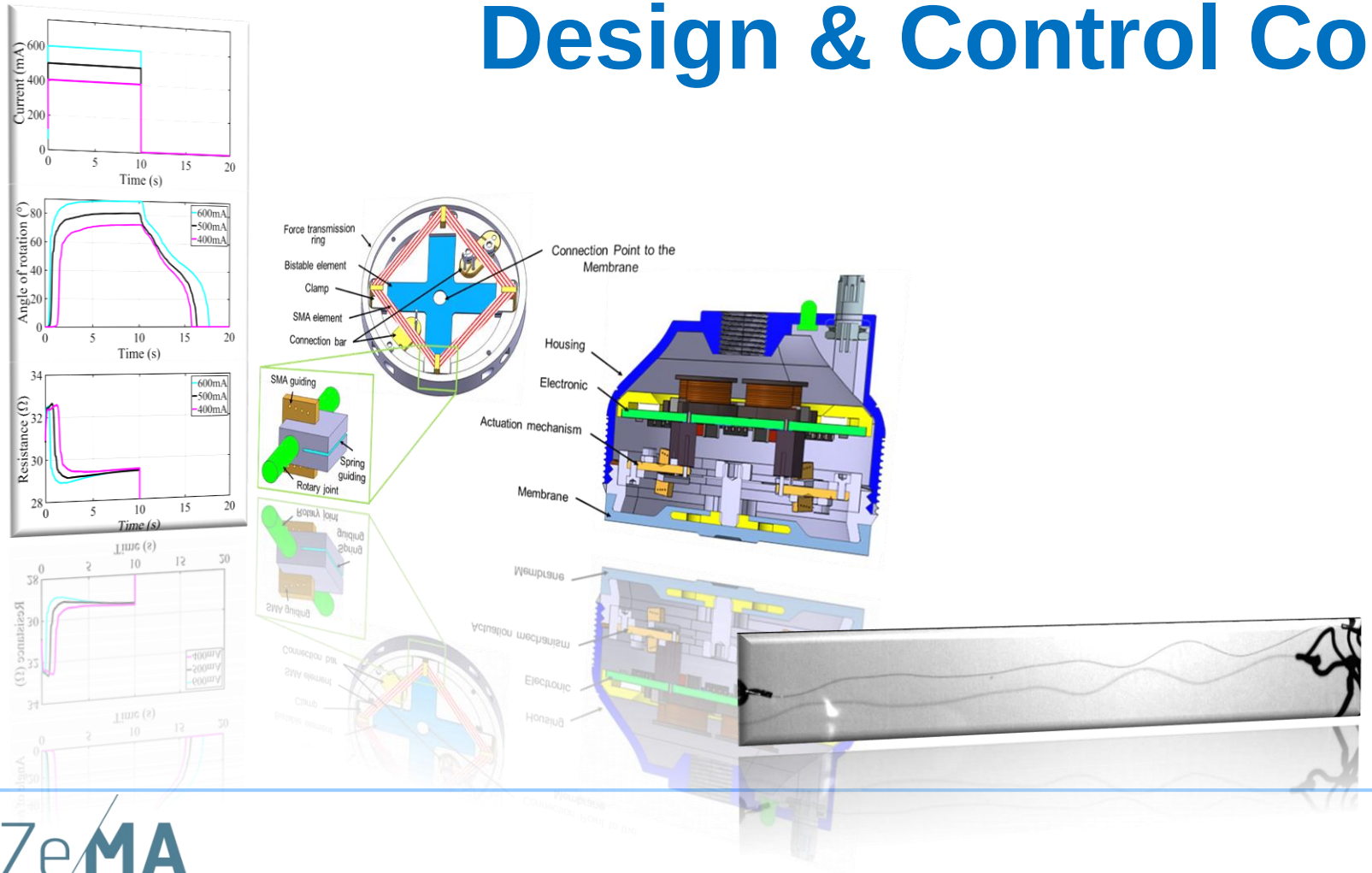
UNIVERSITÄT DES SAARLANDES

Intelligent Material Systems Laboratory

Efficient SMA Actuation - Design & Control Concepts



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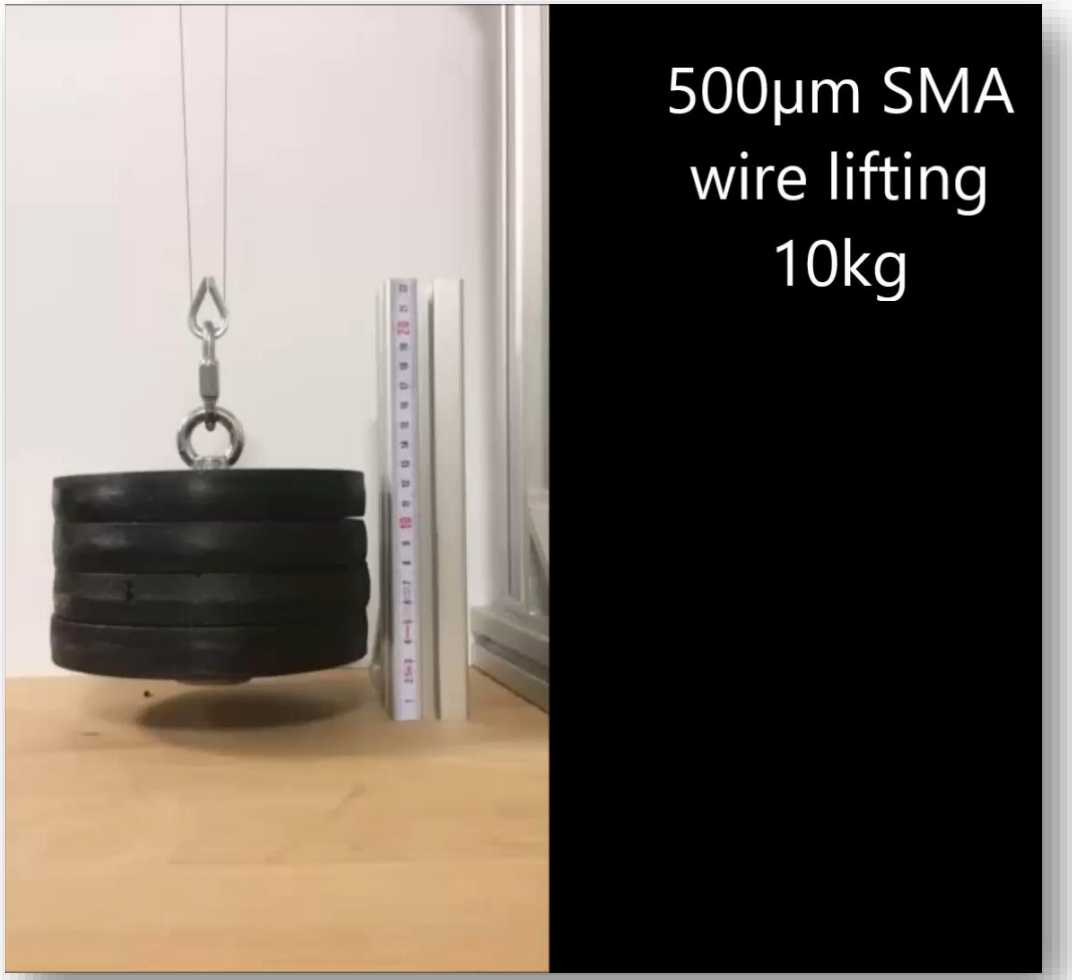
ZeMA

SMA Fundamentals

Shape **M**emory **A**lloy – **SMA**

Phase transformation from Martensite to Austenite during a heating and cooling period

