler F&T; Volkswagen (VW); EADS CRC F&T; Siemens Ultrasonic Techniques; Siemens Medical Techniques; HEGLA, Beverungen; Carl Zeiss, Oberkochen. The project structure (see Fig. 11) includes application motivated basic research such as the development of active materials and material systems, simulation and design tools and prototype test structures as well as industrial prototypes in different fields of applications.

Besides the well established piezoelectric wafer technology in the material developments the focus is on the chemical production of thin piezoelectric fibers with a diameter of about 10-30 μm (SolGel technology) and the manufacturing process to receive finally micro-systems which can be embedded or attached to carbon fiber reinforced plastics or metals (see Fig. 12) [47, 51, 55,

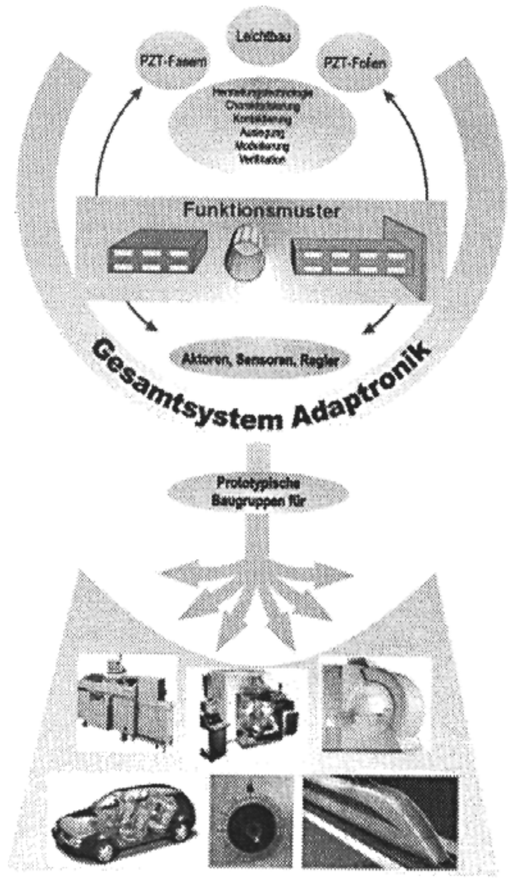

Fig. 11. Structure of the project ADAPTRONIC [50]

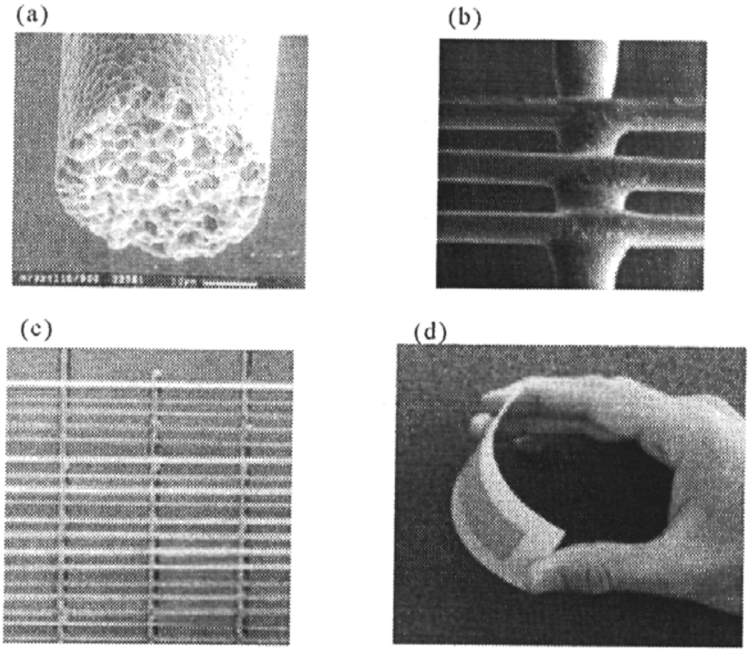

Fig. 12. Active piezoelectric fibre composite micro-system; (a) fibre [66], (b) bonding, (c) assembling [47], (d) micro-system [69]

66, 70]. Materials testing and evaluation methods as well as micro-mechanical models for designing of such structures are also developed and applied.

