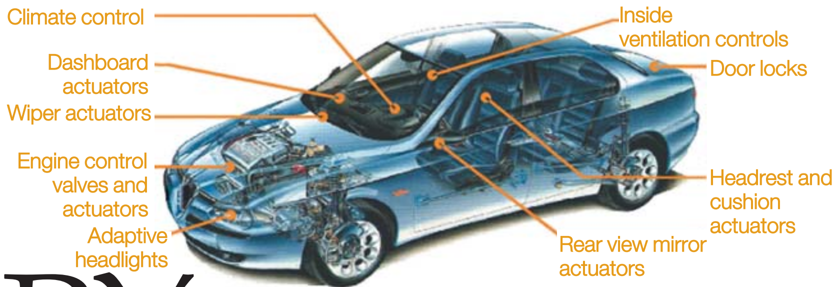

Potential vehicle application for shape memory components.

SHAPE MEMORY ACTUATORS FOR AUTOMOTIVE APPLICATIONS

Shape memory alloys enable development of simple, very compact, reliable actuators that can be integrated into components and structures.

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Shape memory alloys are metallic materials that demonstrate the ability to return to some previously defined shape or size when subjected to the appropriate thermal procedure. Generally, these materials can be plastically deformed at some relatively low temperature, and upon exposure to some higher temperature, they return to their shape prior to the deformation.

The basis of the nickel-titanium system of alloys is the binary, equiatomic intermetallic compound of Ni-Ti. This intermetallic compound is extraordinary because it has a moderate solubility range for excess nickel or titanium, as well as most other metallic elements, and it also exhibits ductility comparable to that of most ordinary alloys. This solubility enables alloying with many elements to modify both the mechanical properties and the transformation properties of the system. Excess nickel, in amounts up to about 1%, is the most common alloying addition. Excess nickel strongly depresses the transformation temperature and increases the yield strength of the austenite. Other frequently used elements are iron and chromium (to lower the transformation temperature), and copper (to decrease the hysteresis and lower the deformation stress of the martensite).

For actuators, the shape memory component is designed to exert force over a considerable range of motion, often for many cycles. Shape memory actuators represent an alternative to electromagnetic actuators in a wide range of automotive applications. Figure 1 shows the functions of several automotive actuators, divided according to category of use, whose characteristics are within the area covered by shape memory alloys. The most interesting actuation functions are those in components used occasionally with nonrotary movements, such as rear-view mirror folding, movement of the climate control flaps for air flow adjustment, and lock/latch controls.

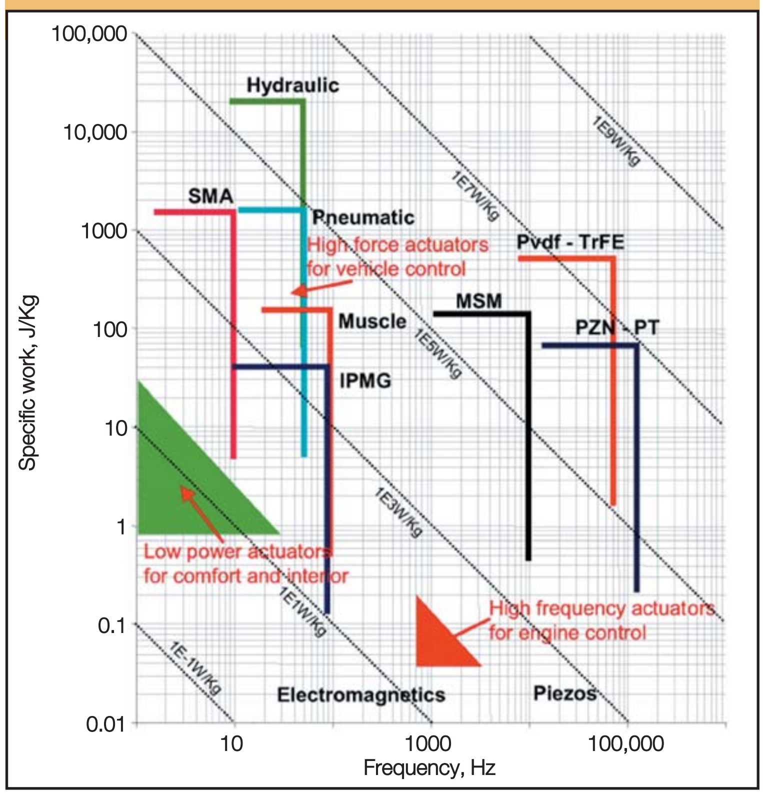

Fig. 1 — This chart shows the main categories of actuators for automotive components.

NiTi alloys

The equiatomic system NiTi has been established as a standard alloy covering a wide range of application requirements. In fact, about 90% of all shape memory applications involve the NiTi pure binary alloy system.

