Automotive Applications of Shape Memory Alloys

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Automotive Applications of Shape Memory Alloys

- Introduction
- Automotive Requirements
- Application Examples
- A Look Ahead
- Summary

IWP WERKZEUGMASCHINEN UND PRODUKTIONSPROZESSE

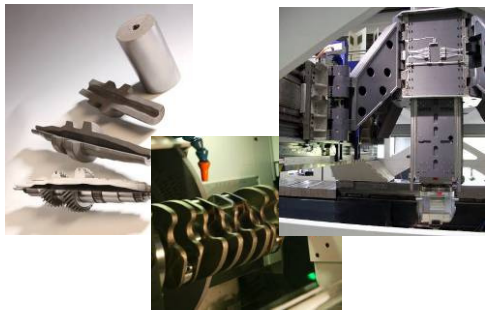
Fraunhofer IWU

Introduction
The Fraunhofer IWU

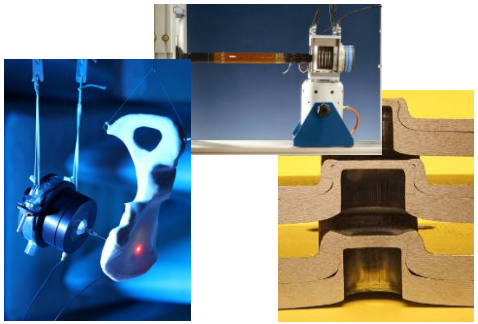
- Founded July 1st, 1991
- about 450 employees
- Budget: 25 Mio €
- Central topic:
  Resource efficient production
- 3 locations:

Headquarter in Chemnitz

Chemnitz (headquarter)
- Machine tools
- Forming technology
- Cutting technologies



Dresden (since 2001)
- Adaptronics
- Joining technology
- Medical engineering



Augsburg (since 2009)
- Systems engineering
- Processing technology

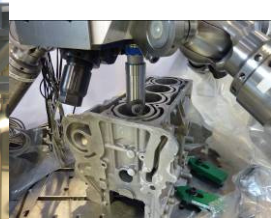
Introduction
Department Adaptronics and Acoustics

- 21 interdisciplinary scientists (material, control, design, electronic, acoustic, measurement)
- Central topic: **Bringing intelligence to passive structures**
  - Using smart material (SMA, Piezo, MRF, ERF, DEA) for functional integration
  - Merging of sensing and actuation functionality