For the overall design powerful simulation tools have been developed based on the finite element method (COSAR software, see: http://www.femcos.de) [36] in combination with an active materials data base, controller design tools (Matlab/Simulink) and closed-loop design procedures (dSpace) [42-45]. Based on these developments several test structures have been designed, manufactured and carefully evaluated experimentally (Fig. 13) [21]. The results lead to improvements in the development of active materials and active micro-systems as well as the design and simulation methods. Researchers from the industrial concerns and basic research institutes work together within mixed teams, closely cooperating in the development of industrial prototypes, creating several interesting new project ideas and solutions, which also results in industrial patents. Some of the main projects are summarized in the following.

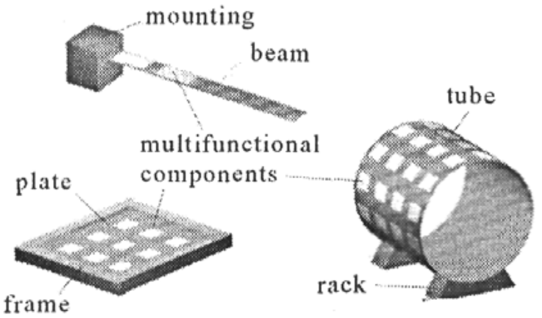

Fig. 13. Prototypes of smart test structures

The noise reduction in passenger transportation systems, such as airplanes, trains, cars, coaches, etc. is one of the challenging problems in transportation engineering. In high speed trains one possibility to reduce the inner cabin noise is a smart interface at the bogie, which cuts the noise transmission from the rail-wheel-system via the bogie into the train cabin (see Fig. 14) [62, 67]. The investigations and developments of EADS Germany GmbH, Ottobrunn, have shown that some of the low-frequencies (up to 500 Hz) are mainly responsible for the rolling-noise in the cabin, and consequently, an active interface was designed which in principle fulfills the objectives, where the main problems were the high load bearing capacity and the large deflection of the actuator system (about 180 μm) as well as the required life time of the system of about 20000 h. First measurements have shown that a significant noise reduction could be achieved with the developed prototype [67].

Another engineering challenge is the noise reduction of cars. As one of the industrial partners of the ADAPTRONIC project, the Volkswagen company is

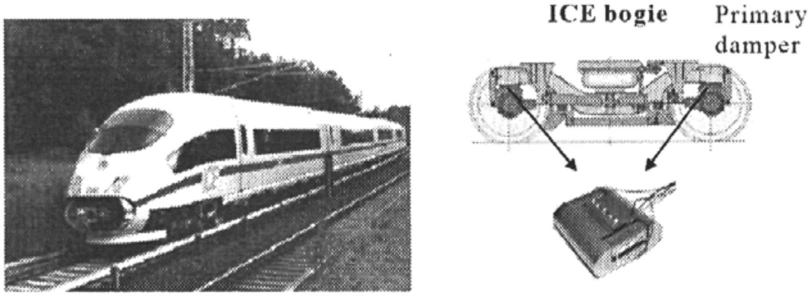

Fig. 14. Noise reduction at the German high speed train ICE by an adaptive interface

investigating the opportunities to reduce the inner cabin noise by changing the passive car roof into a smart one by attaching piezoelectric wafer modules developed in the project to the upper side of the roof shell (see Fig. 15). At the Institute of Mechanics of Magdeburg University in cooperation with Volkswagen several computer design studies are in progress as well as vibration and acoustics measurements.

