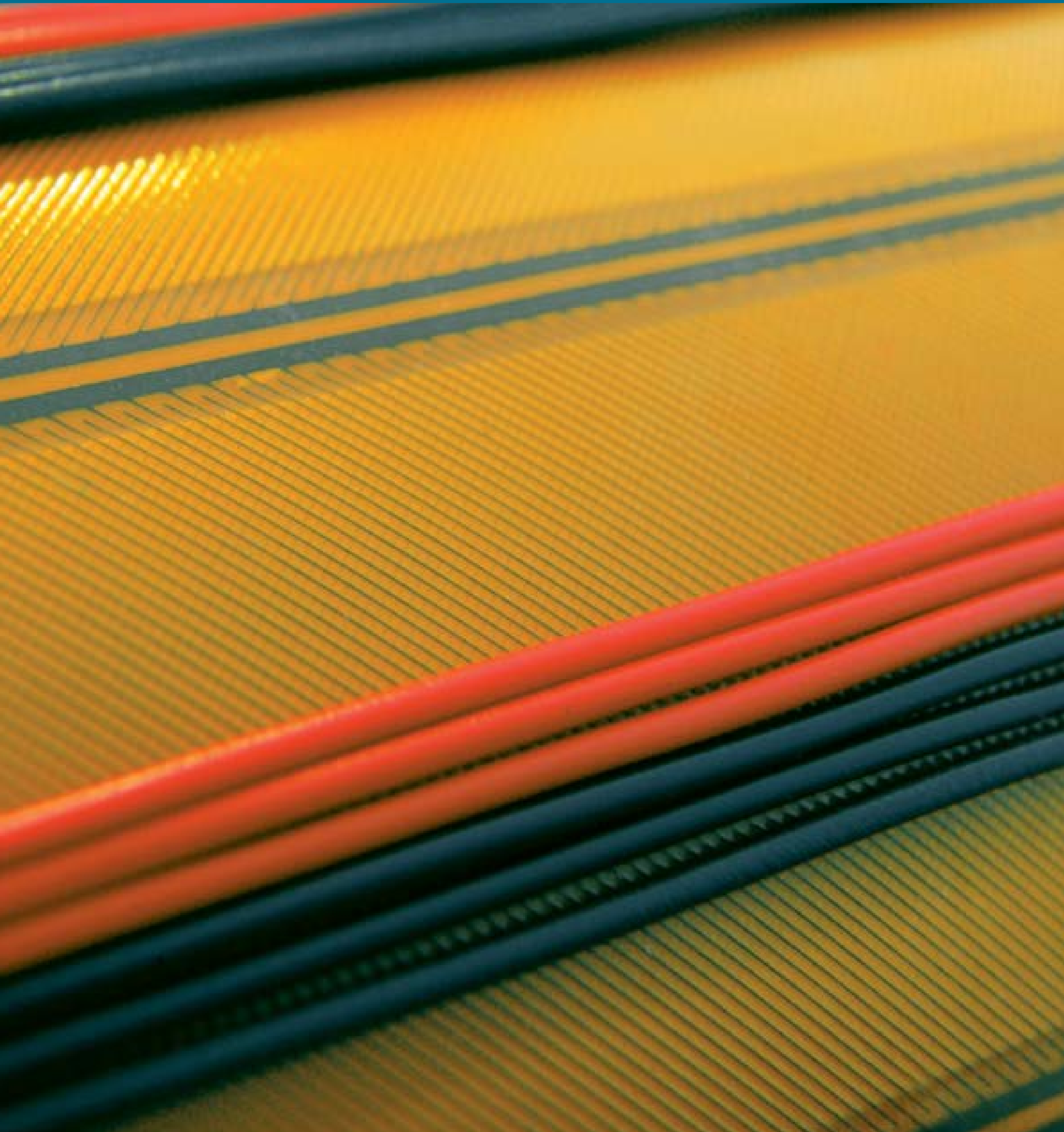
Fraunhofer IWU

FRAUNHOFER INSTITUTE FOR MACHINE TOOLS AND FORMING TECHNOLOGY IWU

ADAPTRONICS

Breathing Life into Passive Structures



Adaptronics is a synonym for a technology of intelligent structures with a large scale of integration. The first developments worthy of mention took place in the mid-80s in the aerospace and military applications sectors in the USA and Japan. By the beginning of the 1990's this technology was also beginning to emerge in Europe and in Germany, likewise initially in the aerospace sector. Since the turn of the century well-known research establishments such as the Fraunhofer-Gesellschaft, the German Aerospace Center (DLR) and the Leibniz-Gemeinschaft (Gottfried Wilhelm Leibniz Scientific Community) have turned their attention to the application potential of adaptronics for civil usage as well.

