Fraunhofer IWU
Department Shape Memory Alloys

Dr. Kenny Pagel

Shape Memory Alloys
Basics

Mechanism:
Mechanically/thermally induced phase transformation

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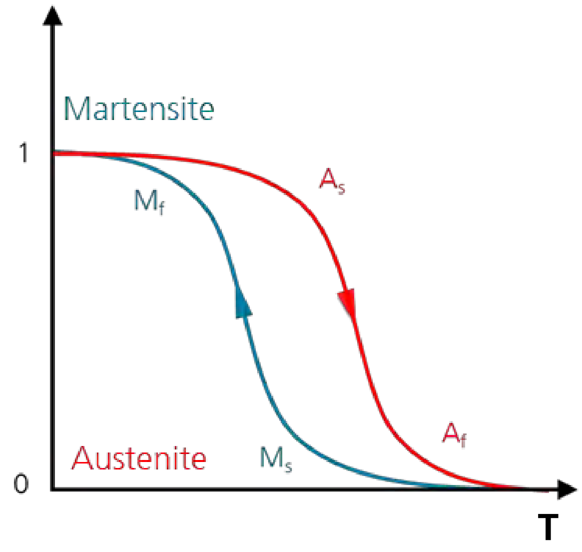
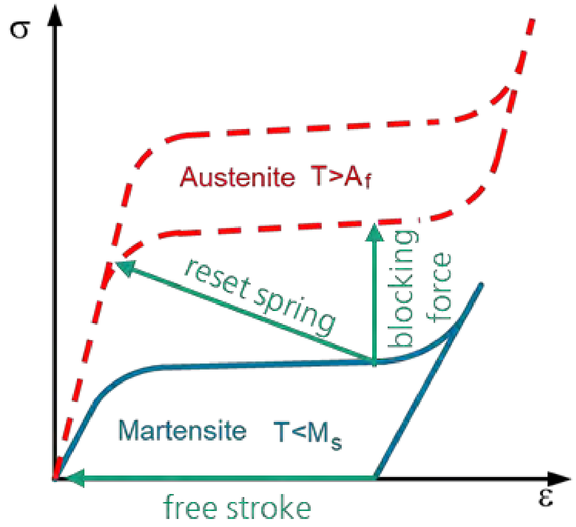
Effects:

- Pseudoelasticity: "elastic" behavior up to 8% strain
- **Pseudoplasticity:** stress-strain behavior that can be used for actuationInternal
- **Sensor effect:** resistance characteristics of phase transformation





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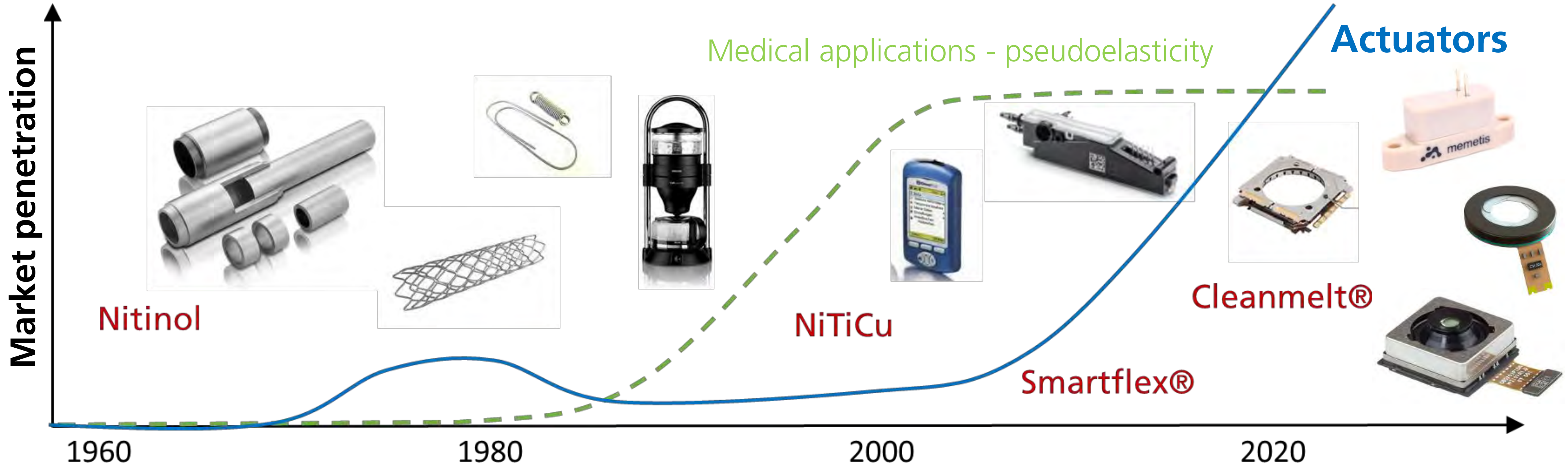
Status Quo



Know-How	SMA effects, design of uniaxial stress state	High-quality semi-finished products, design and manufacturing of components, sheet metal and tube manufacturing, manufacturing technology	Semi-finished products with high PTT, FEA simulation, spring manufacturing	Cyclically stable semi-finished products, industrial actuator manufacturing, electrically activated wire actuators, SMA control,	Thin films, HT alloys, textile integration, automated manufacturing processes, quality control
Application	Shrink connectors	First actuator applications	Springs in the consumer and automotive sectors	Valves, smartphone cameras, thermostats, medical devices	MEMS, Smart Textiles, Active Composites, Morphing, Consumer Products

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Focus on the entire value chain

Material Characterization

- Determination of characteristic values in each development step
- Methods of metal-lurgical, physical, and mechanical analysis

Test Benches

- Testing of systems with high maturity
- Wire actuators
- Springs
- High-load actuators
- Microsystems, MEMS

Simulation

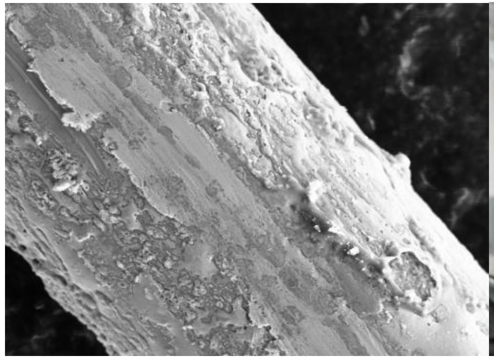
- FEA for components with multi-axis loads
- Transient models for system analysis of wires

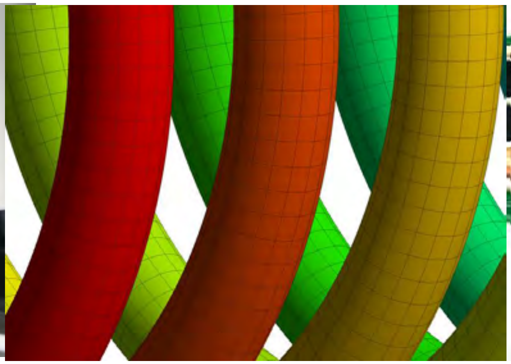
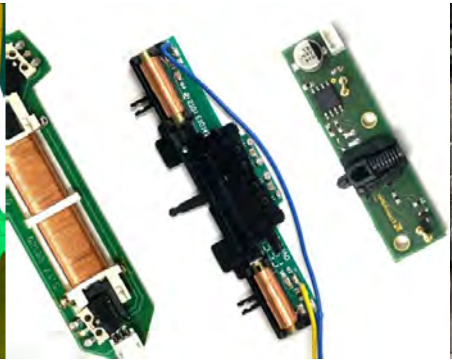
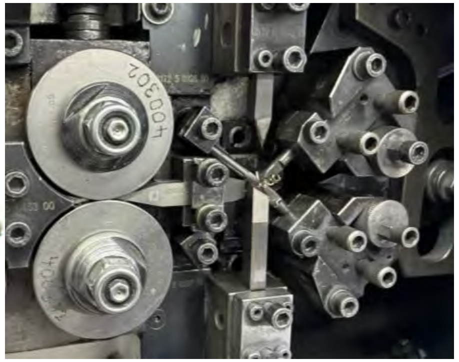
Application Development

- Microactuators,MEMS
- Wire actuators
- Self-sufficient actuators
- High-load actuators
- Stepper drives

Production Engineering

- Semi-finished product processing
- Automated manufacturing,
- Joining
- Generative manuf.