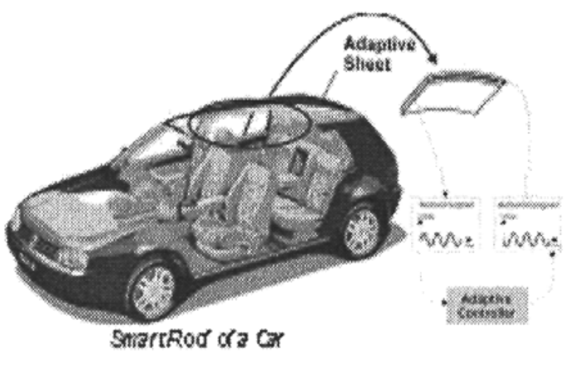

Fig. 15. Smart roof to reduce the inner cabin noise level

The shape of orbital antenna structures is influenced by temperature changes in a range from about +150°C to −150°C. Smart structures technologies are under development at DaimlerChrysler Research and Technology, Dornier Friedrichshafen, Germany, to stabilize the performance, taking into account the temperature changes. Their developments have shown that the project objectives to control the shape of the antenna structure can in principle be fulfilled. Figure 16 shows the wave front error at the surface before and after switching on the controller. The antenna structure is manufactured from carbon reinforced honeycomb material covered with layers including a piezoceramic wafer layer and an optical layer as the top layer [39].

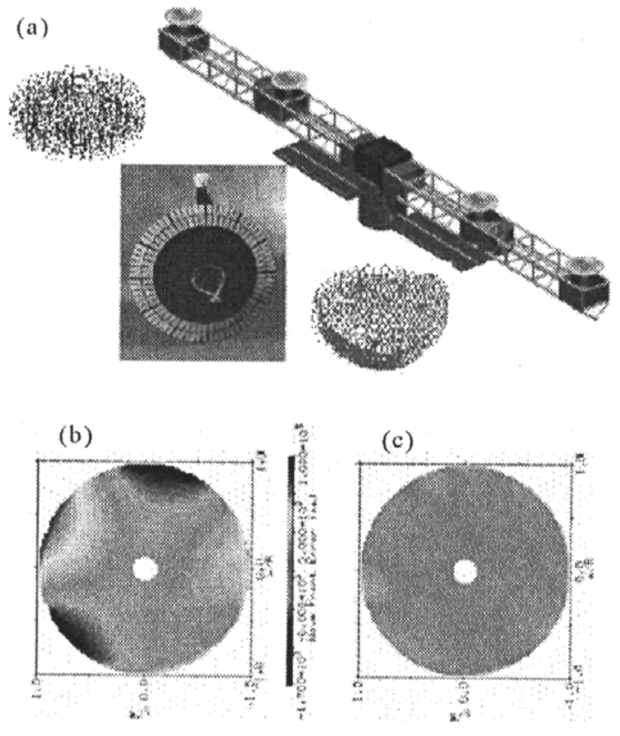

Fig. 16. (a) Smart aerospace antenna structure, (b) surface error of the mirror, (c) corrected surface

Some other industrial developments of the ADAPTRONICS project are: active enclosure shell to reduce the noise level of magnetic resonance tomography devices during operation (Siemens Medical Technologies); ultrasonic transducers for different fields of application, e.g. sound field control, pipe testing, etc. (Siemens Ultrasonic Techniques); optical systems with extreme high resolution, e.g. for semiconductor production, interface technology for bimorph structures in optical applications, etc. (Carl Zeiss) [50, 55].

But there are also several other very interesting industrial applications of smart structural concepts reported [15, 17, 18, 21], such as: application of electro-rheological fluids for damping systems in transportation of sensible goods [27], adaptronics applications in robotics [21], vibration suppression of cutting operations [57], monitoring of CFRP panels [21], intelligent materials for vibration reduction in cars [21], vibration reduction in cabriolets [21], development of active cables [5], adaptive micro-actuator based on SMA [53], vibration reduction of the European wind channel [21].

3. Future trends in smart materials and structures

The active materials and smart structures technology has meanwhile passed the border between the basic research and laboratory prototypes to industrial applications. Until now, the main driving forces are still military and aerospace applications, but more and more very exciting civil applications are reported as mentioned above. These developments show the great potential of smart structures concepts.