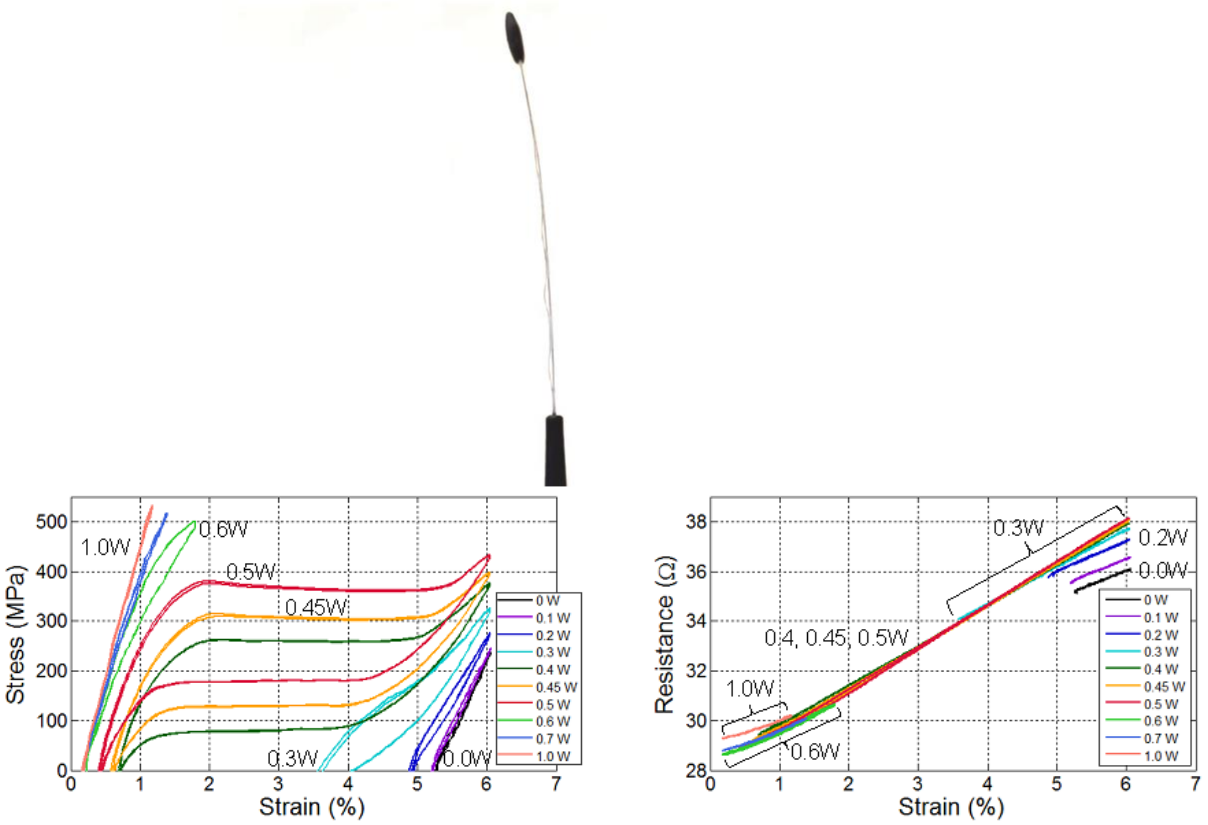
„Metal muscles“ – Nickel-Titanium (NiTi) wires



SMA Properties

- HIGHEST ENERGY DENSITY
- High Forces
- Unique form factors
- Noiseless operation
- Bio-compatible
- **SELF-SENSING**

Compact and Lightweight Actuator-Sensor Systems



N. Lewis, A. York, and S. Seelecke, "Experimental characterization of self-sensing SMA actuators under controlled convective cooling," Smart Mater. Struct., vol. 22, no. 9, p. 094012--, 2013.

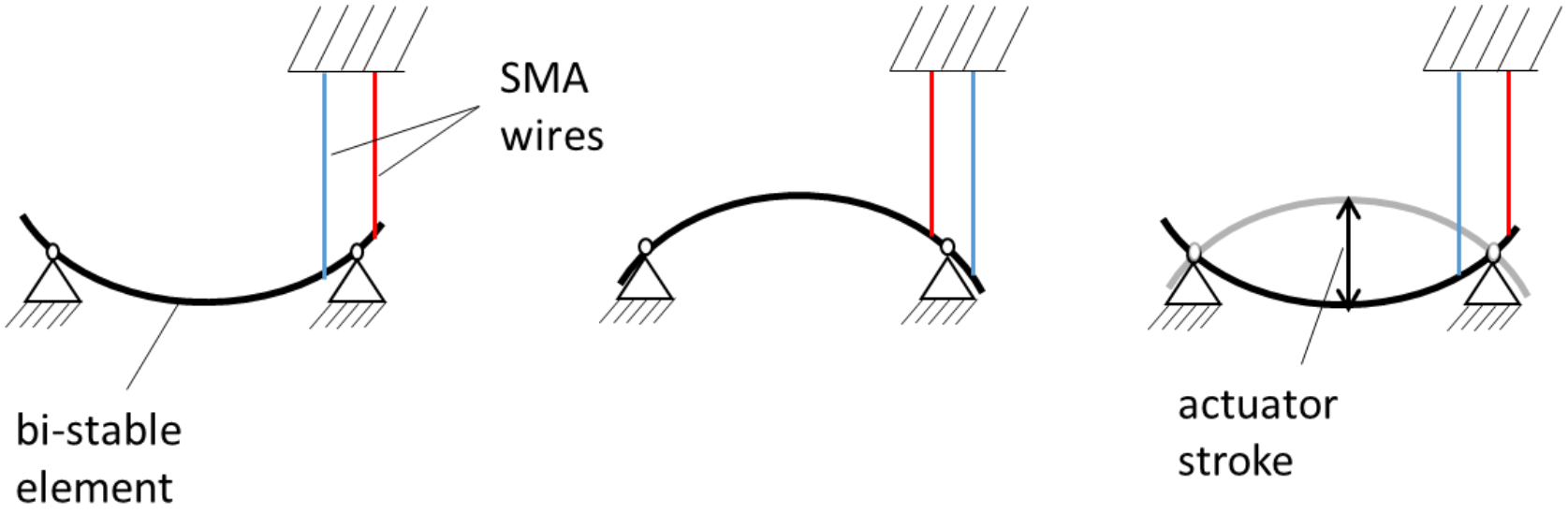
Advanced Actuator Design

SMA drawbacks: → **Development of an SMA actuator, that...**

- High strokes require long wire length or gear/transmission system → ...has a **compact design** and can still generate high strokes and high forces.
- Holding activated positions is **energy-intensive** (mono-stable) → ...can hold 2 positions energy-free (**bi-stable**).
- Frequency directly coupled to cooling time of the SMA wires (biasing mechanism necessary) → ...can reach **higher frequencies** in both switching directions.