NiTi shows the best combination of properties, especially in terms of the amount of work output per material volume and the large amount of recoverable strain. The obvious simplicity of me-

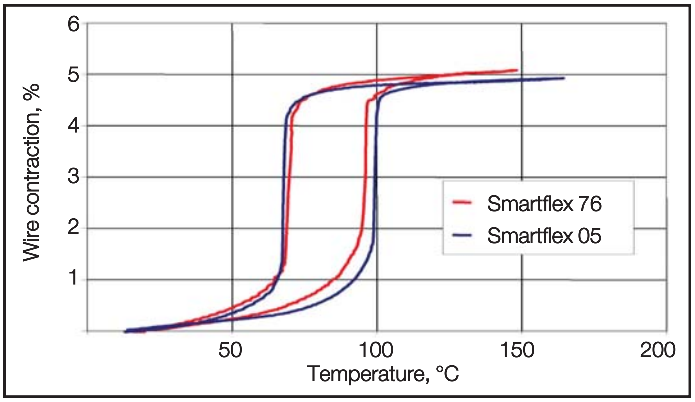

Fig. 2 — Constant load test on SmartFlex 76 shape memory wire.

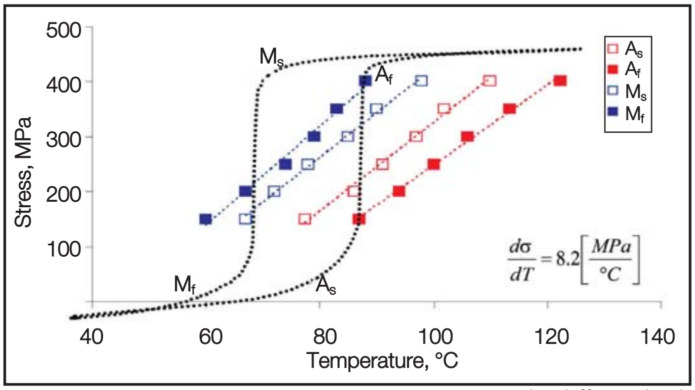

Fig. 3 — Transition temperatures under different loads

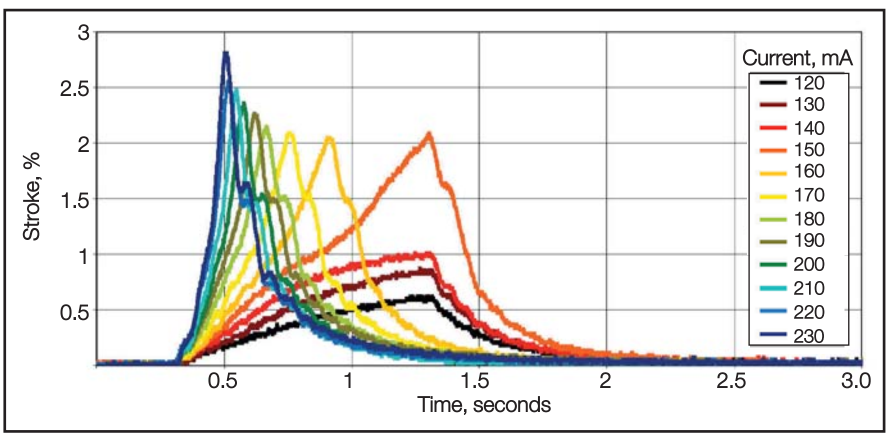

Fig. 4 — Actuation times and strokes of SmartFlex 76 at different heating currents.

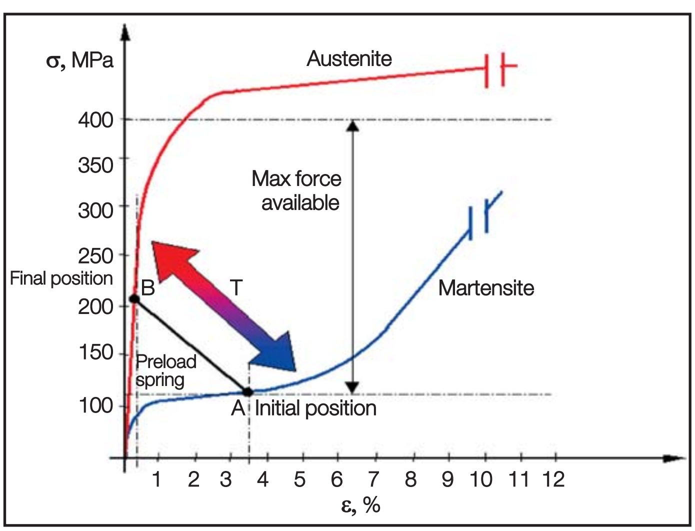

Fig. 5 — Design example of a shape memory element with a bias spring.

chanical design and minimum number of moving parts is its primary benefit as an actuator.

In particular, the mechanically stabilized binary NiTi SmartFlex wire actuator, produced by SAES Getters, shows a very sophisticated profile of properties. This article examines these properties in depth to enable engineers to design the actuator so that the functional properties of the material can be optimized and fully exploited.