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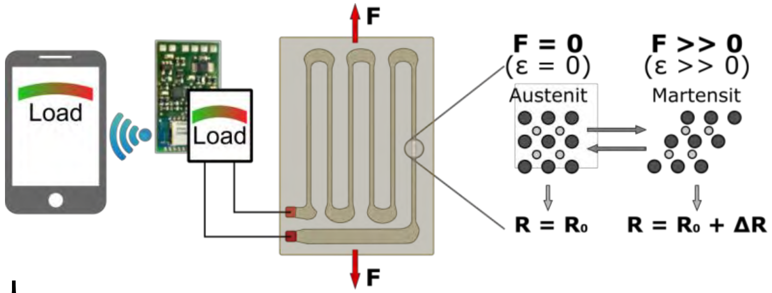
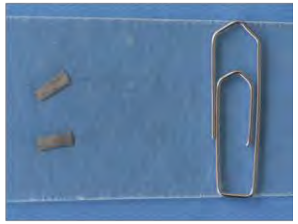
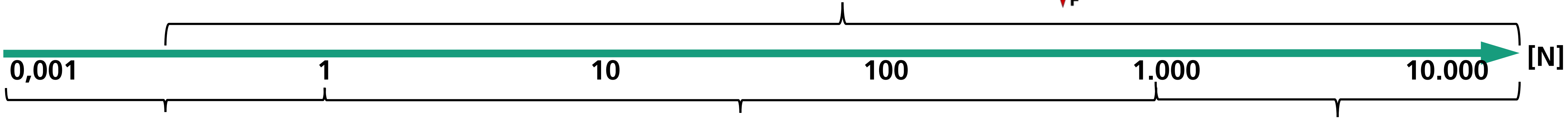
Range of applications

SMA sensors



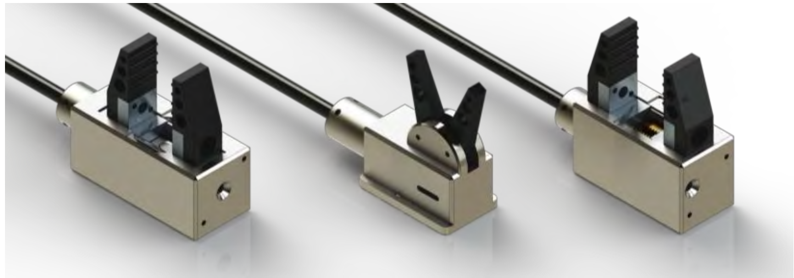




MEMS and SMA micro actuators

SMA wire actuators

High Load Actuators



Abteilung Formgedächtnistechnik

Range of applications

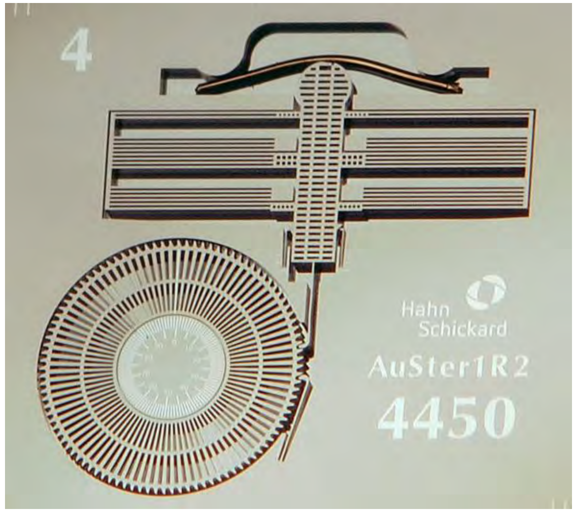
SMA-Sensors

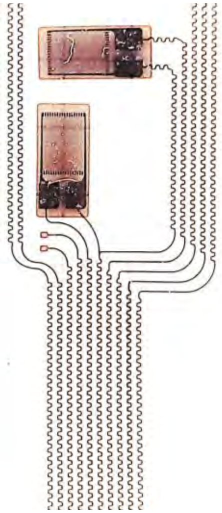
0,001 | 1 | 10 | 100 | 1.000 | 10.000 [N]

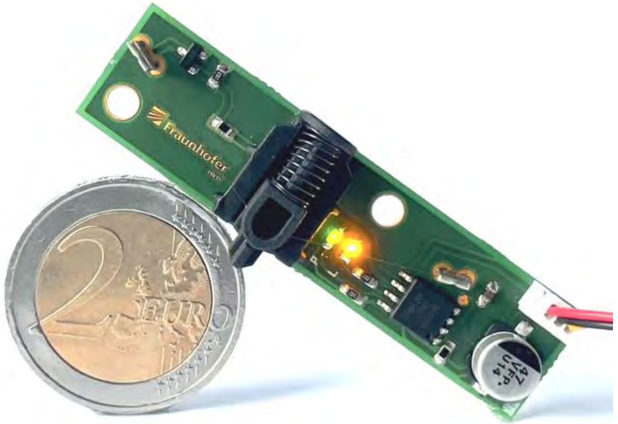
MEMS and SMA micro actuators

SMA wire actuators

High Load Actuators







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Material Characterization

Determination of material characteristics in every design step

Portfolio

Metallurgical analyzing methods:

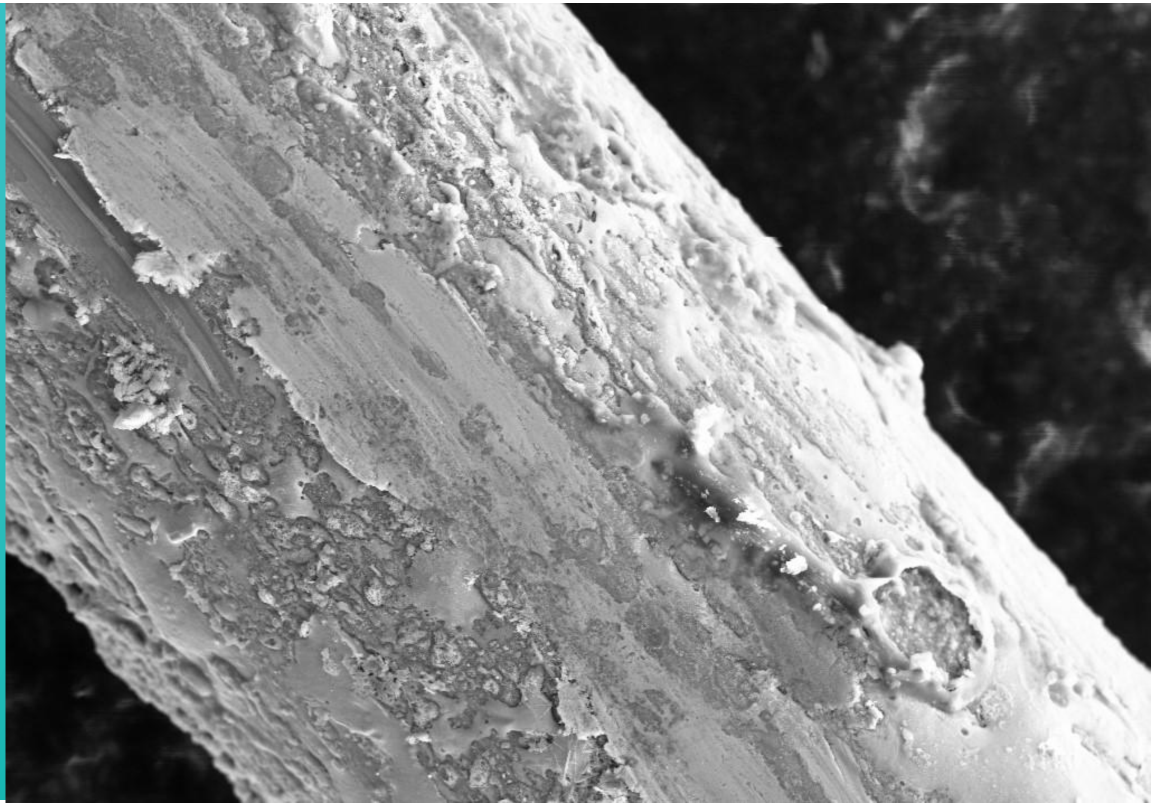
- SEM - Scanning electron microscopy
- XRD - X-ray diffractometer

Physical analyzing methods:

- DSC - Differential Scanning Calorimetry
- DIL - Quenching and Forming Dilatometer
- Magnetic property determination using Permagraph

Mechanical analyzing methods:

- Tensile-compression testing machine ZwickRoell
- quenching and forming dilatometer DIL 805