Bi-stable Actuator Design

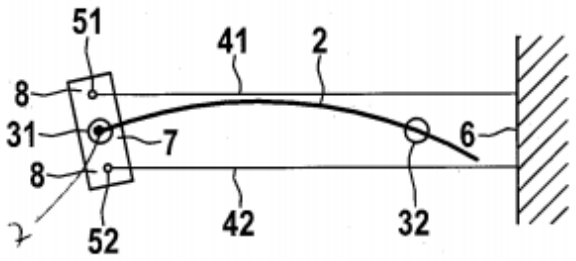
Core item: **Bi-stable element** (e.g. metal sheet beam)

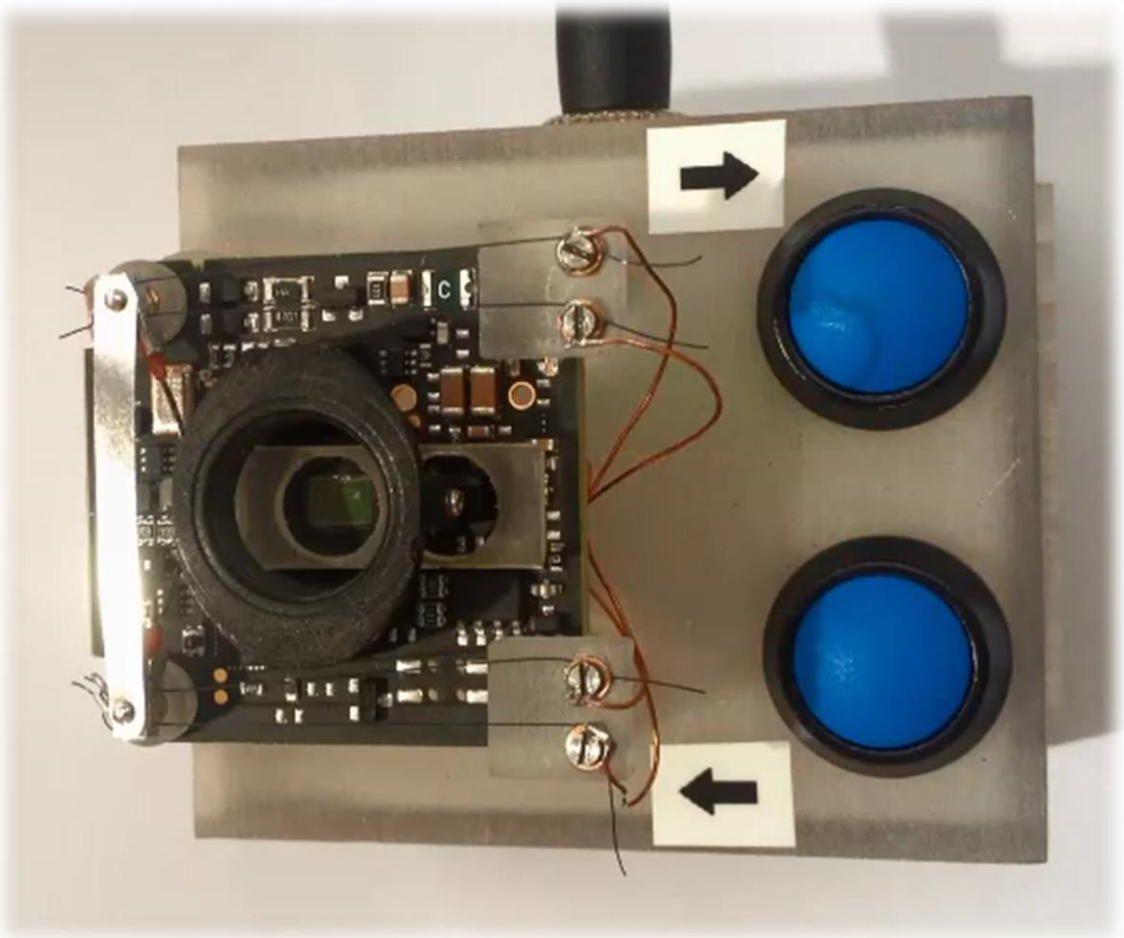


P. Motzki and S. Seelecke, "Bi-stable SMA Actuator," in Actuator 16 - 15th International Conference on New Actuators, 2016, pp. 317–320.

Actuator Properties

1. **Bi-Stability** → 2 defined **energy-free** positions
2. ***Antagonistic* Wires** → **No passive cooling time**
3. **Actuator Stroke** scaled by SMA attachment



