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# ACTIVATION STRATEGIES AND THEIR IMPACT ON THE LIFETIME OF SMA

Smart Materials & Structures, June 15-17, 2015, Las Vegas, USA

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# OUTLINE

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1. Motivation
2. Influences on the lifetime of SMA
3. Factors and response for experimental procedure
4. Experimental setup
5. Impact of activation strategies on SMA behavior
6. Conclusion and outlook

# 1. MOTIVATION

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- **Shape memory alloys** (SMA) have the ability to remember a previous imprinted shape.
- Their **advantageous properties** make them interesting for many applications.
- Especially if **high workload**, **low weight**, electromagnetic compatibility or **integration of functions** is required.
- Potential applications of SMA are often **limited** by their **lifetime**.
- Lifetime of SMA is affected by **structural** and **functional factors**, including control and activation.
- The **resistance** is an indicator for functionality and fatigue of SMA.

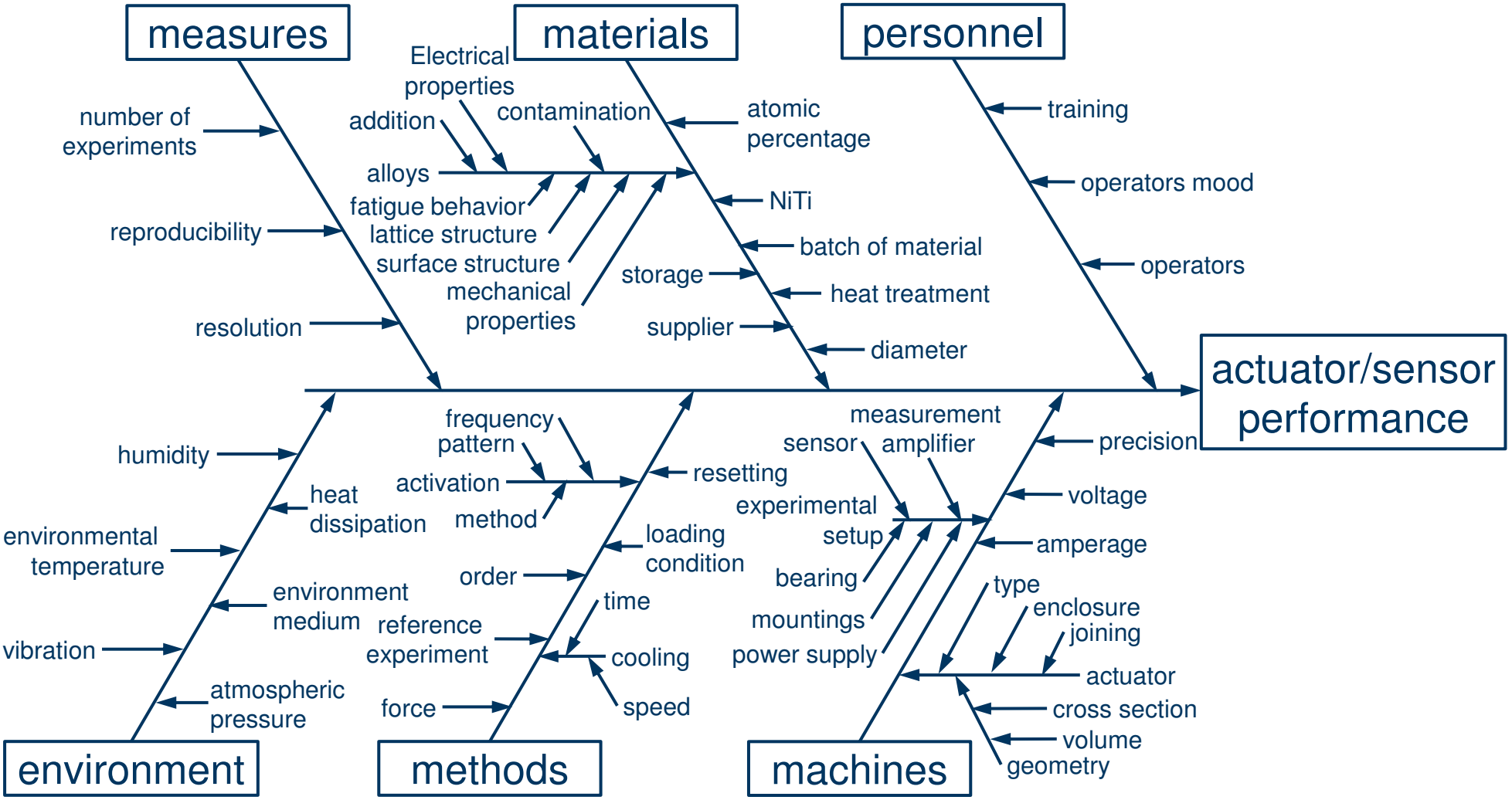






Proper **activation is crucial** for longtime operation of SMA-based actuator systems. Therefore different **possibilities of activation** need to be investigated.