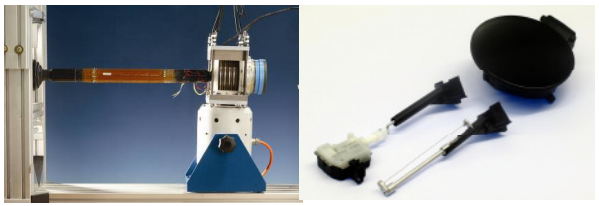
Material and Components

Acoustics and Measurement

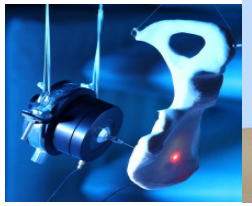
Production Technology



Automotive Engineering



Medical engineering



Introduction
Thermal Shape Memory Alloys

- Reversible phase transformation causes re-arrangement of lattice structure

Martensite ⟷ **Austenite**

➔Changes of mechanical and electrical behavior

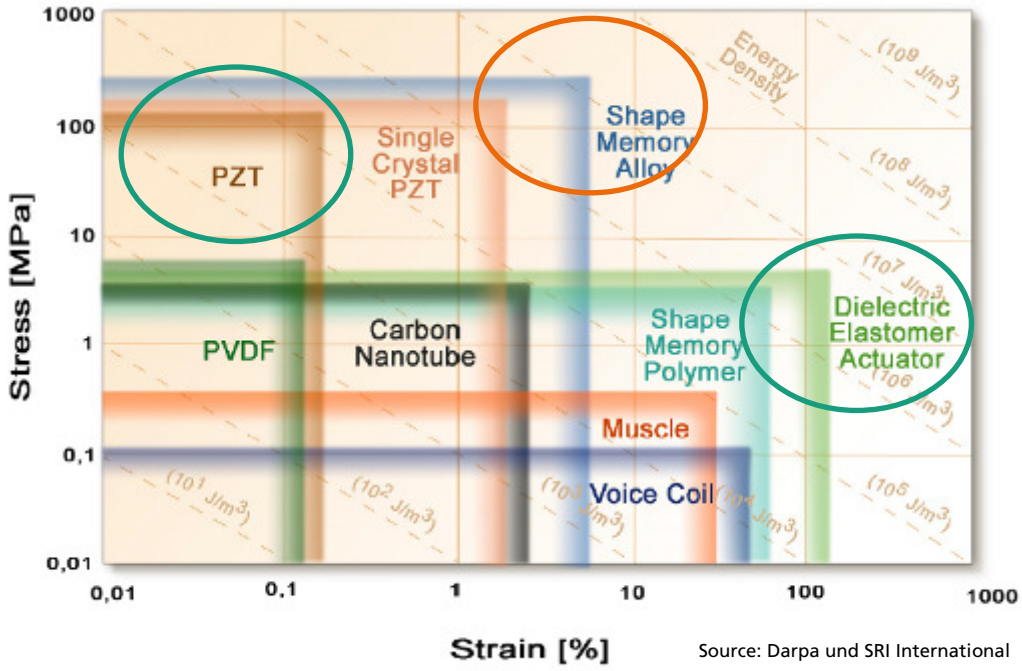
➔Changes of geometry

Actuation parameters

- High stress (forces)
- Medium strain (deflection)

Special features

- High specific work load
- Sensing and acting capabilities
- Integrate ability
- Thermal activation
- Noiseless



Source: Darpa und SRI International

Automotive Requirements
On the Way to Electric Mobility

Mechanic age – Combustion engine
- Focus: Power, Speed, Comfort
- No / minor electrification

Electro-mechanic age – Combustion / Hybrid electric vehicles
- Focus: Comfort, Power, Efficiency
- Partial electrification of vehicle
  - Assisted steering, - braking
  - Electrical controlled thermo management

Source: BMW AG

➔Increasing number of mechatronic components

Electronic age – Battery driven electric vehicles
- Focus: Efficiency, Efficiency, Efficiency
- Full electrification of vehicle
  - Electric steering, braking
  - Electric thermo management


Source: Audi AG

➔Further increasing number of mechatronic componen

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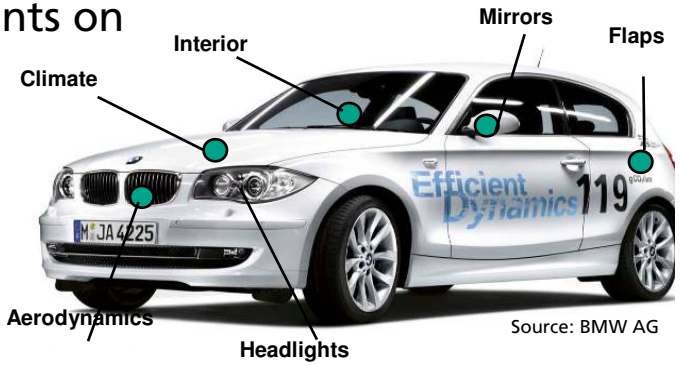
Automotive Requirements
State of the Art

- Increasing proportion of mechatronic components on
  - Costs
  - Weight
  - Cross-section
  - Energy consumption
- More than fifty drives in modern cars
- Typically applied actuators
  - **DC-drives** ➔ all-round (mirrors, climate control, interior)
  - **Solenoid actuators** ➔ valves, locks, safety systems
  - **Pneumatic drives** ➔ pressure valves engine and emission
- **Highly optimized** ➔ decades of development
- **Modular, all purpose** ➔ construction kits
- **Well known, often used** ➔ design tools

Can SMA-drives become an alternative???