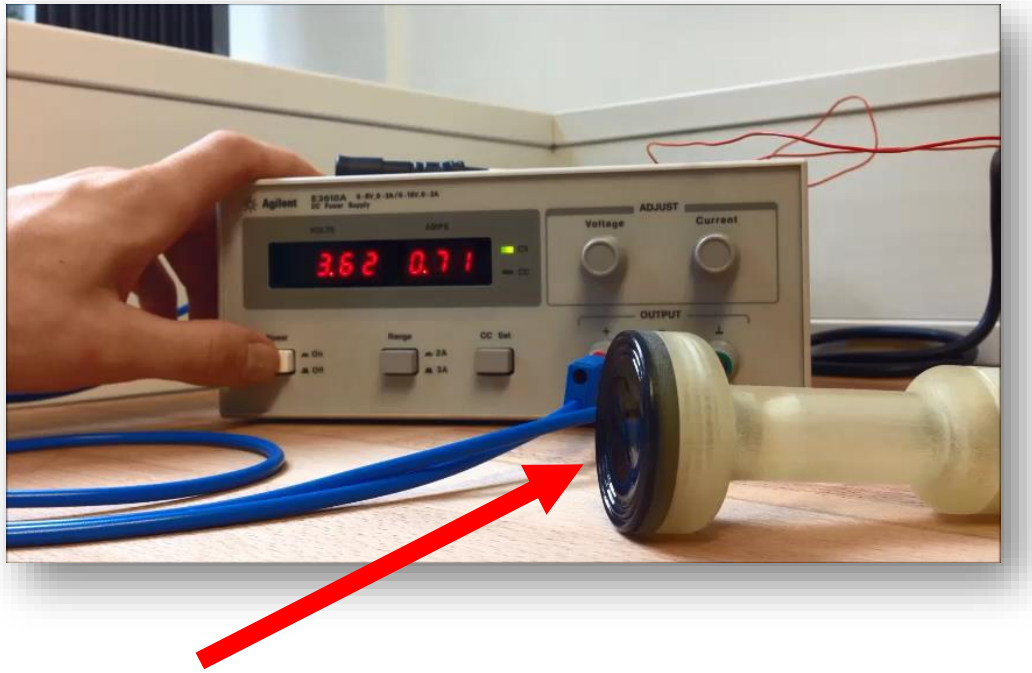


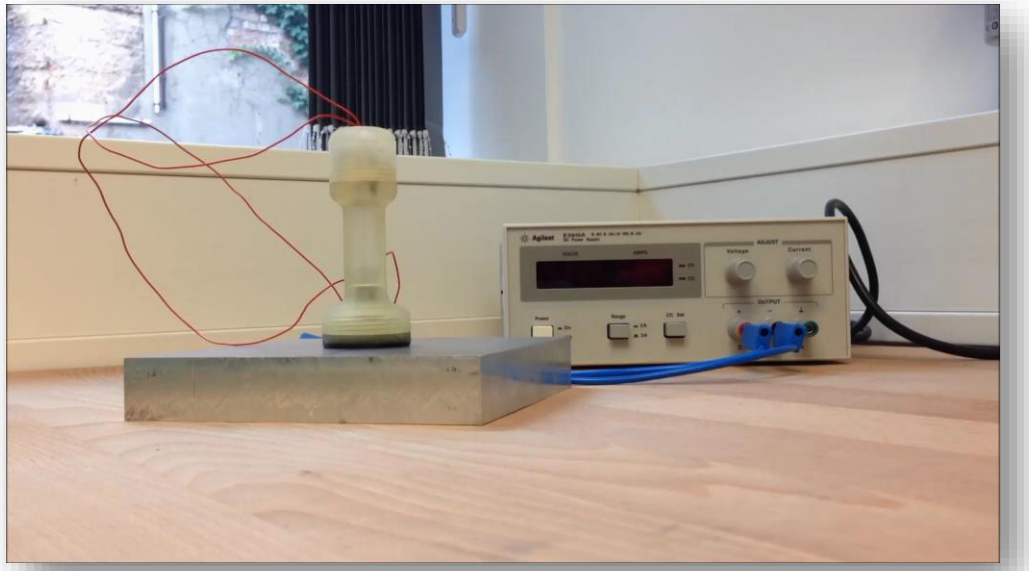
PATENT PENDING - *(licensed in USA)*

P. Motzki and S. Seelecke, "BISTABLE ACTUATOR DEVICE HAVING A SHAPE MEMORY ELEMENT," WO 2017/194591 A1, 2016.

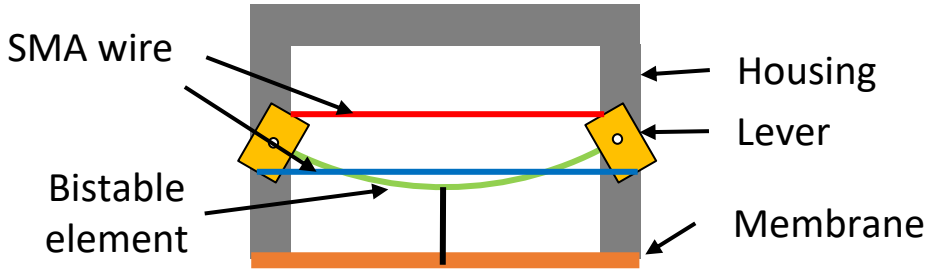
P. Motzki and S. Seelecke, "Bistabile Aktorvorrichtung mit einem Formgedächtniselement," DE 10 2016 108 627 A1, 2016

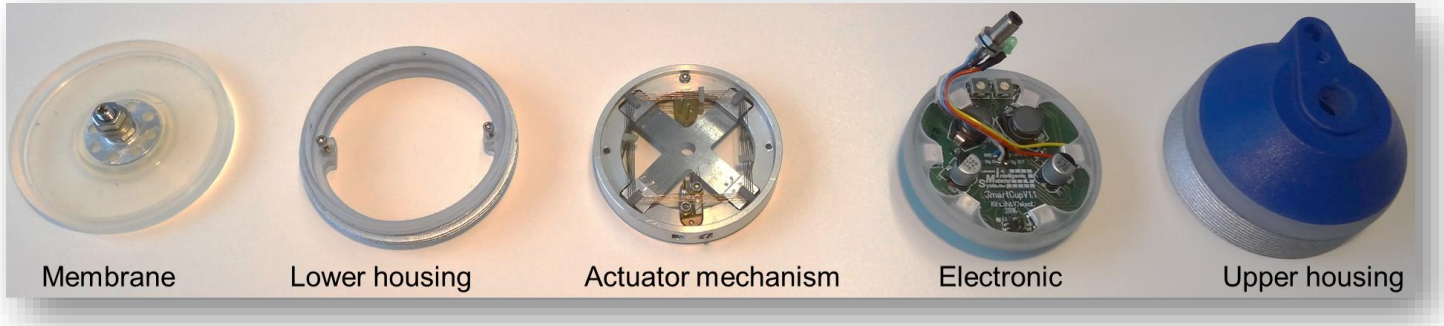
SMA Suction Cup



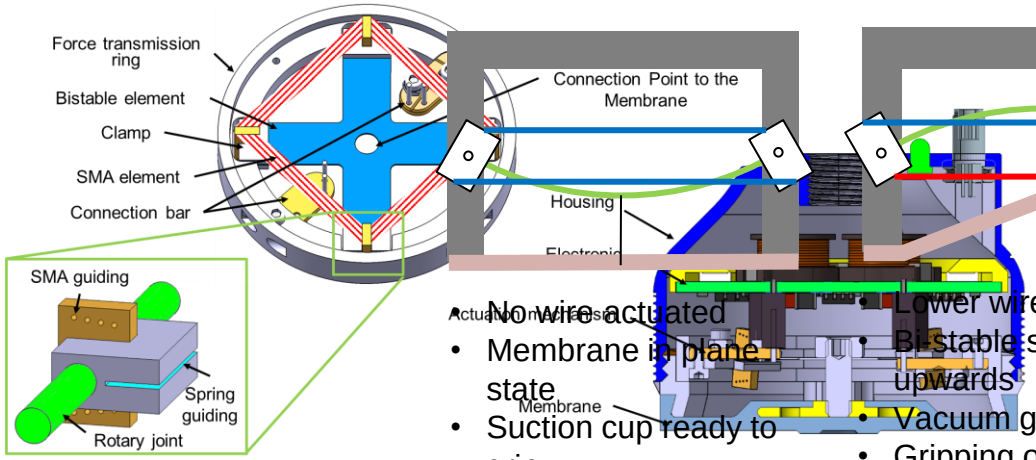


Bi-stable SMA Suction Cup



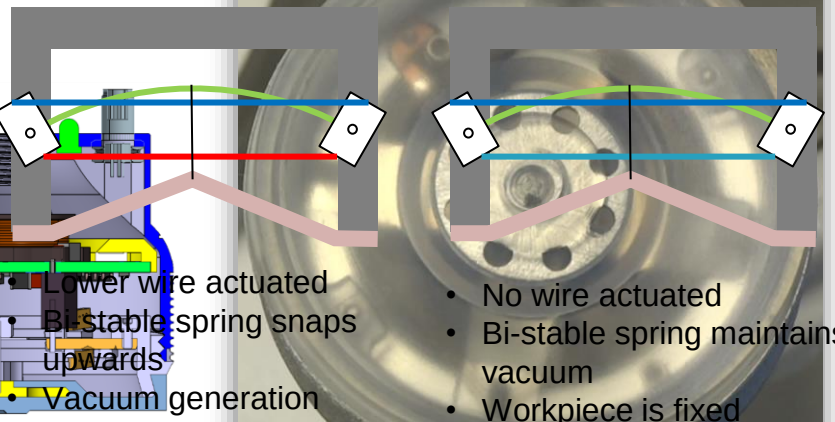


1. Standby



- No wire actuated
- Membrane in plane state
- Suction cup ready to grip

2. Gripping

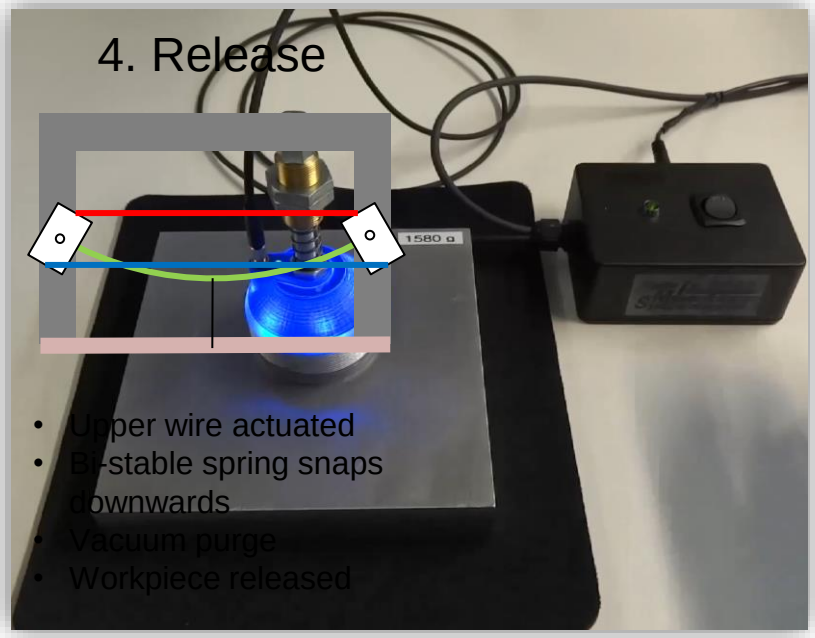


- Lower wire actuated
- Bi-stable spring snaps upwards
- Vacuum generation
- Gripping of workpiece