Sensing and acting functions are integrated into parts of the supporting structure which is able to adapt to modified conditions independently. Therefore active or „smart" materials are used which are activated by electric, magnetic or thermal fields. Active materials are especially piezoelectric ceramics, magnetostrictive alloys, shape memory alloys and electro-/magnetorheological fluids. They are characterized by the transformation of a field unit into a mechanical effect and the change of the material properties under field influence, respectively. The essential ingredient of a complete adaptronic system is, in addition to the sensor and actuator characteristic of the material, open and closed loop control technology which also demonstrates real time capability and energy self-sufficiency.

Adaptronics is recognized as one of the central key technologies when it comes to innovative products in the mobility, energy and health sectors of the market. Any sub-assemblies or components where the aim is to influence vibration behavior, sound radiation, the contour and geometry characteristics or even the damage tolerance may be considered as potential application scenarios. A particularly significant increase in anticipated performance would appear to be evident within the sectors of automotive manufacturing, energy technology, mechanical engineering, rail vehicle manufacture, medical technology and building and housing technology.

The manufacturing plant and production technology sector demands systems which not only display a high level of precision but are also simultaneously characterized by a high degree of dynamism in relation to the process conditions as well as considerable influence on the part of the environment. Because adaptronic components adapt very well to changes in external conditions and individual production tasks, machines and machine components can be designed to be more accurate, more robust and more flexible – a field of parameters that otherwise frequently appear to be diametrically opposed in classical design methodology.

At Fraunhofer IWU research in the field of adaptronics has been actively conducted for many years. The Dresden branch of the Institute, with a test area of 600 square meters, offers optimum conditions for handling research projects starting with the active material and culminating in trialling prototypal sub-assemblies. Materials scientists, technical mechanics and designers, control and automation engineers together with measuring technicians handle the full spectrum of complex projects related to adaptronics.

Macro-fiber composite actuators applied on a drive shaft with 45° alignment reduce troublesome bending and torsional vibrations.

ACTIVE MATERIALS – A SELECTION

There are numerous active materials with a very wide range of active mechanisms. The Adaptronics Department at Fraunhofer IWU is primarily concerned with piezoceramics, magnetic and thermal shape memory alloys as well as electro- and magnetorheological fluids.

Common to all active materials is the sensor and actuator function inherent in a material. This qualifies the group of materials not only for sensor tasks but also for actuator tasks and makes a new level of integration possible as well as extreme consolidation of functions. Traditional construction materials such as steel, aluminum or fiber plastic composites are rendered more intelligent by the application or integration of active materials and can be presented as an overall range of components that are lighter and thus incorporate savings in terms of weight and resources.

Piezoceramics

The way piezoceramics work is based on the electro-mechanical interaction between the electrical and mechanical state of a particular class of crystals. These are capable of converting electrical energy into mechanical energy and vice versa. Under mechanical load, piezoceramics generate an electrical field (sensor effect) or deform as the result of the application of an electrical field (actuator effect). This active mechanism may be ascribed to the unusual Perowskit grid structure. In order to also make the piezo-electric effect macroscopically usable, piezoceramics are polarized during the manufacturing process by the application of an electrical field.

This polarization is the reason why different deformation effects form, depending on the direction of the applied electrical field along with the direction of polarization. Indexing the effects provides information on the direction of deformation (Index 1) subject to the direction of the applied electrical field (Index 2), for example d31. The structural shapes and action mechanisms of piezo-electrical actuators may differ widely. The most common are the stack type and the strip type.