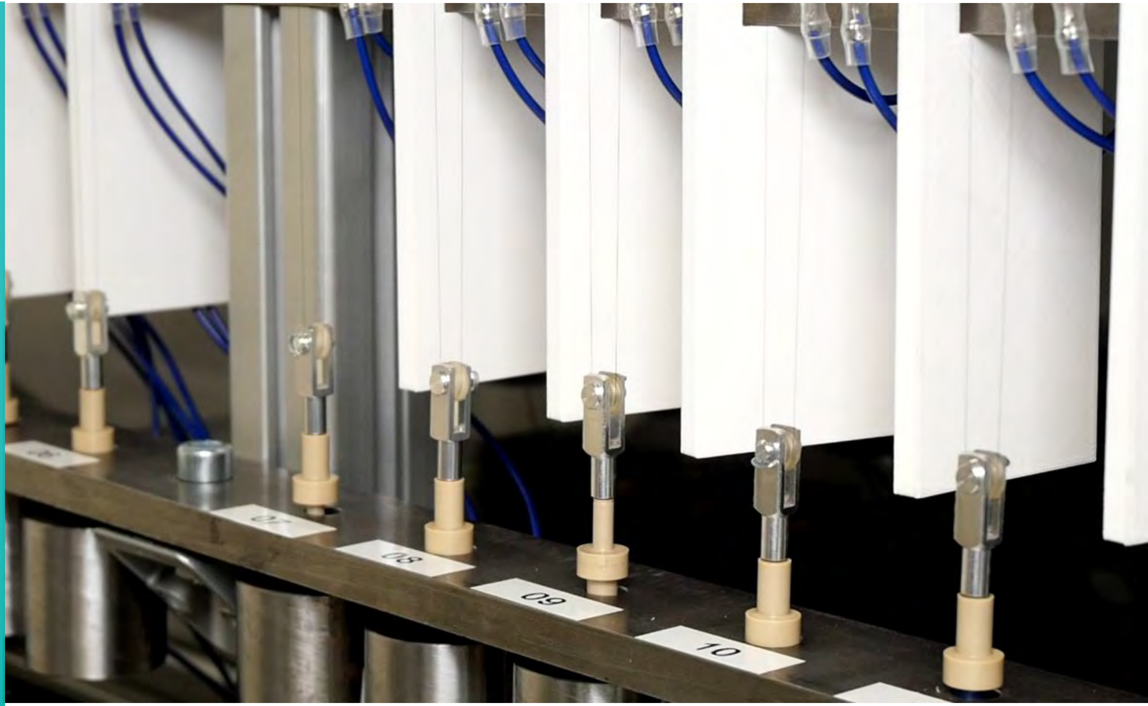


Test Benches

Testing of SMA actuator arrangements with a high maturity level

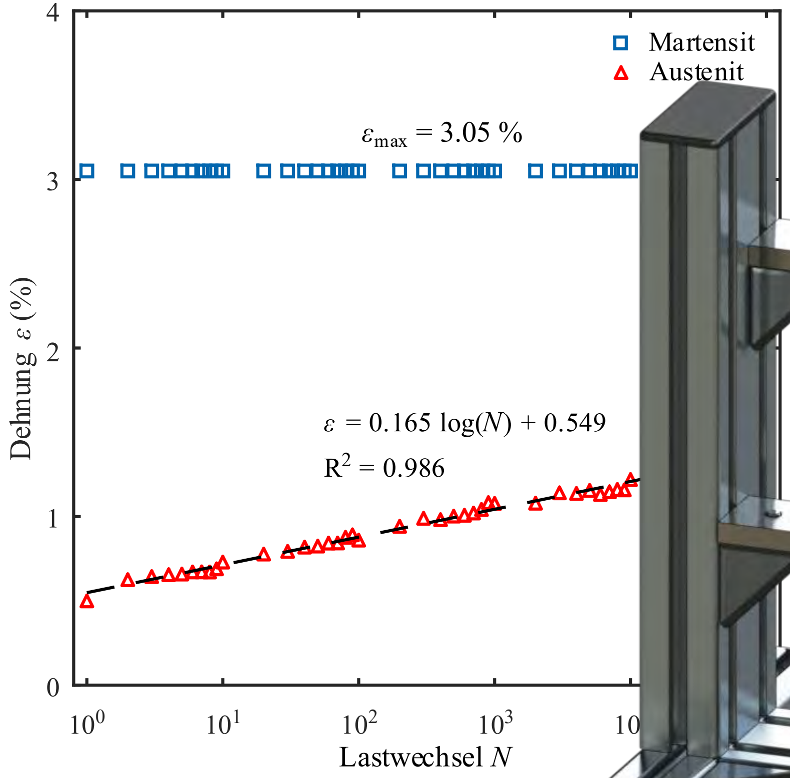
Services

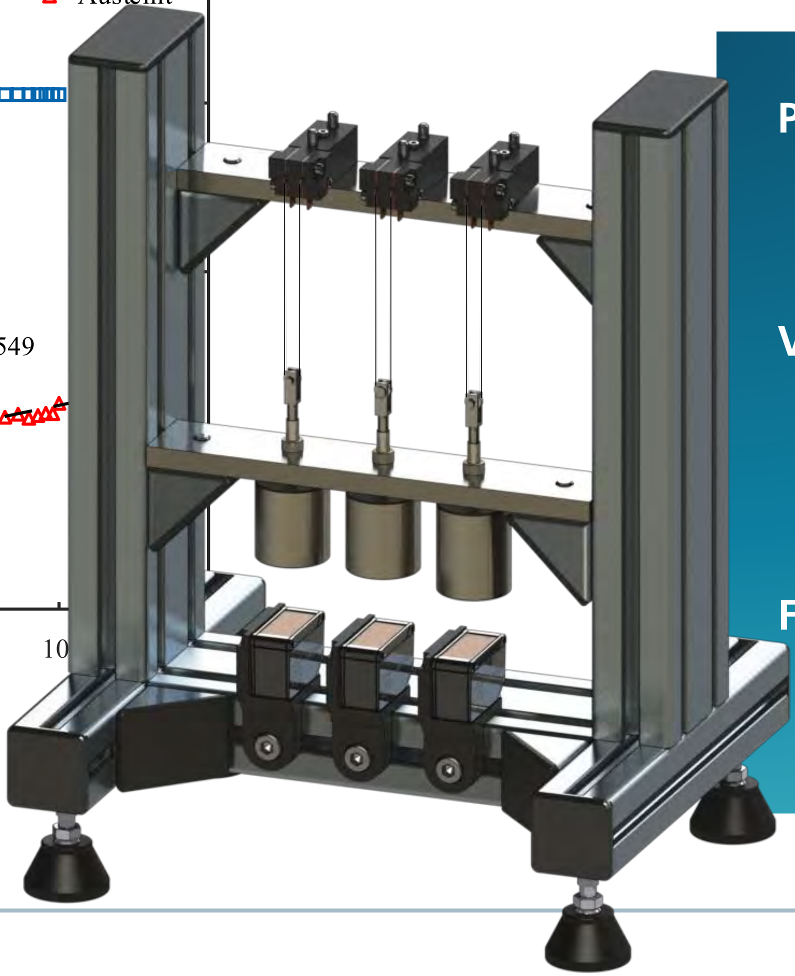
- Measurement and testing of SMA microsystems
- Wire test benches for quality, reliability and service life tests
- Testing of SMA spring components
- Testing of SMA high-load actuators in kN range
- Development of customer-specific test benches



Test Benches

Test Bench Functional Fatigue





Performance and measurement accuracy :

- Up to 3 actuator wires can be individually cycled
- Measurement of the cyclical change in stroke and resistance

Variable load simulation :

- Constant load using specially manufactured weights
- Adjustment of the stroke to an accuracy of 0.125 mm
- Realization of short and long-term tests

Flexible control:

- Current control
- PWM with constant voltage

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Test Benches

Test Bench Structural Fatigue

Life cycle analyses :

- Investigation of the fatigue behaviour of actuator wires until failure
- Determination of the maximum number of cycles depending on parameterizable electrical and mechanical load scenarios

Performance and measurement accuracy :

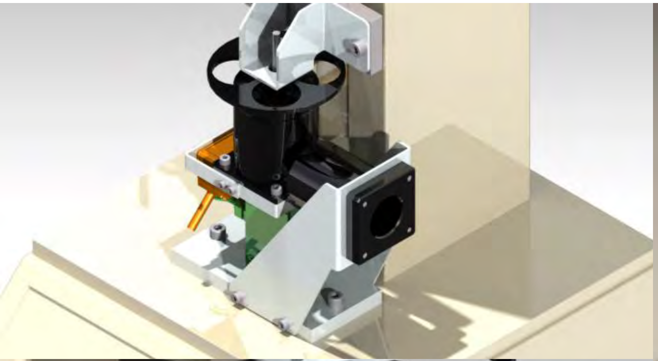
- Laser displacement sensors for measuring the stroke
- Measurement range: 10 mm, measurement resolution: 1 µm
- Current-controlled PWM modules for setting load currents up to 2 A

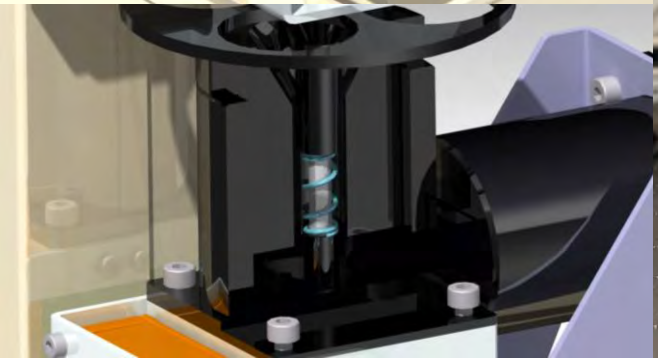
Flexible activation :