3. Holding

- No wire actuated
- Bi-stable spring maintains vacuum
- Workpiece is fixed

4. Release



- Upper wire actuated
- Bi-stable spring snaps downwards
- Vacuum purge
- Workpiece released

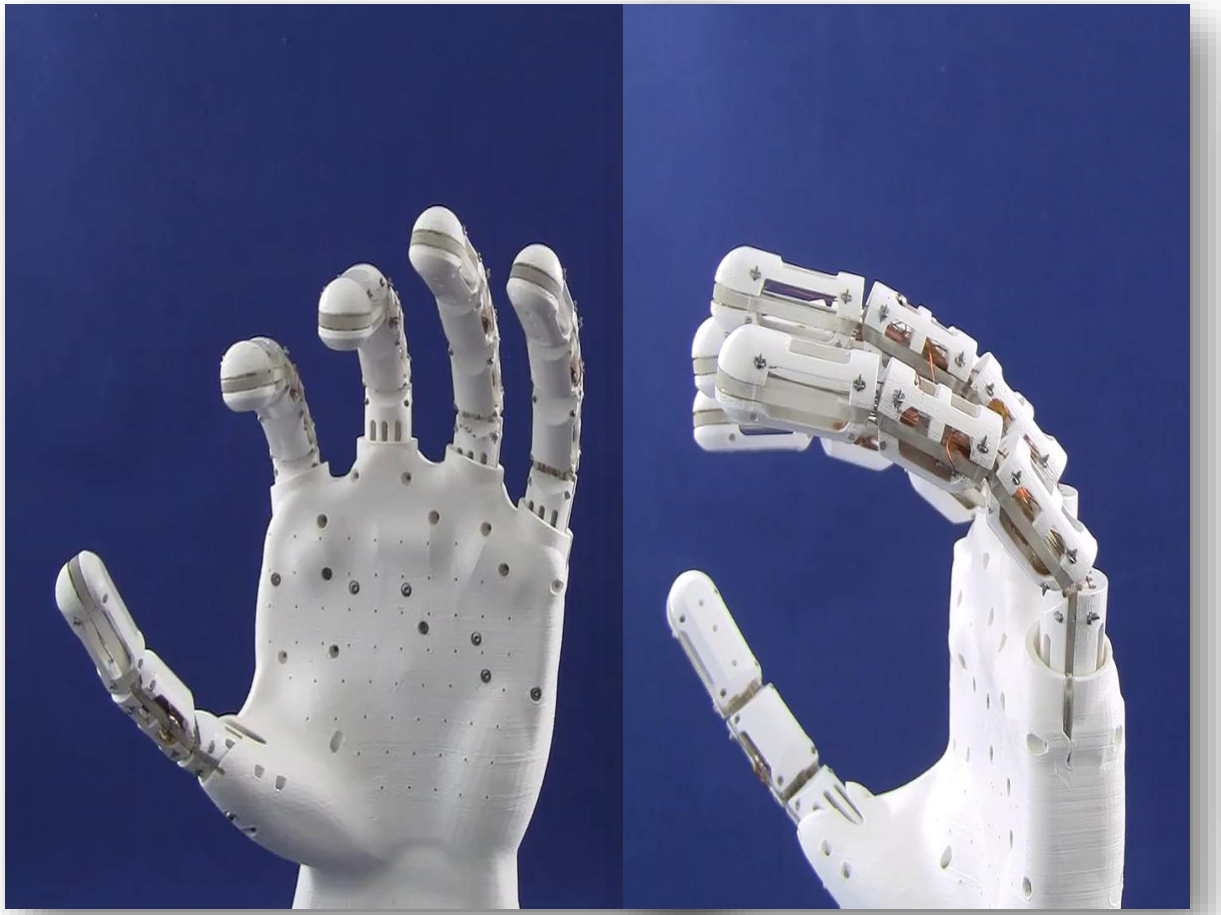
S.-M. Kirsch, F. Welsch, M. Schmidt, **P. Motzki**, and S. Seelecke, "Bistable SMA Vacuum Suction Cup," in Actuator 18 - 16th International Conference on New Actuators, 2018.

F. Welsch, S.-M. Kirsch, **P. Motzki**, M. Schmidt, and S. Seelecke, "Vacuum Gripper System Based on Bistable SMA Actuation," in ASME 2018 Conference on Smart Materials, Adaptive Structures and Intelligent Systems - SMASIS18, 2018.

Bi-stable SMA Suction Cup

MOTEK 2017 & Hannover Messe 2018

Proportional SMA Actuators



Advanced Control Concept

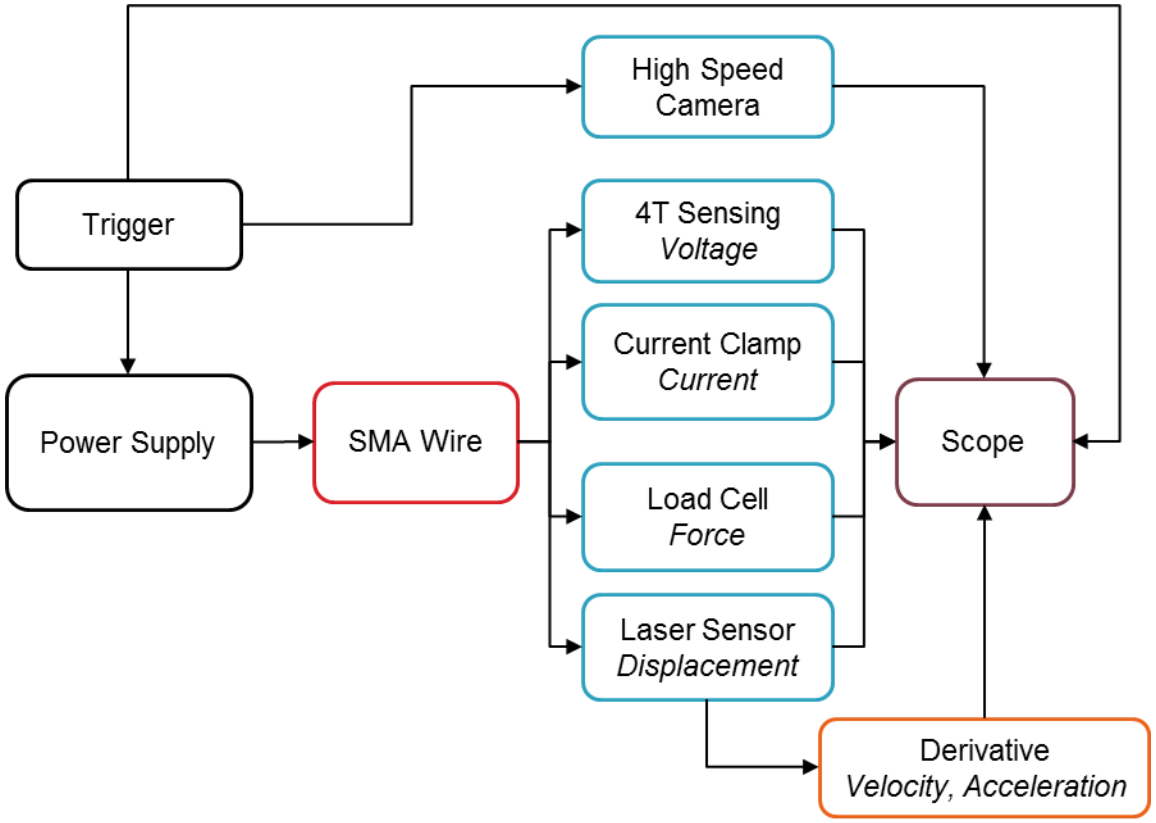
Given supply voltages in applications:
12 V, 24 V, 48V, 230 V, 400 V, …, DC/AC