Issues of Smart Structures and Structronic Systems

- Nonlinear modelling, simulation and design tools / control structure interaction / benchmark problems
- System integration and system design criteria, standards, tools, limits, ...
- Material processing, new material with enhanced engineering properties and temperature stability, restrictions, material library / database, diffusion-driven smart materials
- New material evaluation techniques, tools
- Product demos, new mechanisms, new materials applied to microelectromechanical systems (MEMS)
- Applications to manufacturing
- Material incompatibility, material/structure integration, ...
- Micro-mechanics: bonding, fracture, fatigue, nonlinear behaviour, etc.
- Health monitoring and diagnosis, NDE/NDT (new modelling tools)
- Real-time system identification and control, implementation, electronics (power efficiency)
- Biological inspired structures, self-growth/repair
- Education (industry, public, government, students, ...) network, web info, "system" approach
- Distributed control of continua (PDE) via structronics technology, demos, ...

Fig. 17. Key issues of future activities in smart structures [10]

The future requirements in research and development were intensively discussed during the final panel discussion at the *IUTAM Symposium on Smart Structures and Structronic Systems* held in Magdeburg, Germany, September 2000 [10]. Distinguished researchers or program managers (E. Garcia, DARPA; I. Hagiwara, Tokyo Institute of Technology; D.J. Inman, Virginia Tech;

H. Irschik, University of Linz; Y.P. Shen, Xian Jiaotong University; J.Ṫani, Tohoku University; V.V. Varadan, Penn State University, H.S. Tzou, University of Kentucky and U. Gabbert, University of Magdeburg) reported their research activities and visions, and then open challenging research issues, current needs, unsolved problems, and future directions were discussed. During this discussion the key issues were interactively created by the auditorium as it is shown in the original shape in Fig. 17 [10]. These key points of the future research and development activities I have summarized in the following eight items:

i) Material processing, materials with enhanced properties and temperature stability, material library, new materials to micro- and nano-electromechanical Systems (MEMS, NEMS);

ii) Material-structure integration, material incompatibilities;

iii) Micro-mechanics (bonding, fracture, fatigue, etc.);

iv) Non-linear modelling, simulation and design tools, control-structure interactions, design criteria;

v) Health monitoring and diagnosis, systems identification;

vi) Distributed control (PDE) via structronics technology;

vii) Biological inspired material systems and structures, self-growth/repair;

viii) Education, web information, benchmark problems.

It is obvious that the development of new active materials, materials with enhanced properties and micro-materials systems are major key points of improving the active material basis of smart structures, which is required in order to meet the objectives of new industrial applications. But also the other topics summarized above require future attention in research and development, where, in my opinion, mainly the systems aspects will play a major role in the future. Some of the issues will be discussed in more detail in the following.

3.1. Active materials

The development of new active materials is a key issue in the smart structures technology. The objectives should be: i) increasing of the power of the materials; ii) safe manufacturing technologies; iii) development of standardized evaluation and materials testing methods (fatigue, crack and damage); iv) better understanding of the physics of active materials; v) development of adequate mathematical models and simulation tools for the prediction of the behaviour. Successful current activities are, in my opinion, such developments as: i) piezoelectric materials: textural piezoelectric material structures; single crystals (seeded grain growth, improving the properties until a factor of 10 in comparison with polycrystalline materials); single crystalline fibres based on ceramic soft fibres (advantages: higher strain $> 1\%$, coupling factor bigger than 90%, but the problem is the stability, especially in multiphase materials); ii) shape memory alloys: magnetically actuated shape memory alloys; shape memories for higher temperature ranges (100-200°C and higher); shape memory polymers (until 400% strain); shape memory materials on Fe basis (lower prise for mass production); shape memory materials based on textile technologies (weaving techniques); iii) electro-active polymers: show an interesting potential and can act as artificial muscles (large strains, but small stresses, low frequency of about 10 Hz, but the systems stability and integrity must be improved); iv) active fluids (ERFs): polarized suspensions are existing with more than 5 kPa by 5 kV/mm, but the small temperature range of operation should be increased, and, also increasing of the stability of the sedimentation process is required; in the future the development of higher shear stresses and tailored fluids is an important task; v) active fluids: first fluids are available on the market with shear stresses of about 80 kPa for 1 T (breaks, damping systems, etc.).