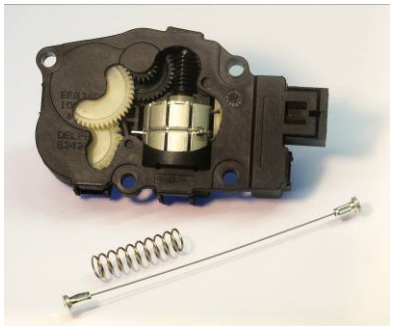
Source: BMW AG


DC-stepper drive


Solenoid drive


Exhaust-gas return valve

Automotive Requirements
What are the benefits?



- Lightweight design by the high specific workload
- Reduction of cross-section due to reduced complexity

  ➔ **Efficiency**
- Reduced complexity reducing drive costs
- Increasing of vehicle value by electrification of further functions

  ➔ **Economy**
- silent drives due to the absence of fast moving parts
- Electrification of further functions due to reduced costs, weight, cross section

  ➔ **Comfort**
- Integrated Fail-Safe Functions by thermal activation
- Self diagnosis capabilities by resistance measurement
- Structure Integrated actuators

  ➔ **Functional enhancement**

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Automotive Requirements
What's the challenge?

- **Efficiency – power consumption of the whole system**
  - Efficiency depends on temperature and thermal design
  - No Stand-By-Current tolerated → mechanical fixing
- **Temperature dependency – secure operation from -40°C up to 85°C / 120°C**
  - Limited operation temperature avoids applications close to the engine
  - On/Off-Time depends on ambient temperature
- **Dynamics – deterministic, constant delay times**
  - Long cooling times for ambient temperatures over 60°C
  - High currents for heating up from -40°C
- **Durability – ensuring live time operation**
  - Complex interactions between thermal, mechanical and electrical design
  - Protection in case of faulty operation

The sum has to be positive!!!

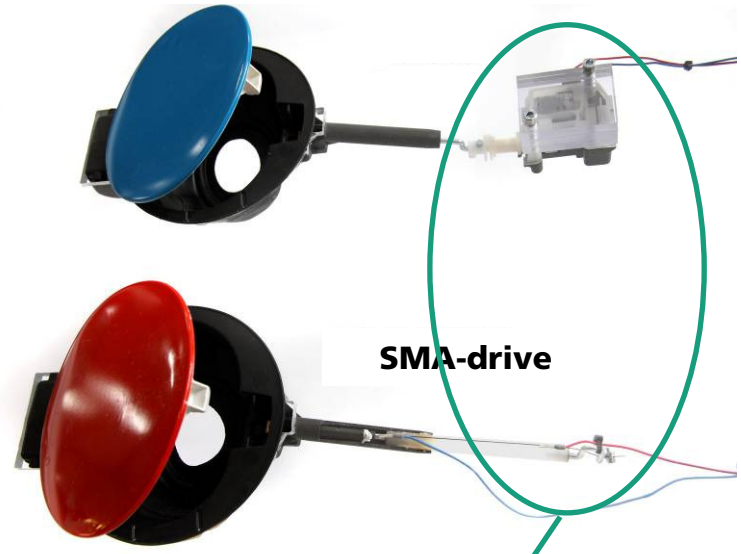
Automotive Application Examples

Petrol Cap Lock

- **Task:** Releasing petrol cap
- **Benefits:** Lightweight design, cross section
- **Drive characteristics:** Fast switching
- **Drive parameters:**
  - Reset by spring
  - Force: 10 N ➔ Diameter: 0,3mm
  - Deflection: 5 mm ➔ Length: 120mm

Parameter	Electric Drive	SMA-Drive
Weight	104 g	10 g
Number of parts	10	3
Cross section	see figure	see figure