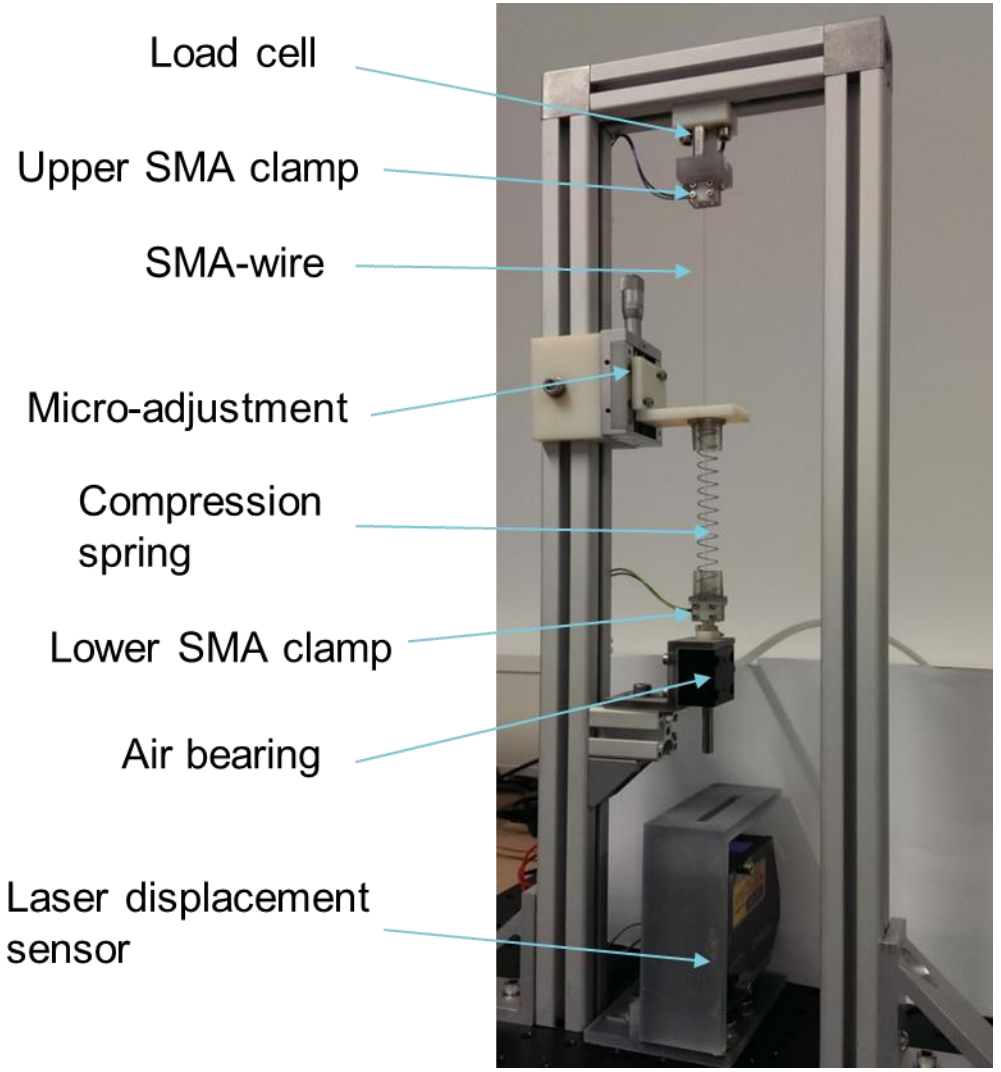
Magnitudes higher than recommendations

- High Speed Activation
  → High strokes and forces in *millisecond*-range
- Energy-efficiency
  → Activation under *adiabatic* conditions

P. Motzki, T. Gorges, T. Würtz, and S. Seelecke, "Experimentelle Untersuchung von Hochvolt FGL-Ansteuerung," in Smarte Strukturen und Systeme - Tagungsband des 4SMARTS-Symposiums 2017, 2017.