Basic properties:
– very high operating frequencies (0.1 Hz up to MHz)
– low strain (up to 0.2 percent)
– high forces (up to 4 kN/cm²)

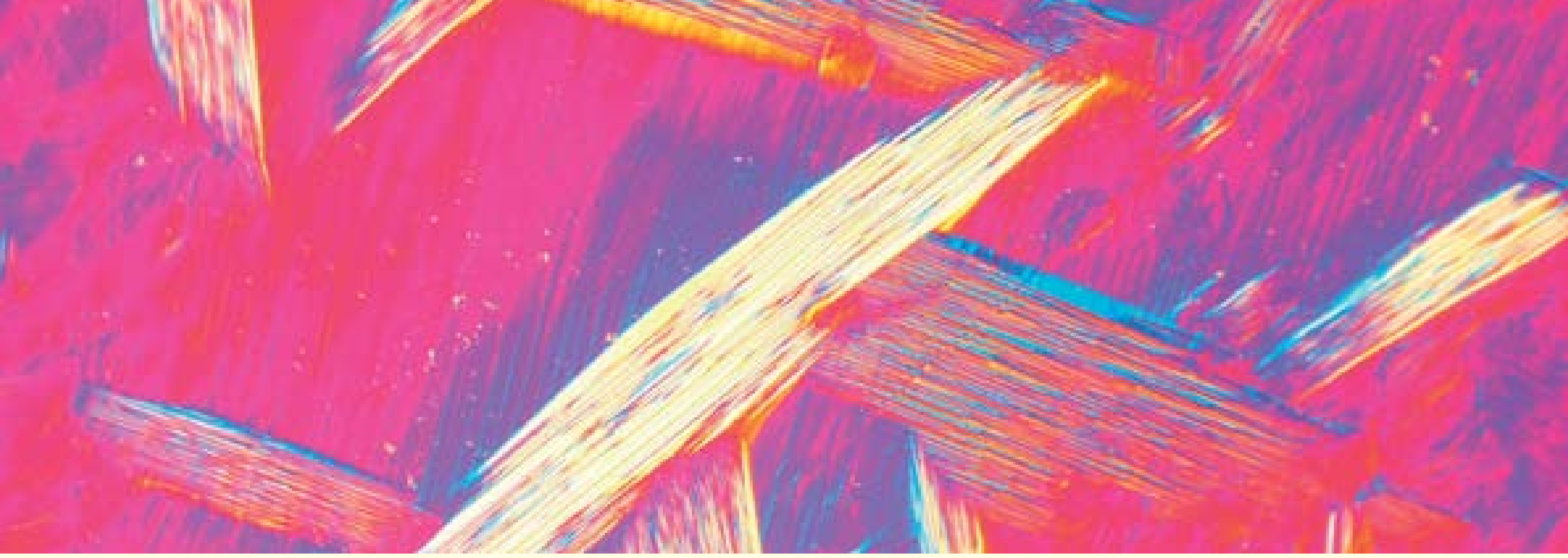
Thermal Shape Memory Alloys

A selected range of metal alloys, various plastics and composite fiber materials, together with a few chemical substances, are capable of „remembering“ defined geometric shapes when a certain physical indicator magnitude acts on them. This process is also described as „memory effect“. It presupposes special material conditioning that is of critical importance in memorizing shape. In the case of thermal shape memory materials, temperature is the physically indicative magnitude.

Thermal shape memory materials have been the subject of materials research for some time. In the metal alloy sector semi-finished products in the form of wires, rods, tubes and sheets are available today. Thermal shape memory alloys have the special characteristic of being able to „remember“ and re-assume their original shape following permanent plastic distortion below a specific critical temperature by means of heating to above this temperature.

A reversible austenite-martensite phase transformation is a pre-condition for the occurence of the shape memory effect. In an ideal situation, the austenite phase is converted into the martensite phase as a result of shear. Due to diffusion-free rearrangement processes in relation to the atoms, this generates a change in the stacking sequence of the crystal lattice levels and hence a change in the structure of the crystal lattice. Thermal shape memory alloys demonstrate good sensor characteristics due to the fact that the electrical resistance is dependent on the strain of the material as well as very good actuator characteristics because of the transformation of austenite into martensite at a particular transition temperature.

Basic properties (for example NiTi):
– low operating frequencies (0 Hz – 20 Hz)
– high strain (up to 8 percent)
– very high forces (up to 250 N/mm²)



Magnetic Shape Memory Alloys

Magnetic shape memory alloys have been the subject of discussion only since a few years. Analogous to conventional shape memory alloys, magnetic shape memory alloys show the characteristic martensite phase transformation, particularly the shape memory effect. In contradiction to the shape memory material, the shape memory effect is not related to a thermal stimulus but to a stimulus induced by a magnetic field.

As a result, it is possible, by contrast to conventional shape memory alloys, for a considerably higher repetition rate to be achieved in the operational sequences. By varying the magnetic field force it is possible to control the transformation process.