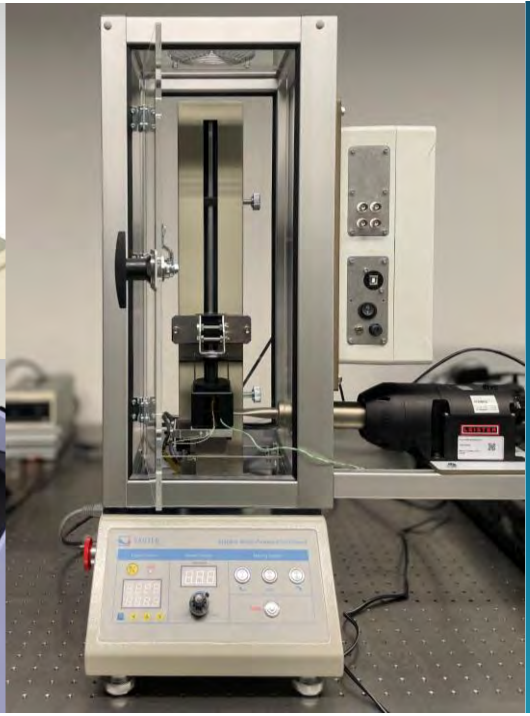
- 12 independent tracks
- GUI for parameterizing, visualization and storage

Test Benches

SMA Spring Test Bench







Performance and measurement accuracy :

- Actuator length of 100 mm, diameter 2–40 mm
- Maximum stroke 50 mm, max. force 500 N
- temperature control 20–150°C
- Fully automated measurement and data acquisition

Operation modes/measurement methods :

- Free stroke, displacement curve without load,
- blocking force for defined positions
- stress-strain curve using defined load
- stress-strain curve in cyclic test,
- force and stroke with controlled temperature curves

Test Benches

High Load Actuator Test Bench

Performance and measurement accuracy:

- Measurement of actuator forces up to 20 kN
- Detection of strokes in the micrometer range up to 1 mm

Operating modes/measurement methods:

- Realization of various load scenarios (force-free, constant load, blocked movement, stress-strain characteristics)
- Investigation of wear and degradation behavior
- Continuous load investigations

Flexible control:

- Power supply for actuator heating coil
- Indirect temperature control via contact surfaces
- Fluid temperature control for dynamic investigations

Simulation

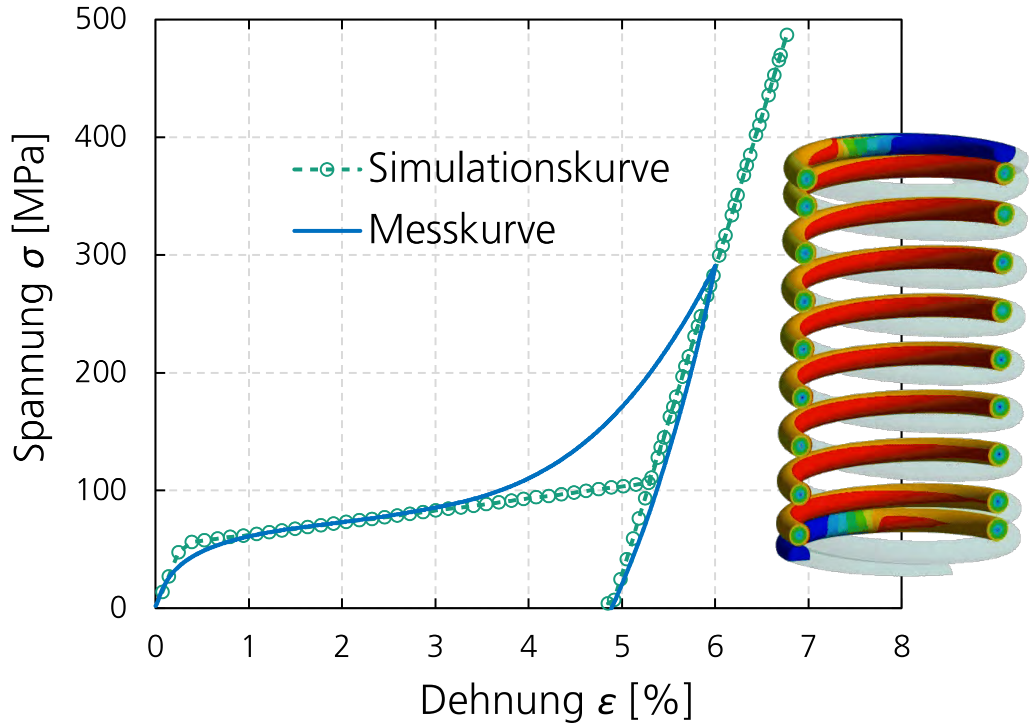
Tools for the design of SMA actuators

FEA-models:

- For calculating multi-axis loaded actuators (springs, bending transducers, bulk actuators)
- Based on measured stress-strain diagrams and stress dependence of the Phase Transition Temperatures
- Representation of relationships in the model with 7 parameters

Transient models:

- Suitable for uniaxially loaded actuators
- Based on balancing of energy components during phase transformation
- Parameters derived from stress-strain diagram
- Application in the development of control concepts



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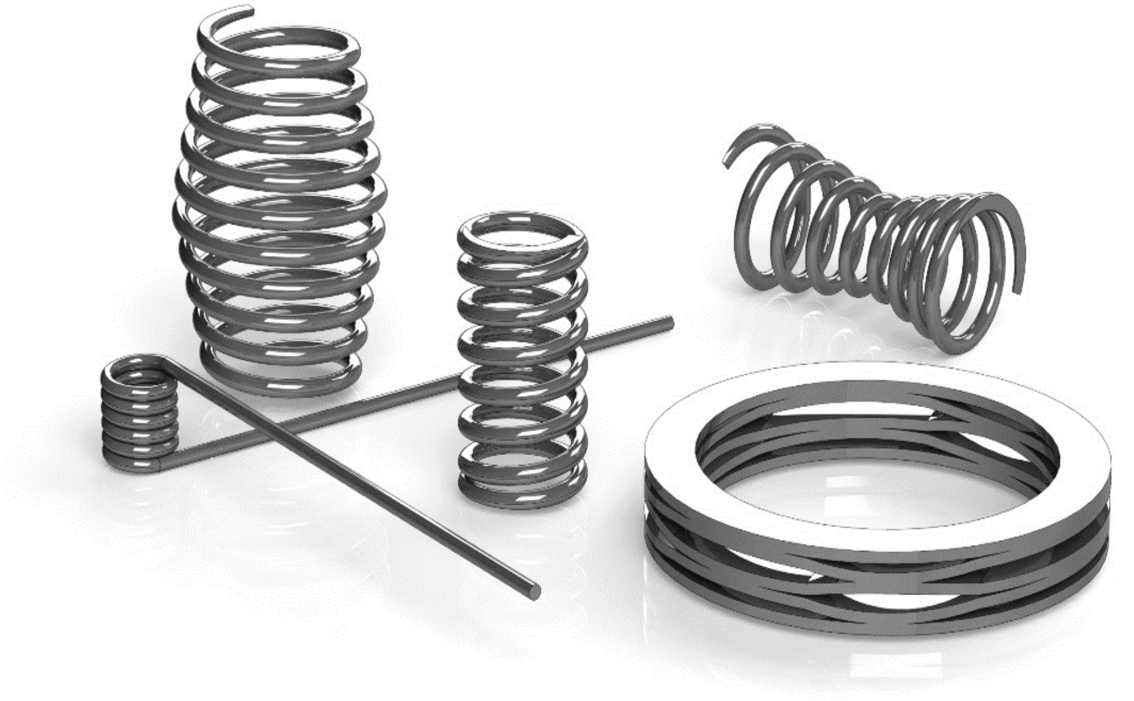
Simulation

Reference Project: Characteristic value-based design system of shape memory springs



Motivation and objective:

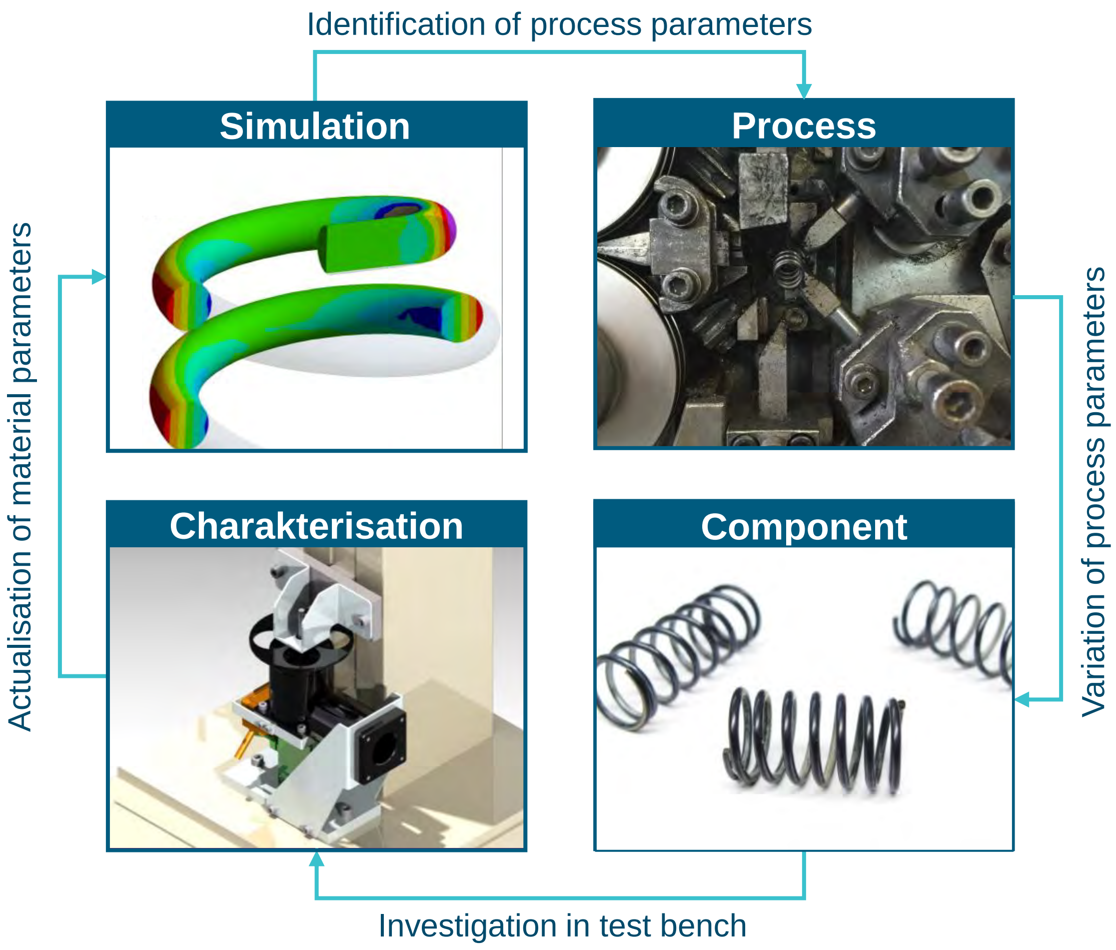
- Designing of SMA springs is a time-consuming, iterative process
- Calculation using FEA is complex
- Development of an industry-standard design system
- Further development of standardized procedures for determining SMA characteristics.

Results:

- Identification of the mathematical relationships between characteristic values, geometry, and force-displacement curve using DoE
- Integration of the equations into a user-friendly design tool

Simulation

Reference Project : Process development for the efficient production of SMA springs



Motivation:

- Manufacturing of SMA springs is complex, as tools for heat treatment are required after winding
- High costs, low flexibility

Objective:

- Tool-free manufacturing concept
- Prediction of permanent deformation using FE models
  Targeted adjustment of the degree of forming to achieve the target geometry
- Shortened process chain

Application Development

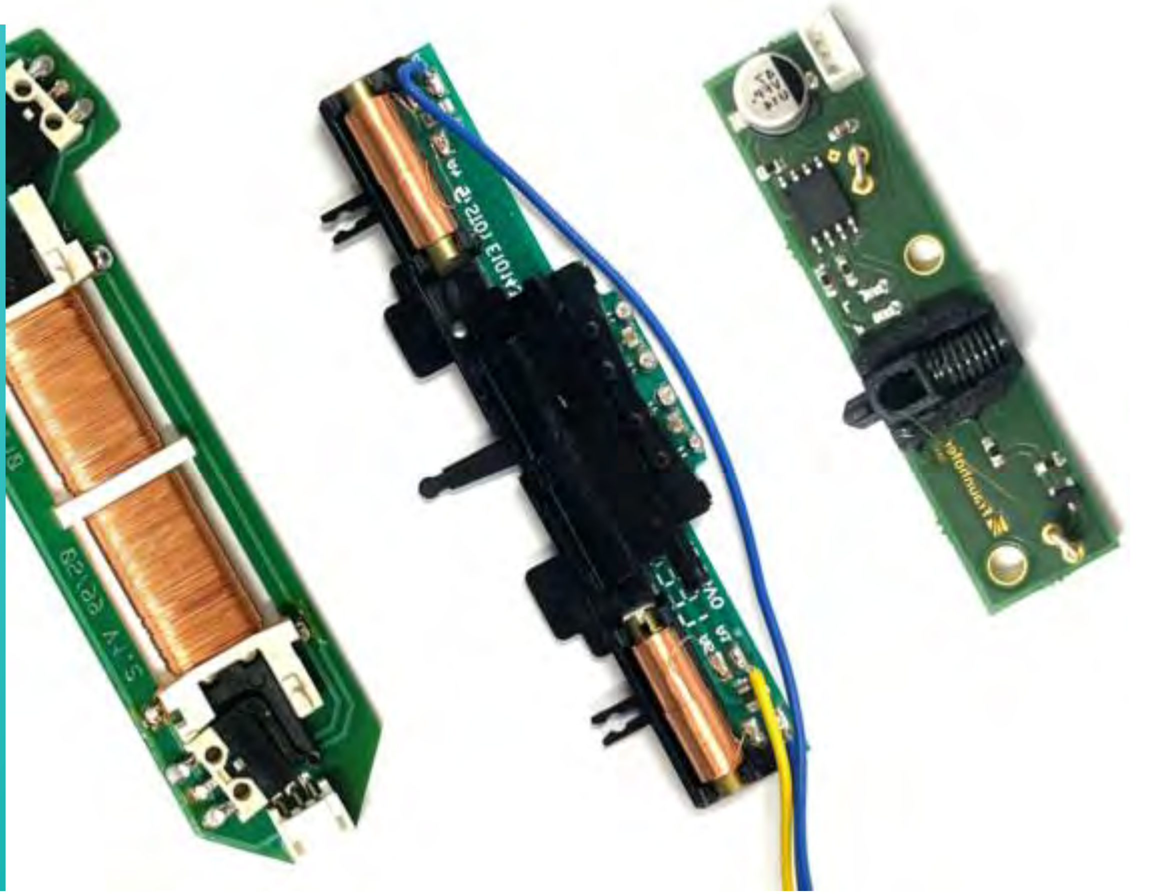
Focus on the entire value chain

Consideration of all product-specific aspects :

- Defined specifications from specifications
- Material-related factors: functional and structural fatigue, phase transformation temperatures
- Design aspects: tolerance chains, target production volumes, manufacturing processes
- Control aspects

Application examples:

- MEMS and microactuators
- Wire actuators for valve applications, drones, grippers, manipulators, and unlocking systems
- Self-sufficient actuators for thermal circuits and electrical connections
- Compact high-load actuators for mechanical engineering



Application Development

Reference Project: Force-sensitive grippers based on SMA

Application area:

- Parallel/pincer gripper for removing molded parts/castings
- Micro gripper, medical engineering

Advantages:

- Lightweight by functional integration – no sensors required
- Compressed air-free operation but flexible installation space
- Electromagnetic compatibility and biocompatibility
- Scalable approach for a wide range of application scenarios

Technical Data	Parallel gripper	Pincer gripper
Gripping force:	5 N	10 N
Stroke / opening angle:	10 mm	50°
Lifetime:	1 Mio. gripping cycles	
Closing time:	1 s	

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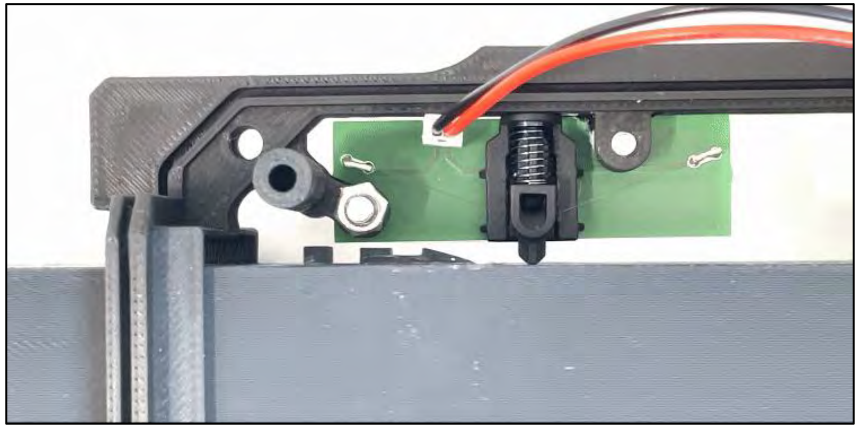
Application Development