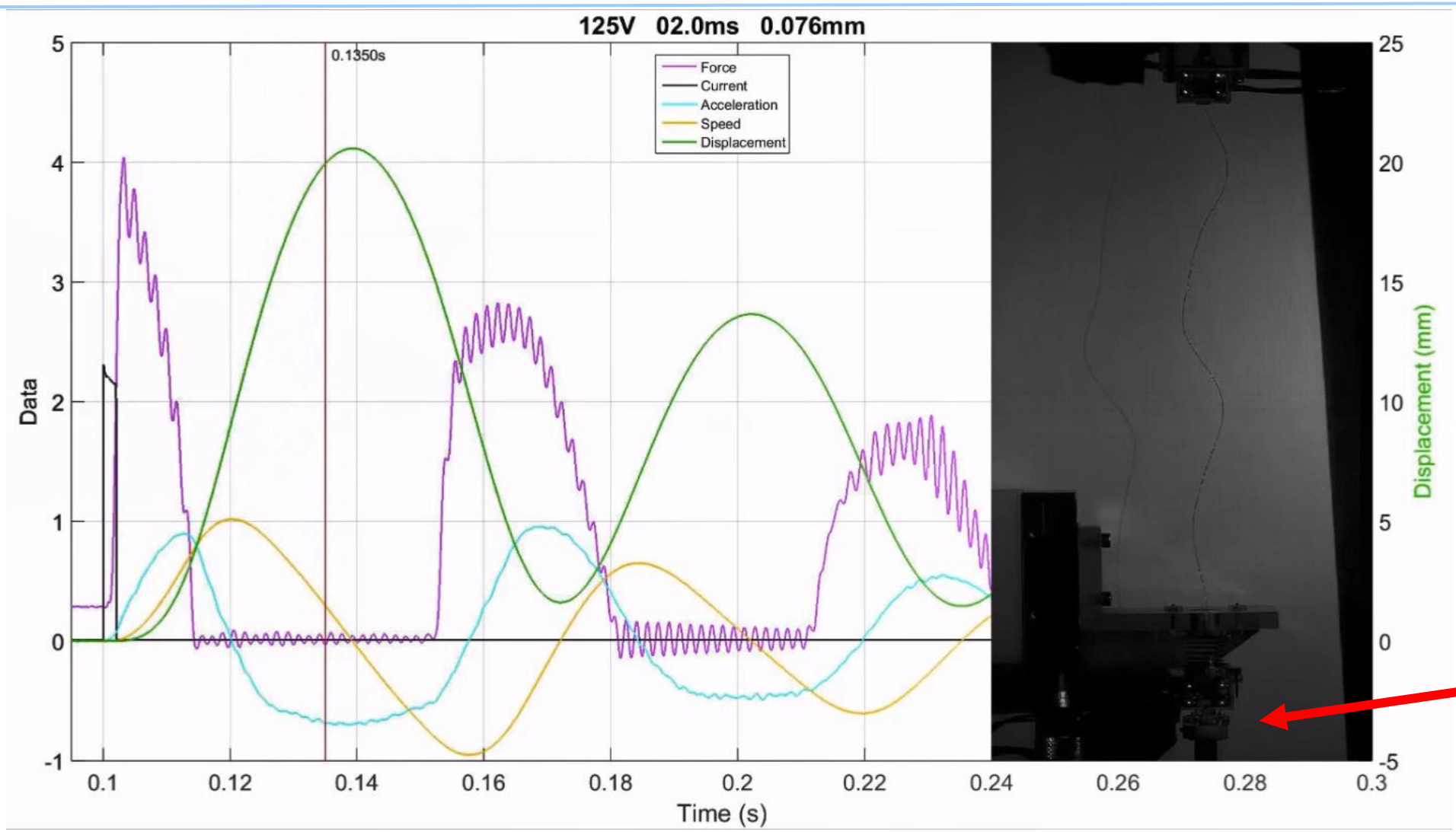
Experimental Setup





P. Motzki, T. Gorges, T. Würtz, and S. Seelecke, "Experimental Investigation of High-Speed/High-Voltage SMA Actuation," in ASME 2017 Conference on Smart Materials, Adaptive Structures and Intelligent Systems - SMASIS17, 2017, p. V001T02A002.

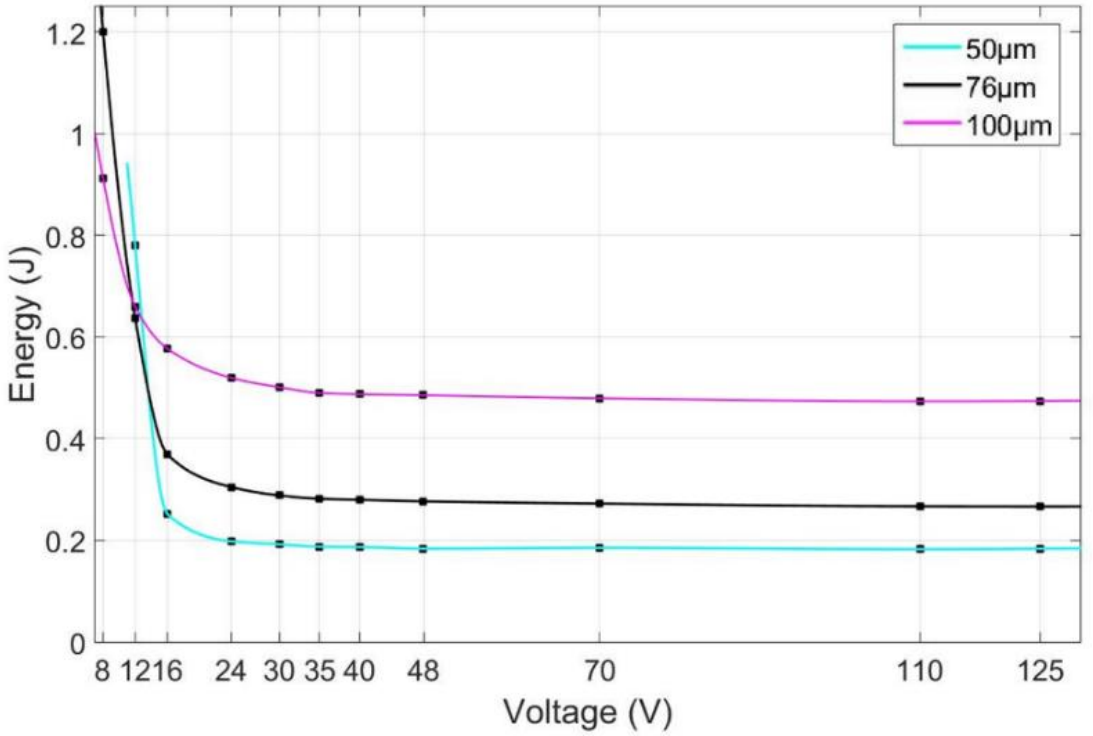
High Speed Activation



P. Motzki, T. Gorges, T. Würtz, and S. Seelecke, "Experimental Investigation of High-Speed/High-Voltage SMA Actuation," in ASME 2017 Conference on Smart Materials, Adaptive Structures and Intelligent Systems - SMASIS17, 2017, p. V001T02A002.

Energy-Efficiency

Voltage [V]	Displacement [mm]	Pulse width [ms]	Activation delay [ms]	Energy [J]	Ratio [%]
8	8.33	1000	1008	1.2	100
12	8.33	226	237.1	0.637	53.1
16	8.33	77	95.2	0.370	30.8
24	8.33	29.2	57.2	0.305	25.4
30	8.33	17.7	49	0.288	24
35	8.33	12.8	45.8	0.282	23.5
40	8.33	9.74	43.9	0.280	23.3
48	8.33	6.71	42	0.277	23.1
70	8.33	3.08	39.7	0.272	22.7
110	8.33	1.21	38.5	0.267	22.3
125	8.33	0.94	38.3	0.266	22.2



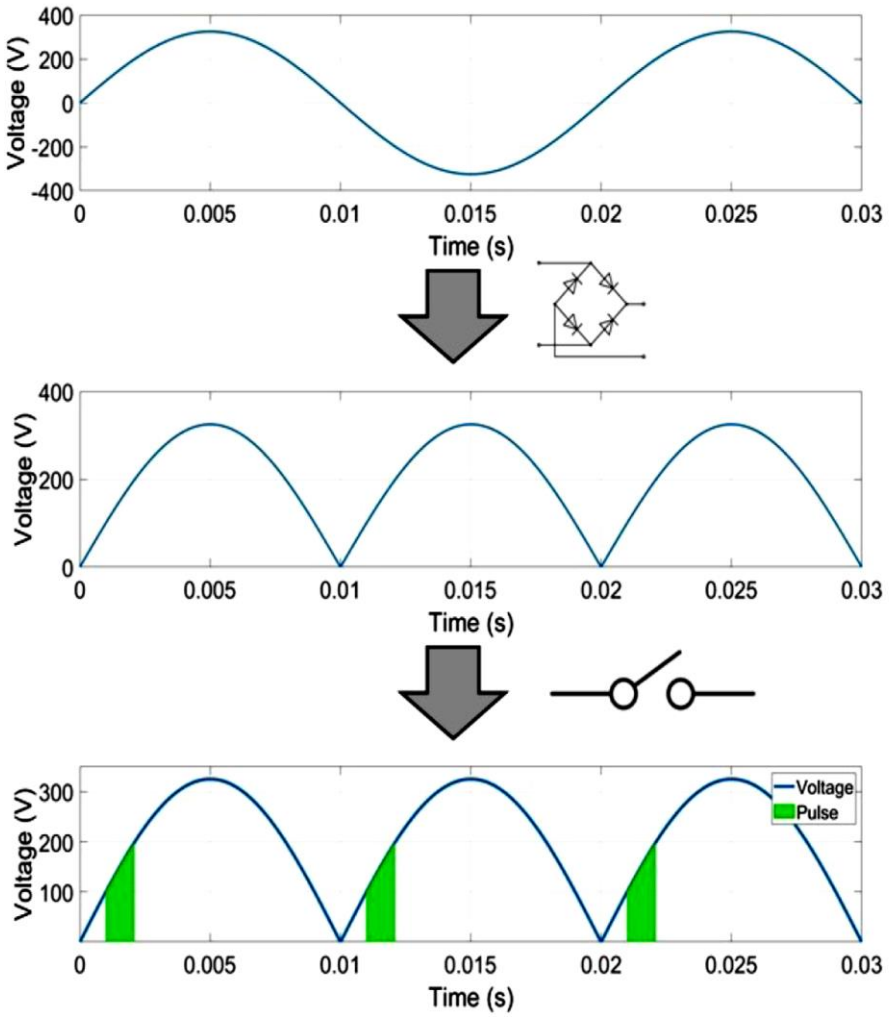
P. Motzki, T. Gorges, M. Kappel, M. Schmidt, G. Rizzello, and S. Seelecke, "High-speed and high-efficiency shape memory alloy actuation," Smart Mater. Struct., vol. 27, no. 7, p. 075047, Jul. 2018.