3.2. Micro-material systems – integration of actuators/sensors/structure to materials subsystems

An improvement of the active materials behaviour can be attained by integrating sensors and actuators in one module, developing multi-actuator-sensor-arrays in standardized shapes and reducing the costs by pre-manufactured modules. But it should not only be looked at integration of different multi-functional materials but also at including in materials subsystems such units as electronics components (measurement electronics, power electronics, control electronics, energy supply such as light, sun energy, etc.), wires, glue materials (especially conducting glue materials should also be a part of such materials subsystems for a quick application to a host structure). Also the development of functional graded materials is seen here as an important step to improve the quality of micro-materials systems. One of the main issues is to guarantee the reliability and the integrity of the system (fail-safe behaviour, redundancy in functions, limits of applications, fatigue, life-time prediction, etc.). But, also effective manufacturing methods are required to fulfil the criteria of mass production, which means that the realisation on an industrial level is an important step with several uncertainties.

There are also developments in progress which aim to increase the density of functions on a smart micro-system, where, in my opinion, the capsulation of sensor-actuator-structure units on a molecular level is one of the challenging topics which could open new fields of application, e.g. in medicine, biology, information technologies, etc.

3.3. New structural systems concepts with higher intelligence

If we are looking at the macro-structural level similar questions occur as in the micro-structural or micro-material-systems levels. For design of such highly integrated systems overall design approaches rather than component design is required. Therefore in modelling, analysis and design the coupling of different software tools (CAD, FEM, BEM, Matlab/Simulink, dSpace, etc.) and the communication between such tools, e.g. via standard data interfaces, must be developed. But in the design studies fully coupled multi-physics models, including non-linear effects, high frequencies, failure mechanisms (fatigue, damage, cracks, etc.), but, also information from measurements (identification of material properties, systems and parameter identification, model updating, etc.) should be taken into account. Even today a better mathematical understanding of the sensing, actuation and systems behaviour as the basis for design and analysis tools, optimisation (topology, shape, actuator-sensor and control design to optimise the system in its close-loop behaviour, overall virtual models for design purposes, etc.) are challenging developments which are required as a basis for an overall systems design of smart structures. But, of course, also the integration of the components into an overall system and the manufacturing technologies are not well solved due to the fact that the most of today's developments are single solutions. Such an overall design, manufacturing and validation technology have been established at our Institute of Mechanics of the Magdeburg University (see Fig. 18). But, unfortunately, such new concepts and solutions are mainly developed and tested under laboratory conditions and are not ready to be used for mass production. Consequently, assembling/disassembling concepts are missing, life-time predictions under rough real life conditions can not be given in most cases, the active materials are in general not reliable enough, etc.

But in the near future the mass production of smart structures or smart micro-material systems has to be solved, where the high integration and the high precision causes several problems in manufacturing, which have to be overcome.