Reference Project: Compact lightweight drives for quadcopters



Battery slide lock in the Grabbit G7 quadcopter

- Lightweight design due to 76-micrometer thin actuator wire
- Easy integration into compact installation spaces
- Electromagnetic compatibility
- Easy scalability for a wide range of applications

Technische Daten

Stroke:	> 2	mm
Activation time:	0,1	s
Dimensions:	56 x 14 x 10	mm³
Operating temperature:	-20 – 65	°C
Weight:	4	g
Lifetime:	> 10.000	Cycles

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Application Development

Reference Project: SMA micro irrigation valve

Motivation:

- Demand-oriented plant watering using passive drip irrigation systems is established
- Influence of pipe lengths, gradients and pressure fluctuations
- Switchable valves required

Solution:

- Miniaturized, switchable diaphragm valve
- Bistable kinematics – push-push mechanism
- Switching by briefly activating an SMA actuator
- Pressure up to 2.5 bar, activation power 16 W, switch time 5s
- Power supply and control via bus system using two-wire cable in the hose

Application Development

Reference Project: SMA high-load actuators

Motivation:

- Mechanical engineering applications require compact actuators with high rigidity, forces in kN range, and strokes up to 1 mm.

Solution:

- High energy density of SMA enables high-performance actuators with a small size
- Thermomechanical optimization of the actuator geometry enables good controllability and efficiency
- Applications: Fine positioning, clamping or loosening, compensation of deformations

Technical data

Dimensions:	h=16 mm, d=15 mm, V=2,8cm³
Free stroke / working stroke:	180/120 µm
Actuating force:	5 kN
Energy consumption	50 Ws
Dynamic:	Bis zu 1 Hz bzw. 180 µm/s

Application Development

Reference Project: SMA Charging Plug

Motivation:

- During DC fast charging of BEVs, high contact resistance between the plug and socket causes heating
- Installed charging capacity is steadily increasing
- Plug system standardized as CCS: changing the geometry or increasing the normal contact force is not possible.

Solution:

- Integration of SMA actuators for self-sufficient contact force increase during heating
- Reduction of contact resistance reduces heat generation and increases charging efficiency

Application Development

Reference Project: Micromechanical sterilization cycle counter

Motivation:

- Manipulation-proof counting of sterilization cycles performed on medical devices remains unsolved
- Human factor remains the biggest source of error despite documentation
- Device manufacturers have no access to data

Solution:

- Micromechanical counter Driven by heterogeneously integrated SMA actuator
- Hermetic and sterilization-resistant encapsulation
- Cycle counts up to 10,000 possible

Application Development

Reference Project: Arts and Crafts

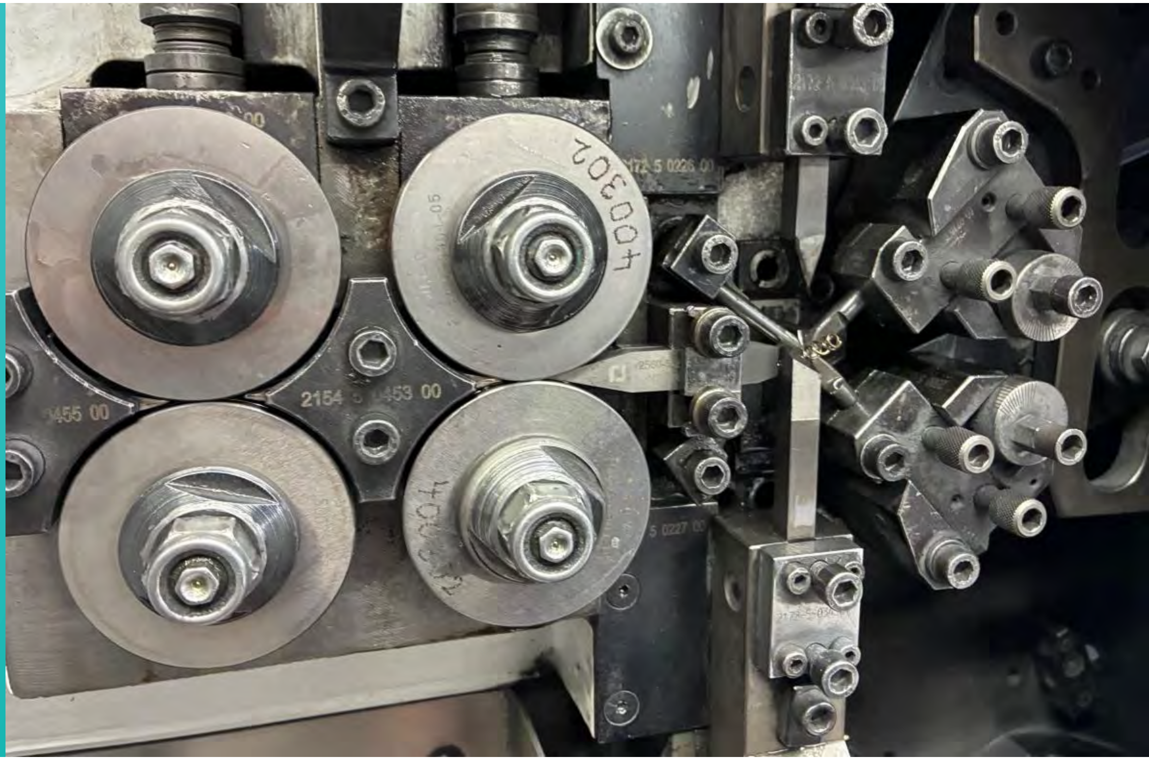
The SMA smoking rocket is the result of a collaboration between traditional Erzgebirge craftsmanship (Original Füchtner Holzkunst) and high-tech materials research (Fraunhofer IWU). The highlight: the heat from a standard smoking candle is enough to activate the shape memory function. After a few minutes, "Wilhelm the Traveling Nutcracker" appears as if by magic. It is no coincidence that he is inside a rocket. Together with German astronaut Matthias Maurer, Wilhelm has already been to the International Space Station (ISS). Back on Earth, a product was created that impressively demonstrates that smart materials have arrived in the world of wood art.

Production Engineering

Economical manufacturing methods as a key to a successful product

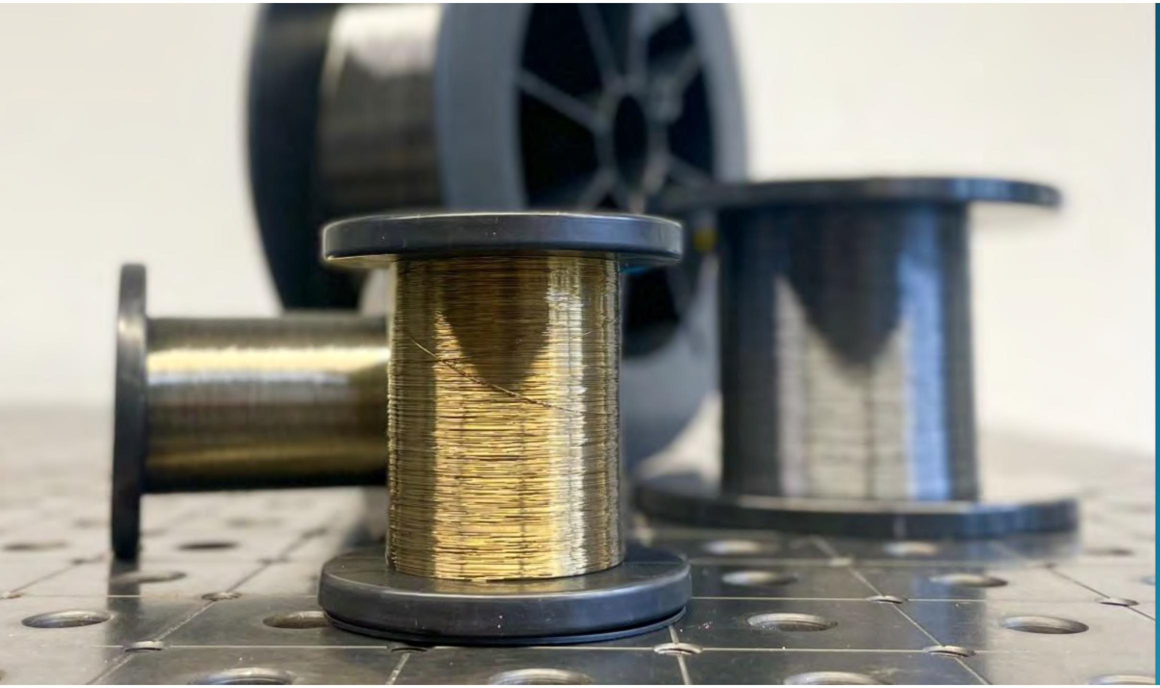
Portfolio

- Process development for semi-finished product conditioning and component manufacturing, e.g., of SMA springs
- Automated manufacturing processes for SMA wire actuators
- Quality control methods
- Development of joining technologies for SMA components: crimping, welding, soldering
- Additive manufacturing of SMA elements
- Textile processes for SMA wires
- SMA polymer integration using thermoset or thermoplastic processes



Production Engineering

Reference Project: SMA semi-finished product conditioning



Motivation:

- Distinctive run-in behavior of SMA wires during the first thermal load cycles.
- Must be taken into account during design or compensated for by time-consuming thermal cycling.