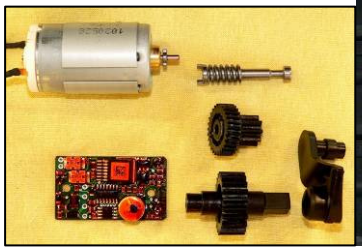
➔SMA-Drive completely noiseless

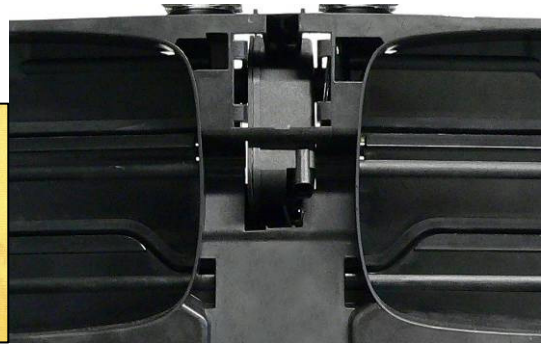


Petrol cap release device

Automotive Application Examples
Air Flow Cutting Device

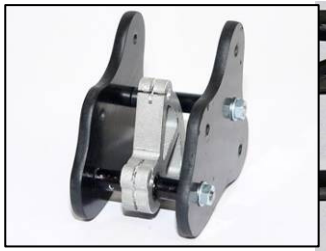
- **Task:** Cutting off the air flow → aerodynamics
- **Benefits:** Light weight design, fail safe functionality
- **Drive characteristics:** Switching and holding
- **Drive parameters:**
  - Reset by spring
    → energy needed for holding end position
  - Force: 100 N → Diameter: 3 x 0,5mm
  - Deflection: 10 mm → Length: 275 mm
  - Force transformation by eccentricity

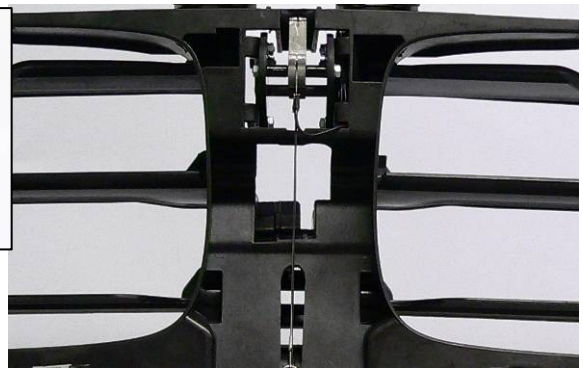




Electro-mechanic Drive

Parameter	Electric Drive	SMA-Drive
Weight	190 g	76 g
Number of parts	5	5





SMA-drive

→ Weight reduction nearly 60%

→ **Thermal fail save function included (electric drive self-locking due to gear head)**

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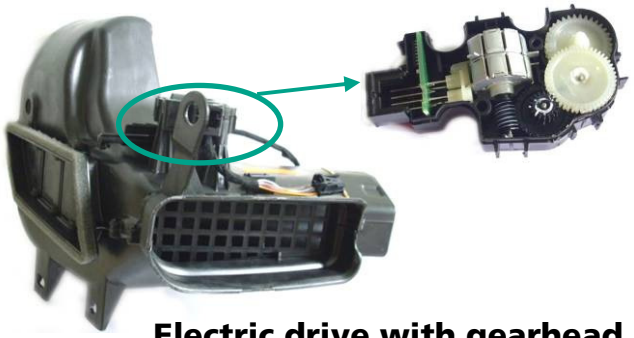
Automotive Application Examples
Climate Control Flaps

- **Task:** Control of climate Air mass flow
- **Benefits:** Costs, comfort (acoustics)
- **Drive characteristic:** Continuously controlled
- **Drive parameter:**
  - Reset by spring
  - Sensor less control using resistance measurement
  - Force: 5 N ➔ Diameter: 0,152 mm
  - Deflection: 9 mm ➔ Length: 230 mm

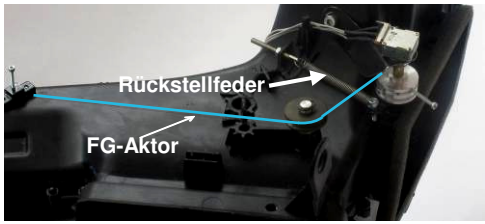
Parameter	Stepper Drive	SMA-drive
Open-close-time	3 s	2-3 s
Cost	ca. 5,00 €*	ca. 2,50 €**
Weight	ca. 65 g	ca. 20 g
Number of parts	ca. 20	ca.10