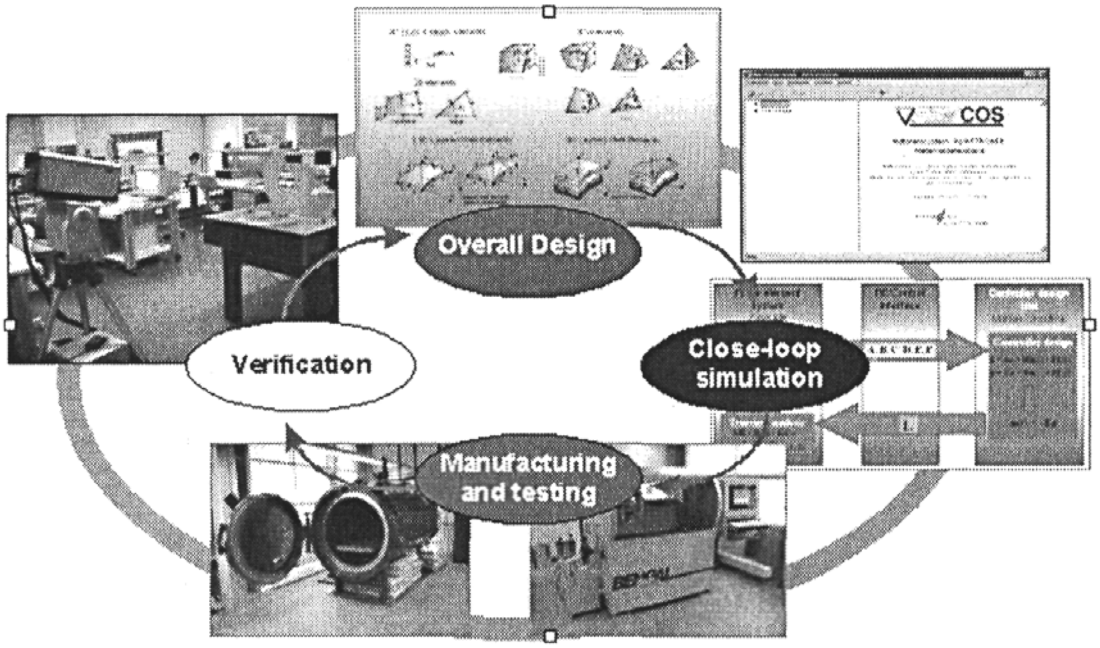

Fig. 18. The smart structures design, simulation, manufacturing and testing technology at the Institute of Mechanics of the University of Magdeburg

It should also be taken into account, that the sensor/actuator configurations, which already exist in smart structures, could also be used in parallel for health monitoring, self-sensing, diagnosis, self-repair capabilities as well.

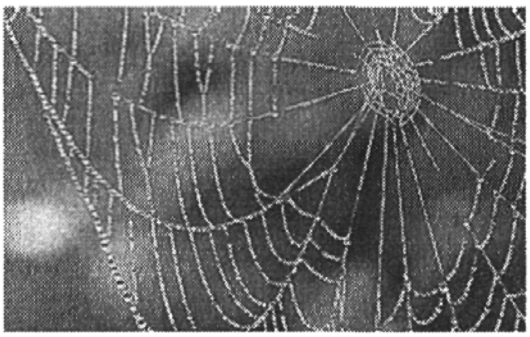

Fig. 19. Research on biological inspired technical systems is one of the future key issues in the development of new smart (intelligent) micro-materials and structural systems

The electronic and control part has not been discussed in detail in this paper, but, today mainly the application of well established concepts of control can be seen, where the new challenges result from the interference of the control with other inherent parts of a smart structure. Of course, there are in most cases uncertainties in smart structures, which require robust algorithms as well as the opportunity to identify the systems status and to draw conclusion from the previous events (learning capability). Localized simple algorithms as parts of micro-material actuator systems (micro-chip including power supply, e.g. small batteries connected with solar cells), which are working as a network of small independent units could provide the basis for a *local intelligence* of smart structures. This last remark was made to clearly show the bridge to more life-like technical systems, which is in my opinion one of the most challenging but also one of the most promising steps in the development of *intelligent technical systems.* The nature provides us with treasure of a huge amount of exciting and surprising answers to technical questions. But, unfortunately, there is not enough research in progress to investigate biological systems in detail and, consequently, our knowledge is still very limited. We should recognize that the very long evolutionary natural development process has created highly integrated, very efficient and intelligent systems, which are especially efficient from an energetical point of view. We should try to better understand biological systems and to transform recognized biological concepts into technical solutions. Some ideas of bio-inspired systems (the term bio-inspired should be preferred rather than the term bio-mimetics, because only to copy natural solutions is impossible and will also not result in good engineering solutions) are for instance: the development of nanoscale powders for functional ceramics, nano-membranes for medical applications, high sensitive sensor/actuators micro-systems, the generation of cell structures for nano-porous ceramics for chemical catalysis and fuel cells, etc. More intelligent materials systems, building biological functions in material systems, including self-control, diagnosis, self-repair, such as bio-molecular templates are challenging new fields.

4. Conclusion

In the paper a rough summary of smart structures developments is given, according to author's best knowledge, where the main focus is on the status quo in research and development activities in Germany. Over the past years in Europe a rapid development of the smart structures technology can be observed, which results also in first civil applications. Of course, the development and the application of intelligent structural concepts still requires a considerable amount of interdisciplinary basic research, which hopefully will be financially supported by national science foundations, ministries and industrial concerns as well.

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