Solution:

- Mechanical cycling in the high-temperature phase – passing through mechanical hysteresis
- More energy- and time-efficient conditioning of wires and components such as springs possible

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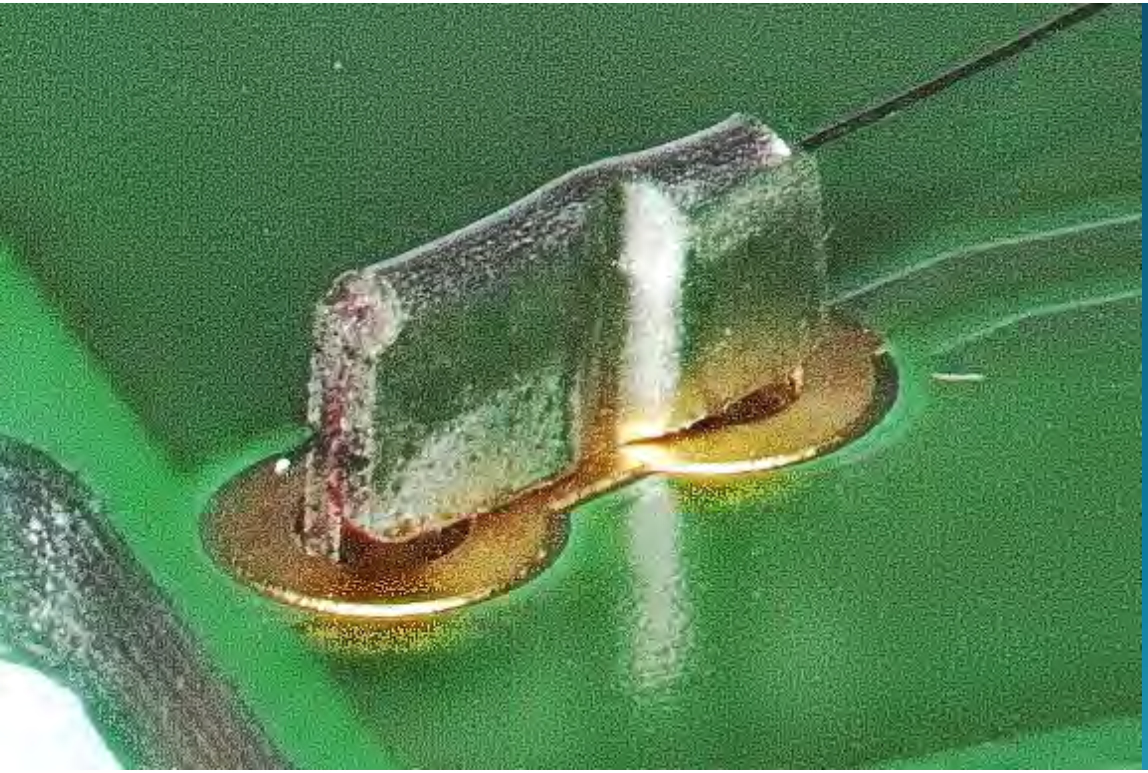
Production Engineering

Reference Project: Crimp Development



Motivation:

- Integrating the thin SMA wires into fully automated production processes is a major challenge.
- In known industrial applications, exclusively crimp or splice connections are used.

Solution:

- Scalable crimping concept with broad industrial applicability
- Characterization of crimp connections using DoE

Validated connections (test terminated before failure):

- Ø 180 µm @300 MPa: 500.000 load cycle
- Ø 150 µm @300 MPa: 800.000 load cycle
- Ø 76 µm @300 MPa: 1,7 Mio. load cycle

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Production Engineering

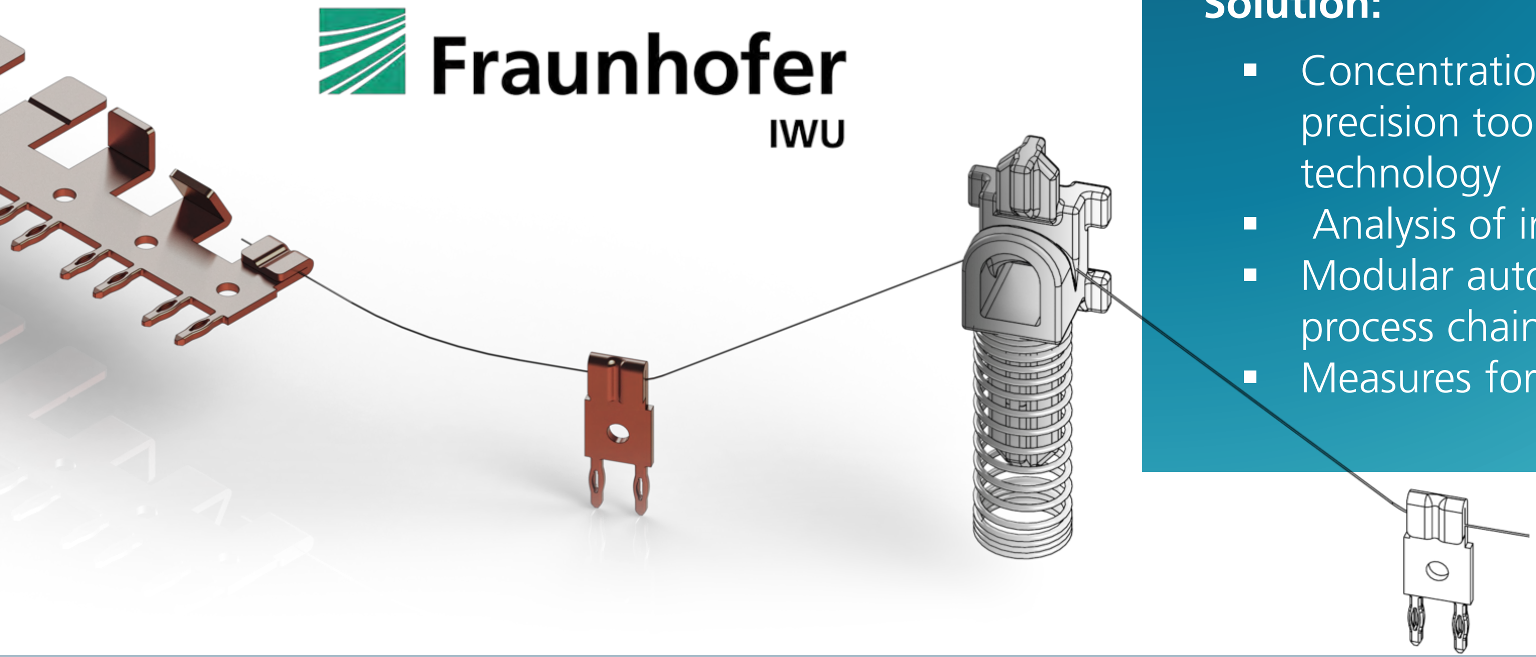
Reference Project: Optimization of series production of SMA wire actuators using a modular platform

Motivation:

- Automated production of SMA actuator systems poses a particular challenge due to the properties of SMAResources for the development of special production equipment are often unavailable, preventing market penetration