# 2. INFLUENCES ON THE LIFETIME OF SMA




Ishikawa diagram regarding influences on SMA-behavior

# 3. FACTORS AND RESPONSE FOR EXPERIMENTAL PROCEDURE

| Valuation matrix for experimental factors | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Factors** | Displacement | Lifetime | Resistance | Change effort | Reproducibility | Cost of Change | Rating |
| **Activation pattern** | 4 | 3 | 2 | 4 | 5 | 5 | 3,56 |
| **Wire diameter** | 5 | 2 | 5 | 3 | 5 | 3 | 3,89 |
| **Activation frequency** | 4 | 4 | 2 | 4 | 5 | 5 | 3,78 |
| **Loading condition** | 4 | 4 | 2 | 4 | 4 | 4 | 3,56 |
| **Environmental temperature** | 4 | 3 | 3 | 1 | 2 | 1 | 2,67 |
| **Sensor** | 0 | 0 | 3 | 1 | 5 | 1 | 1,44 |

# 3. FACTORS AND RESPONSE FOR EXPERIMENTAL PROCEDURE

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**Three factors** were chosen regarding the highest ratings.
Investigations on **activation patterns** were considered more relevant for activation strategies than loading conditions.

# 3. FACTORS AND RESPONSE FOR EXPERIMENTAL PROCEDURE

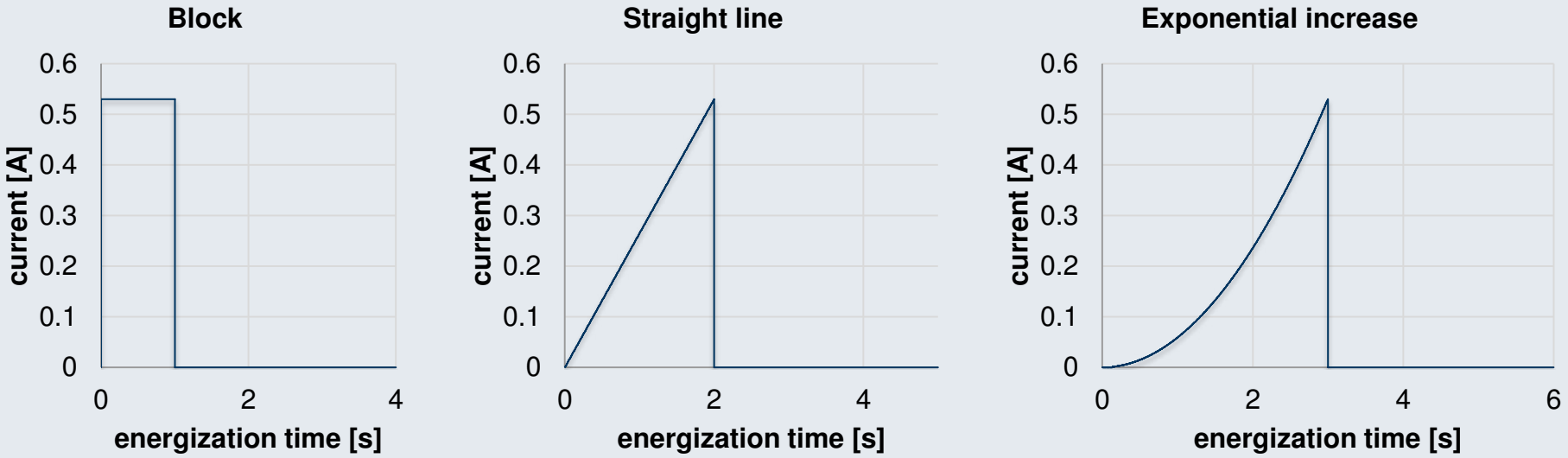
- 3 types of activation patterns
- 3 different activation frequencies
- NiTi-wires with 2 different diameters
- **18 experiments**