Basic properties:
– high operating frequencies (0 Hz up to kHz)
– high strain (up to 10 percent)
– low forces (up to 5 N/mm²)

Optical Shape Memory Materials

Optical shape memory materials are currently available in the form of light-sensitive shape memory polymers. As in the case of the thermal shape memory polymers, the material may also be converted from an amorphous state (flexible and elastic) into a crystalline state (stiffening). The effect of the light influences the density of cross-linkage and, at the same time, the elastic characteristics of the material. Once the targeted increase in cross-linking points is achieved, the actual shape of the material will be fixed. On subsequent dissolution of this fixed state, the material will „remember" its fundamental geometric state.

Basic properties:
– high strain
– very low forces
– cheaper to manufacture

Electro- and Magnetorheological Fluids

Electro- and magnetorheological fluids are materials that react to the presence of electrical and/or magnetic fields with an increase in their viscosity. They consist of a basic fluid (for example, silicone oil) and particles of solids embedded in it. ER- and MR fluids are generally of very low viscosity and one of their characteristics is their ability to undergo a reversible change into a state similar to a solid state body under the effect of a field.

ERF's are made up of solid particles of high disruptive strength which are distributed throughout a base oil. If an electrical field is applied vertically to the direction of flow, the resistance of the fluid to the flow is thereby increased. Cellulose, silicium compounds or materials on a carbon base may be regarded as solid particles. The base oil used is often a silicone oil.

MRF's typically consist of soft iron particles, 20 to 40 percent by volume, suspended in a base fluid. Water, silicone oils and carbon-based oils are used as base fluids. The achievable limit shear stress of an MRF is essentially dependent on the saturization magnetization of the particles of solids used. Pure iron particles as well as alloys of iron and cobalt are some of the solids used.

Basic properties of ERF:
– maximum limit shear stress 2 – 5 kPa
– density 1 – 2 g/cm³
– excitation with 2,000 – 5,000 V at 1 – 10 mA

Basic properties of MRF:
– maximum limit shear stress 50 – 100 kPa
– density 3 – 4 g/cm³
– excitation with 2 – 50 V at 1 – 2 A

INTELLIGENT SOLUTIONS FOR MECHANICAL, AUTOMOTIVE AND MEDICAL ENGINEERING

Performance capability, durability, functionality – the demands on industrial products are clearly defined. Competition and the race to achieve success in the market place calls for innovative ideas and solutions. Here adaptronics represents a key technology.

Adaptronics in Automotive Engineering

Applications of active systems based on „smart materials" in automotive engineering cover systems for intelligent automotive production and the adaptive adjustment of bodywork structures aimed at optimizing aerodynamic drag coefficient and hence reducing fuel consumption.

Using an active tool based on piezo-actuators, for example, the possibility exists of optimizing sheet metal blank insertion in the deep draw process or of monitoring and controlling the sheet metal insertion with the help of intelligent sensor technology. Applications based on shape memory alloys, on the other hand, enable cost-effective and weight-optimized positioning drives to be created by way of a substitute for conventional electric drives. A further considerable advantage of an adaptronic shape memory alloy drive is the complete absence of any noise. This is of particular interest when it comes to applications in the vehicle cockpit. In addition, energy self-sufficient thermal management is possible thanks to the sensor- and actuator-related characteristics of shape memory alloys. The use of active materials in automotive engineering means not only resource savings production but also highlights the potential for resource-friendly automobile operation with a number of additional functionalities.