The thermo-mechanical properties of NiTi wire can be investigated and measured by several methods. The most common and useful tests are described here for a commercially available wire called SmartFlex 76, a 76-µm high-temperature NiTi shape memory wire.

Hysteresis evaluation

In this test, the wire is subjected to a constant load and its deformation is measured during a controlled temperature profile in an environmental cell. Figure 2 shows the test output for SmartFlex 76 under constant stress of 300 MPa. As the graph shows, some important information can be gathered, such as the maximum stroke and the transition temperatures. The maximum stroke of the wire is around 5%, M_f at 65°C, and A_s at 96°C.

The applied load is an important factor affecting wire performance, as shown in Fig. 3. The martensite (M)-austenite (A) transformation temperatures increase with load, as also expected from a modified Clausius-Clapeyron equation (shown on the graph).

Wire transformation temperatures are of course fundamental parameters. The main problem related to the hysteresis test is the duration, because a single cycle between 15 and 150°C at a rate of 1°C/min lasts more than four hours.

Another problem is the maximum usable length: In a typical hysteresis system, only samples of about 100 to 150 mm can be analyzed. For this reason, SAES Getters has developed and patented a new characterization method in which quality control on the total length of the produced wire is performed. This equipment will enable an on-line 100% product quality control to measure and guarantee NiTi wire thermo-mechanical properties.

Fatigue life

Another very important feature that defines the wire suitability for a specific application is the shape memory effect stability during cycling. Thus, a fatigue life test is fundamental in the characterization of SMA wires. In these tests, the wire is subjected to electrical actuation cycles under an applied constant load. This gives the possibility to investigate fatigue behavior in a very wide range of operating conditions, because lifetime strongly depends on the heating current, actuation time, applied load, and required stroke.

Given the test parameters and configuration, the total number of thermal cycles is a customer's typical specification (on the order of 100,000 cycles) that must be accommodated. SmartFlex 76 shape memory wires have been tested with a current of about 170 mA under a constant load of 325 MPa and controlling the stroke to 1%. Under these operating conditions, the specimens have survived longer than one million cycles.

By using the same equipment, it is also possible to carry out "one-shot" cycles. This means that studies of current, applied load, or fixed stroke effects on actuation times can be assessed. Such evaluations are very important as they allow exploitation of the material performance at its best. Thus, through appropriate design, material can be adapted to a very wide range of industrial and automotive applications.

Design process

According to the design approach described in the paragraph above, the first step in developing a component activated by shape memory actuators optimized in terms of performance, size, cost, and reliability, is functional analysis and definition of the specifications as a function of the system.

After defining the functional specifications of the system, the alloy is selected and the active element is designed. Depending on the force, motion, and number of cycles required, the voltage and deformation values of the material are established in the martensitic and austenitic phase. Based on the sigma-epsilon σ-ε-diagram (Fig. 5) in the two phases of the alloy considered, the load history of the actuator is reconstructed and any preload parts are scaled.

Figure 5 shows an example of the design of a SMA element with a preloaded spring. The element is deformed up to 3.5% by the spring in the martensitic phase with an initial stress of around 110 MPa. During heating, the element passes to the austenitic phase, following the characteristics of the spring. It then recovers its initial deformation, minus a small fraction due to the elasticity of the austenite. Once transformation has been completed, final stress will be around 210 MPa.

During the phase change from martensite to austenite, the element is able to develop a maximum force corresponding to the maximum level of stress reached by the elastic zone of the material. This is the maximum available force during actuation. In the cooling phase, the element is deformed again by the action of the spring, which returns to its initial condition ready for subsequent actuation.

In this way, the element is designed to safely carry out a high number of cycles before

After the material has been selected and the actuator element designed, the NiTi component is then characterized.

reaching yield point and mechanical breakage.

After the material has been selected and the actuator element designed, the NiTi component is characterized. This phase will be used subsequently to design the control electronics of the element.

The next step in integrating the SMA element in the component is perhaps the most critical in the process of developing a shape memory actuator. For mechanical fastening, thermal and mechanical conditions of the element must not be altered, to prevent critical situations such as concentrated stress or inefficient heat exchange between the SMA element and the environment. At the moment, the best method of fastening is still mechanical crimping.

Electronic driver

To reach the performance levels required and to guarantee long service life of the device, it is important to develop drive electronics able to provide the right levels of power to heat the shape memory element and to control actuation. For this purpose, a feedback control system which, according to mechanical output, controls the electric power provided, is the best way to control transformation of the shape memory alloy. This control is important to avoid overheating of the material, which could be fatal for the actuator.

Future developments

Future evolution can be described according to progressive phases, involving different levels of integration and therefore component redesign. The first step involves a single actuator that replaces traditional motors. Subsequent developments are based on SMA elements integrated into components, with partial redesign, up to and including new disappearing actuators embedded in the composite matrix; this involves complete redesign of the components without any external mechanisms or moving parts. The last solution in particular represents a major breakthrough in the concept and design of automotive components.

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