➔ **Completely noiseless**

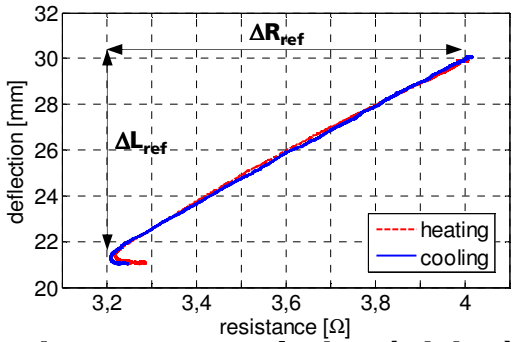
➔ Integration of actuator in plastic housing



Electric drive with gearhead



SMA-drive



Length – Resistance - Correlation (NiTiCu)

* Cost Electric Drive: Supplier

** Cost SMA-drive: FhG-IWU purchase price of components, no development costs included

Automotive Application Examples
Headlight Range Adjustment

- **Task:** Deviation balance of headlights
- **Benefits:** Cross-section, weight, acoustic
- **Characteristic:** Continuously controlled
- **Drive Parameter:**
  - Antagonistic wires → fast acting in both directions
  - Flexible wire arrangement in Bowden-cable
  - Force: 15 N ➔ Diameter: 0,3 mm
  - Deflection: 6 mm ➔ Length: 200 mm

Parameter	Electric drive	SMA-drive
Up-Down-Time	6 s	4 s
Weight	ca. 52 g	ca. 35 g
Number of parts	7	7

➔ **Completely noiseless**

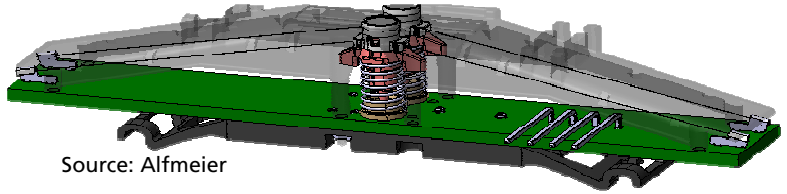
➔ Integration of actuator in the headlight housing

Headlight adjustement - electric drive

Headlight adjustement – SMA-drive

Automotive Application Examples
Summary

- SMA-actuators are able to replace conventional actuators
- ➔ The key is the right application
- ➔ Serial Production of valve drive by Alfmeier Präzision AG
- **Main Benefits:**
  - Lightweight
  - Small
  - Cost effective



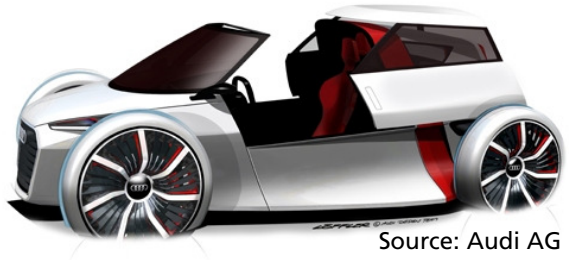
Source: Alfmeier

- **But:** the benefits strongly depend on the drive requirements
  - Temperature dependency
  - Dynamics
  - No Stand-By-current
  - ...

Nearly everything is technical feasible but does it makes sense?

What is coming next?

A Look Ahead
Self-controlled actuation systems


Source: Audi AG

- **Thermal activation** as unique feature of SMA
  - ➔ SMA works as **sensor and actuator**

Motivation

- Energy for thermo-management has to be delivered by battery
  - ➔ Compact car in the city (50 km/h, winter): **3 kW engine power**
    3 kW heating power

Objective: Material based thermo management → no fluidic circuits, no extra energy