Energy savings up to 80 %

Relevance:

- Trigger, safety, 1-time actuation, …

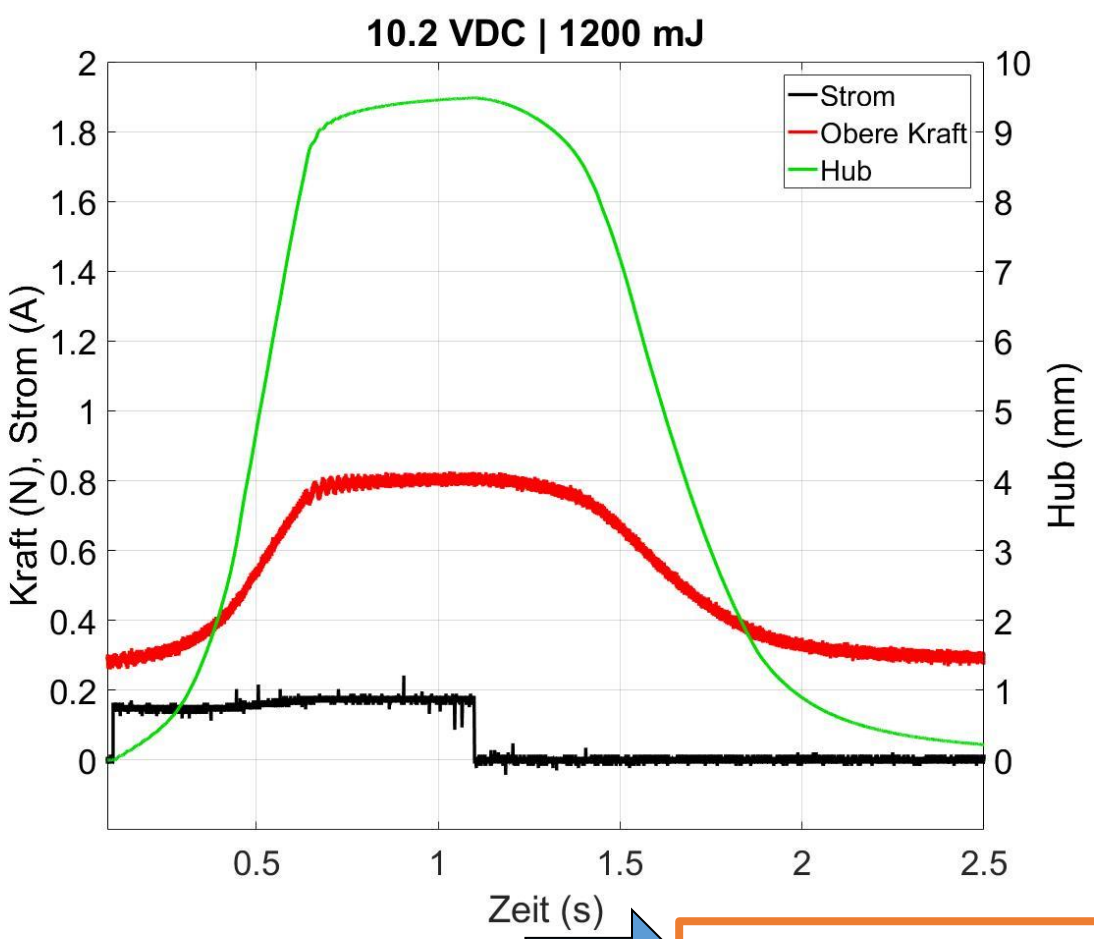
AC Activation

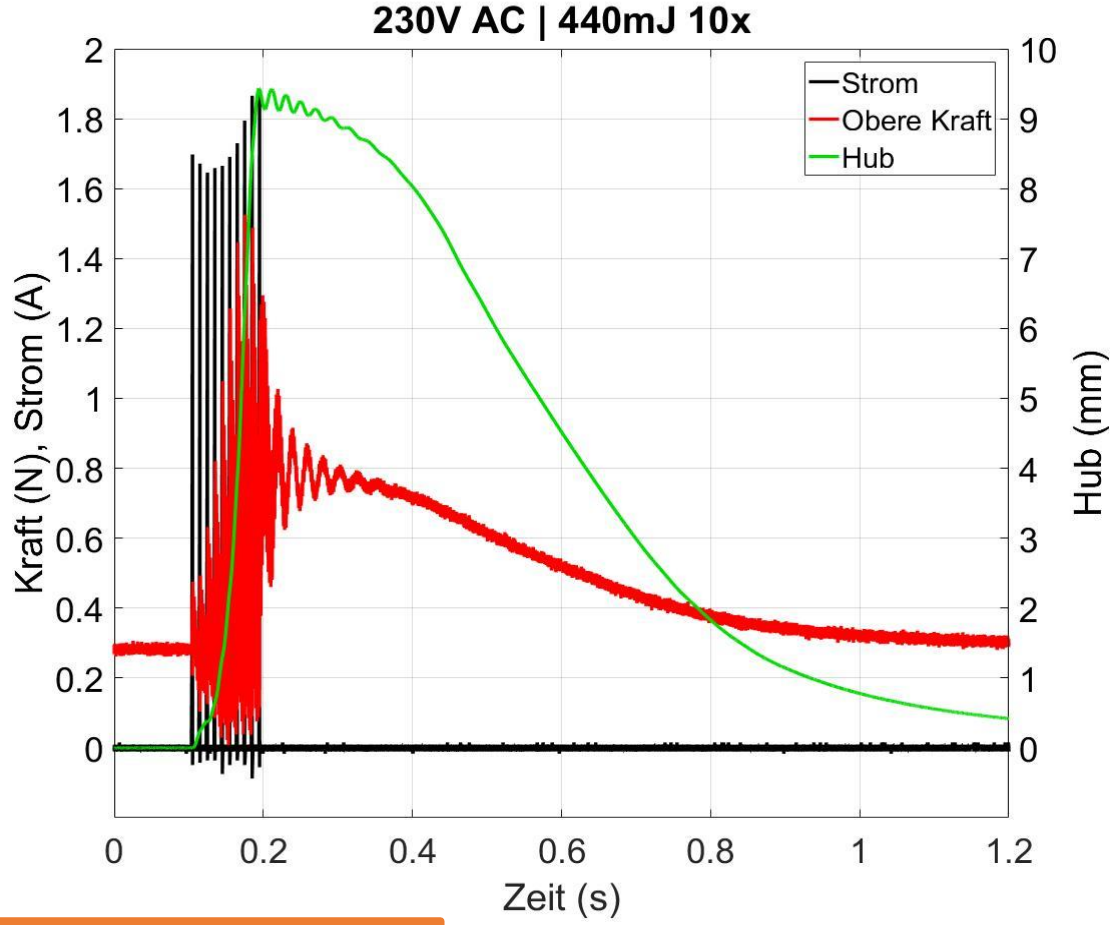


Real time energy measurement

$$W_{el} = \sum_{i=1}^{n} U_i \cdot I_i \cdot \Delta t$$

Energy-Efficient PWM





Same displacement with 63 % energy savings

Thank you for your attention!