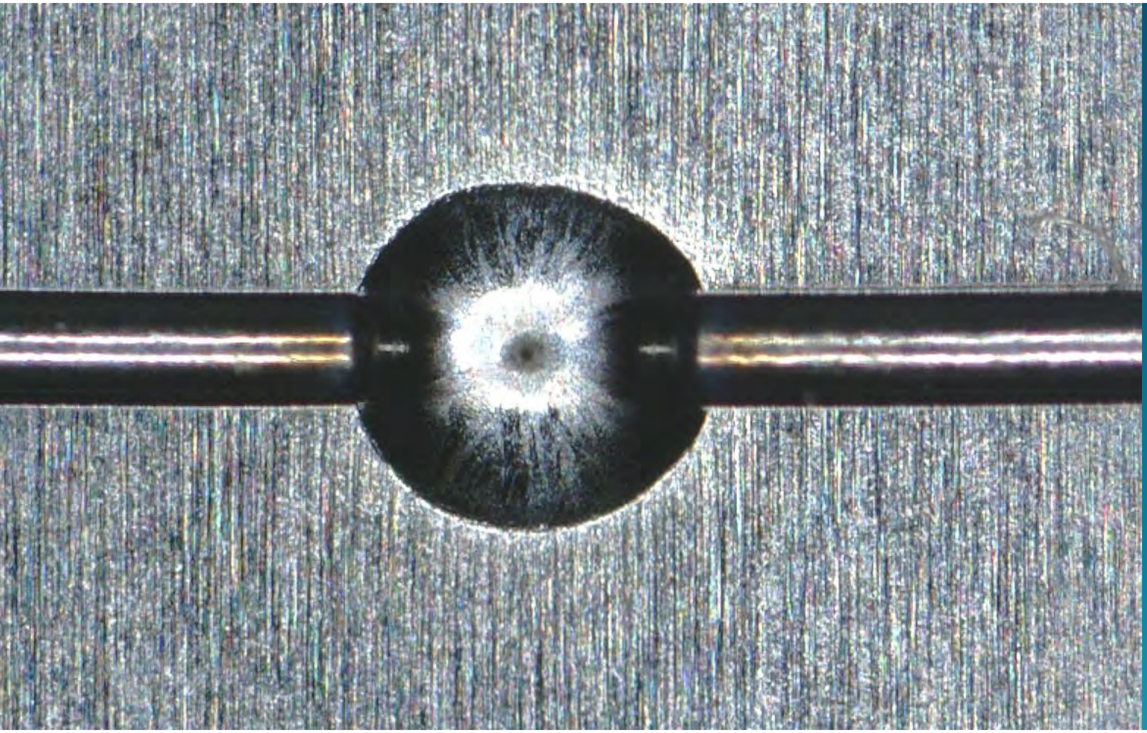
Solution:

- Concentration of expert knowledge on: SMA, special and precision tools, handling, thin wire processing, and automation technology
- Analysis of individual processes and interactions
- Modular automation platform for representing exemplary process chains
- Measures for automation-compatible design



Production Engineering

Reference Project: Thermal joining processes for SMA



Motivation:

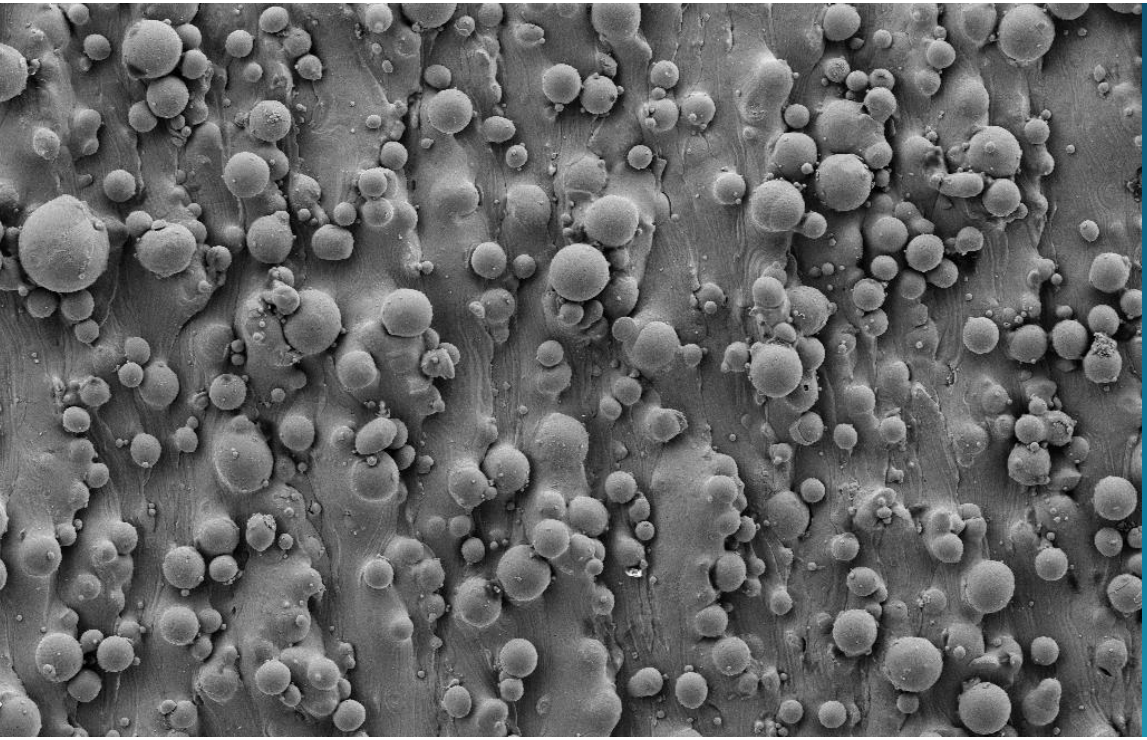
- Joining of SMA remains a challenge
- Crimp technology unsuitable for thin films or thin wires
- Thermal joining processes may offer a long-term alternative

Solution:

- Systematic investigation along the entire joining process chain – plasma polishing, coating, laser welding, thermomechanical post-treatment
- Economical and production-ready process chain

Production Engineering

Reference Project: Additive Manufacturing of SMA



Motivation:

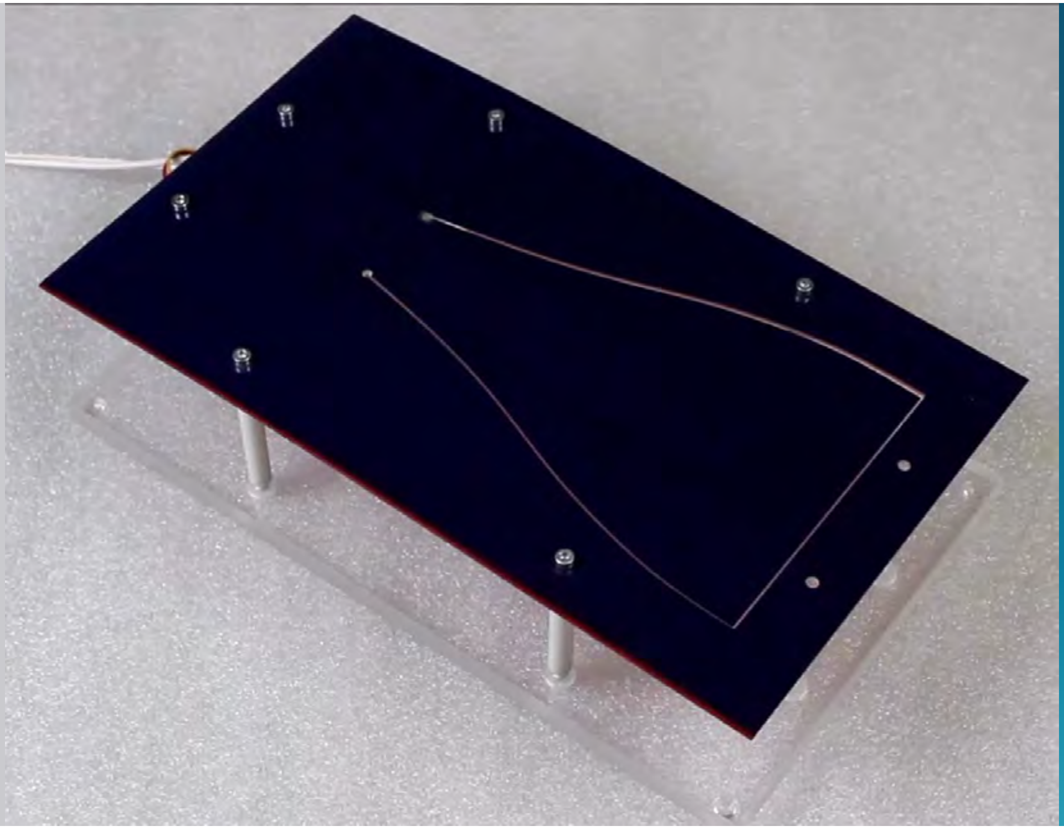
- Processing of SMA semi-finished products is still very complex
- Technologies for metallic 3D printing suitable for the cost-effective production of complex SMA components
- Additive manufacturing must always be considered and viewed as a process chain – so far insufficiently researched

Solution: Holistic development approach

- Analysis and consideration of all individual process steps along the value chain
- Holistic understanding of the technology from melting to product

Production Engineering

Reference Project: SMA Polymer Integration



The integration of SMA into polymer structures opens a wide range of possibilities for the production of active components

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Manufacturing processes :

- Injection molding: for embedding SMA elements directly into the polymer matrix, manufacturing complex actuator systems in a single process step
- Extrusion or pultrusion processes: for manufacturing profiles with integrated SMA wires or foils
- Thermoforming processes: for targeted shaping of SMA semi-finished products and adaptation to existing designs
- Laminating processes: for layer-by-layer integration of SMA, also in combination with textile semi-finished products

Thank you very much!

Contact

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