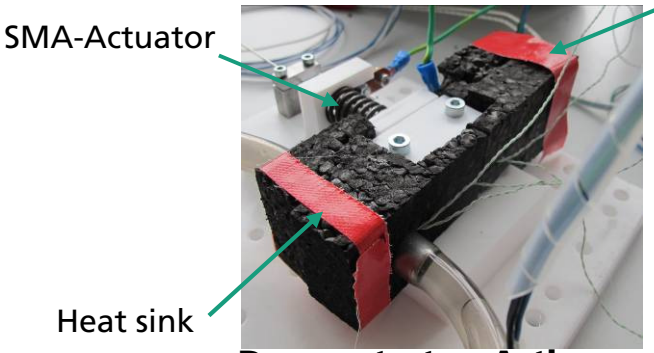
- **Material based storage** of thermal energy ➔ **Phase-Change-Materials**
- **Material based control** of heat flow ➔ **Shape-Memory-Alloys**

Application Example: Battery

- High conductivity to prevent over-heating
- Low conductivity to prevent under-cooling

Challenges:

- Thermo-mechanical design methods
- Manufacturing technologies



Demonstrator: Active Controlled Heat Flow

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A Look Ahead

Intelligent Structures (I) – Composite Structures

- **Integrate ability** as unique feature of SMA
  - ➔The Material is the actuator

Motivation

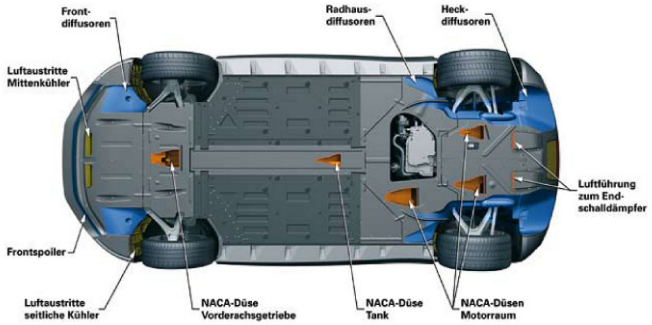
- Increasing efficiency by tailored aerodynamics

Application Examples

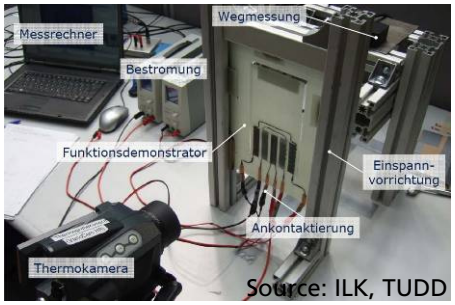
- Adaptive vehicle underbody ➔ **Air intake**
- Adaptive exterior parts ➔ **Rain drain**
- Adaptive interior parts ➔ **Air outlet**

Challenges:

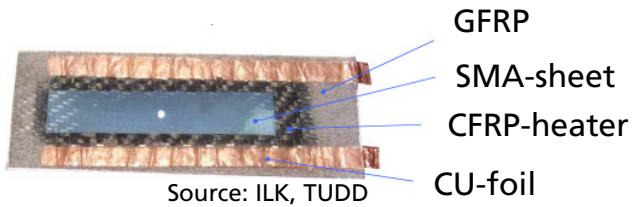
- Modeling of SMA-composite structures
- Integration techniques (heating, thermal management)
- Integration technologies



Vehicle underbody



Demonstrator: Active GFRP-composite



CFRP-heater for structure integrated SMA-sheets

A Look Ahead

Intelligent Structures (II) – SMA-Metal-Composites

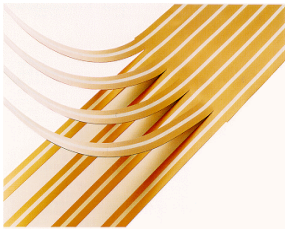
- **Integrate ability** as unique feature of SMA
  - ➔ The Material is the actuator

Motivation

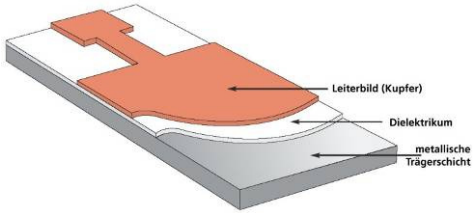
- Adaptive car body components for adaptive aerodynamics
- Similar materials, thermal efficient environment