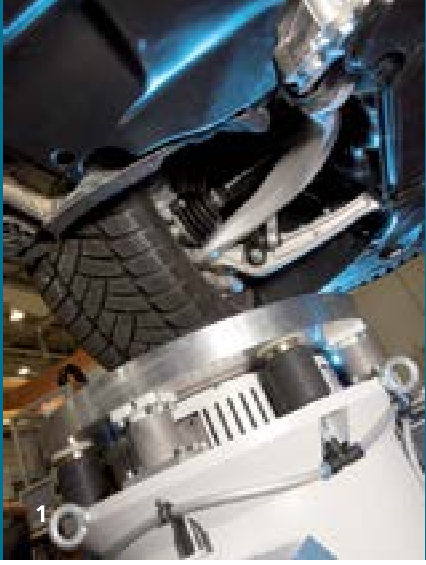
Adaptronics in Mechanical Engineering

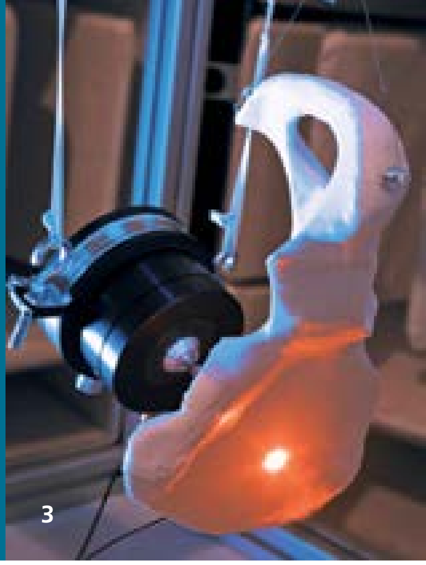
The manufacturers of machine tools are facing major technical challenges. The products developed by them need not only to become more productive and more precise, but initial investment costs for the customer as well as the life cycle costs need to come down so as to enable them to hold their own worldwide in a competitive environment.

Here too adaptronics have solutions to offer based on the use of high-integration intelligent systems. Particular focal points in the development and use of adaptronic components are production systems and production technologies that demand a high level of precision but which are at the same time also characterized by a high degree of dynamism in terms of process conditions or variable environmental conditions.

One potential solution to the problem of how to reduce non-productive time is by increasing drive dynamics. This is achieved by consistent adaptronic lightweight construction and intelligent additional components that expand the limits that have up to now existed as far as dynamics are concerned. One specific example are piezoceramic sensor actuator units for torsion, bending and/or axial vibration compensation in feed drives on machine tools. By using adaptronics, however, existing machining technologies can also be expanded and/or completely new areas of technology opened up.

One of the ways of expanding machine tool function is to use an adaptive spindle holder. One example is the hexapod kinematics developed at Fraunhofer IWU as a holder for an HSC motor spindle and based on piezo-stack actuators. The kinetic momentums are derived from the strokes and setting angles of the piezo actuators. The decentralized control sub-system consisting of sensor technology, actuating elements and controller structure can be integrated into existing machine tool concepts.





Reducing the weight of a moving mass is an effective way of increasing energy efficiency in production processes. However, this will of necessity lead to a reduction in the rigidity of the drive axles. Hence, the vibrations resulting from the process forces will increase and the accuracy of the machine is reduced. These vibrations are precision recorded by the subkinematics and effectively combated by means of decentralized controller. At Fraunhofer IWU the application limits for the adaptive system were analyzed in relation to the quasi-static characteristics of a piezo-based sub-assembly and the margin of active vibration reduction was determined for the system. Active control is effective up to 250 Hz and achieves a distinct reduction in resonance peaks.

One key technology with high potential when it comes to opening up future markets is micro-technology. The introduction of micro-pockets is leading to an improved lubrication effect and hence to a reduction in friction loss. Up to now additional stages in the process have been used to create micro-structuring. The time and effort required for this precludes any wide-ranging application. With the adaptive spindle holder, highly dynamic movements within the micrometer range can be superimposed on the actual milling process. Micro-structured surfaces are thus generated during the milling process; additional stages in the process are either dropped or substituted.

However, in mechanical engineering, shape memory alloys also have their own application entitlement. For example, thermal distortions of machine components and the machine frame can be compensated for by using actuators of this type.

Adaptronics in Medical Engineering

Active materials such as shape memory materials (metals and plastics) or piezoceramics also offer a wealth of possibilities in the medical devices technology sector and in prosthetics. Due to their high specific energy capacity these materials enable compact actuators and sensors to be developed. They may therefore be integrated into existing solutions as alternative drive elements, but also allow the development of completely new complex systems with new functionalities.

The use of so-called „self-sensing actuators" based on shape memory alloys makes it possible, for example, to develop compact grab systems. This technical solution involving a sensor-free drive and control concept offers a range of approaches for supplementing existing drive systems in the sectors of exoprosthetics and orthetics. In addition, active elements based on „smart materials" may have an effect on contact force at the bone implant interface and thus make active implants possible.

1 *Road simulation tests are carried out on an electro-dynamic multi-axial vibration test rig.*

2 *An adaptive spindle holder based on piezo-actuators helps to compensate for vibration in machine tools.*

3 *The model parameters for a pelvic bone are determined with the help of a 3D laser vibrometer; these parameters are necessary for creating realistic bone models.*

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