Automotive Applications

- Adaptive spoilers
- Thermo active engine parts
- Passive brake cooling



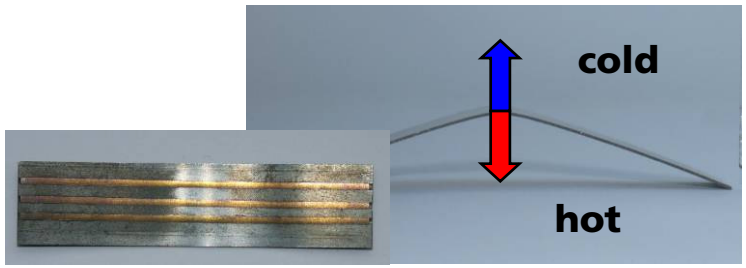
Roll clading of NiTi-Wires



Punching/printing of heating elements

Challenges:

- Modeling of SMA-composite structures
- Integration techniques (heating, thermal management)
- Integration technologies

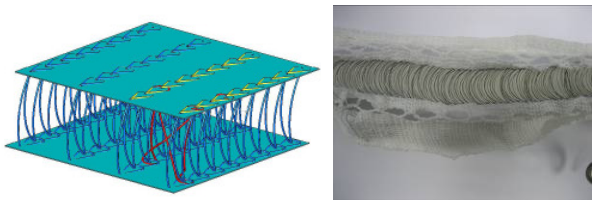


Source: TU BAF **Demonstrator: SMA-Metal-Composite**

A Look Ahead

Intelligent Structures (III) – Textile Structures

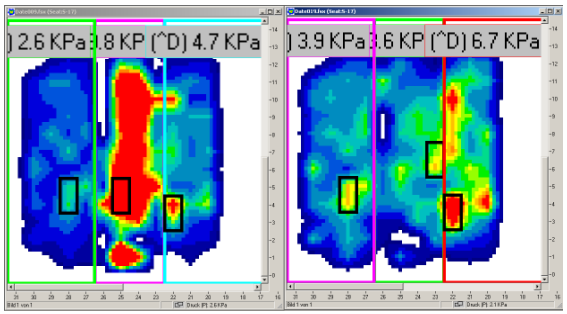
- **Flexibility** of wire **actuators** as unique feature of SMA



Adaptive distance fabric

Motivation

- Variation of geometry and behavior of
  - Textile **2D-structures (woven fabrics)**
    ➔ seat / interior cover layers
  - Textile **3D-Structures (distance fabrics)**
    ➔ seat structure



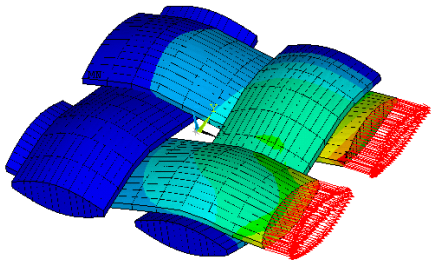
Increasing pressure by integrated SMA-wires

Automotive Applications

- Tactile textile structures
- Morphing textile structures ➔Adaptive seat side walls
- Variation of stress-deformation behavior

Challenges:

- Modeling of textile-SMA-structures
- Integration techniques (contacting, fixing)
- Integration technologies (production processes)



FE-model of textile SMA-structure

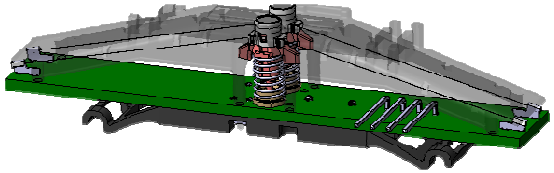
Summary

Today

- Many applications show the potential of SMA in the laboratory
- First series production application established
- Interest of OEMs and suppliers is rising, but still an information deficit exist

➔ For **suitable applications** SMA will reach the market

Laboratory demonstrator



Series application

Future

- Actuator integration and thermal activation as unique feature of SMA
  - Active material composites for intelligent structures
  - Self controlled structures
- Future Challenges:
  - Modeling of composite structures (metal, plastics, textile)
  - Integration technologies and manufacturing processes

SMA-composite materials

Thank you for your attention!

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