| Experimental design | | | | | | |
|---|---|---|---|---|---|---|
| | Factors | | | Response | | |
| Exp.No. | Activation Pattern | Activation frequency | Wire diameter [mm] | Displacement [mm] | Lifetime [cycles] | Resistance [Ω] |
| 1 | block | long | 0,3 | | | |
| 2 | block | long | 0,15 | | | |
| 3 | block | optimum | 0,3 | | | |
| 4 | block | optimum | 0,15 | | | |
| 5 | block | short | 0,3 | | | |
| 6 | block | short | 0,15 | | | |
| 7 | straight line | long | 0,3 | | | |
| 8 | straight line | long | 0,15 | | | |
| 9 | straight line | optimum | 0,3 | | | |
| 10 | straight line | optimum | 0,15 | | | |
| 11 | straight line | short | 0,3 | | | |
| 12 | straight line | short | 0,15 | | | |
| 13 | exponential increase | long | 0,3 | | | |
| 14 | exponential increase | long | 0,15 | | | |
| 15 | exponential increase | optimum | 0,3 | | | |
| 16 | exponential increase | optimum | 0,15 | | | |

Activation strategies consist of different **activation patterns** and **frequencies**.

## Activation pattern:

All patterns offer the same amount of electric energy

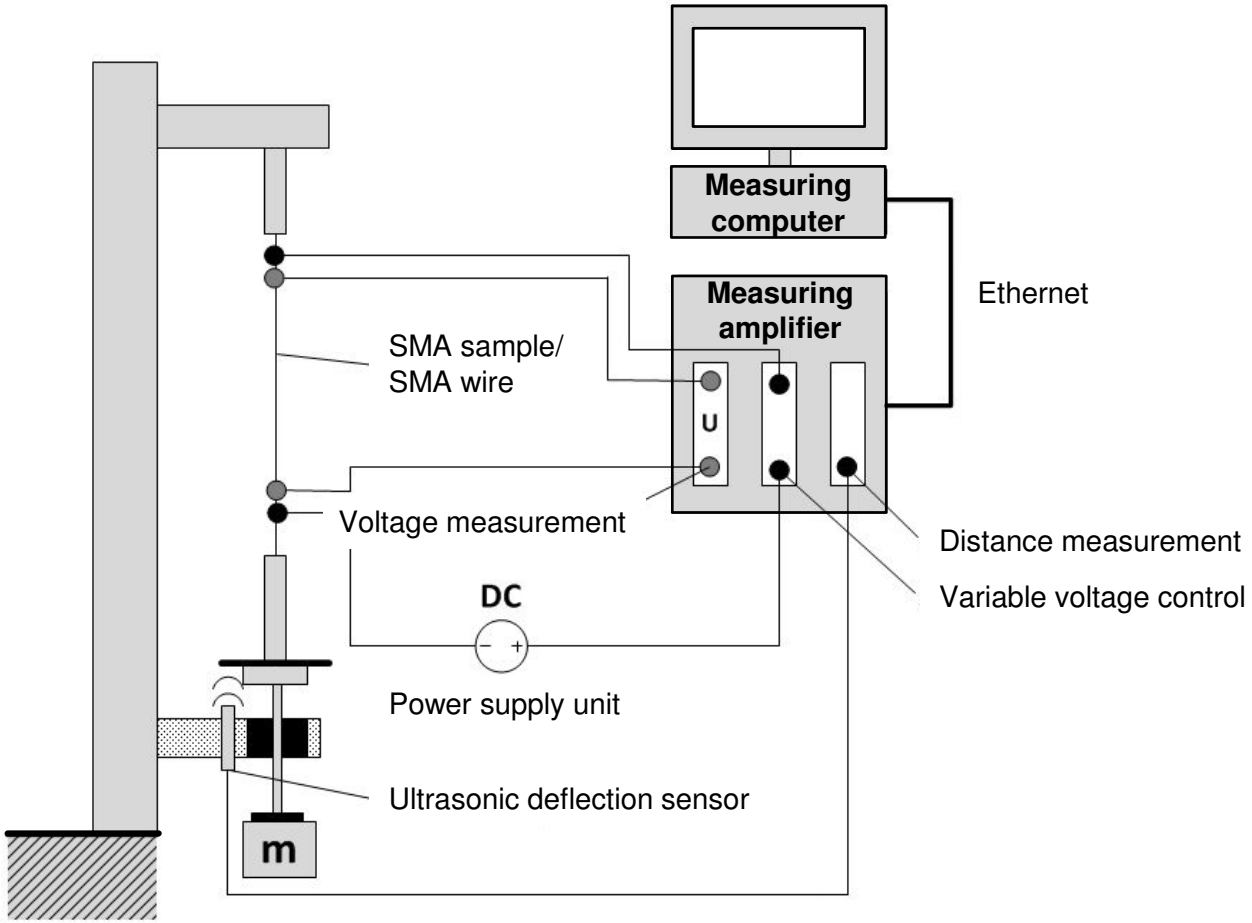


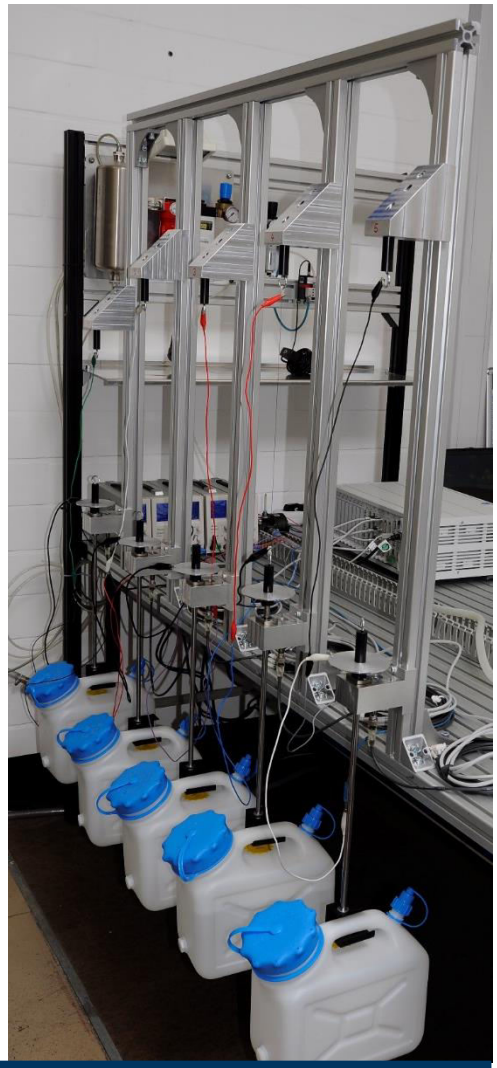

## Activation frequency:

- Long
- Optimum
- Short

# 4. EXPERIMENTAL SETUP





Experimental setup for wire activation

# 4. EXPERIMENTAL SETUP

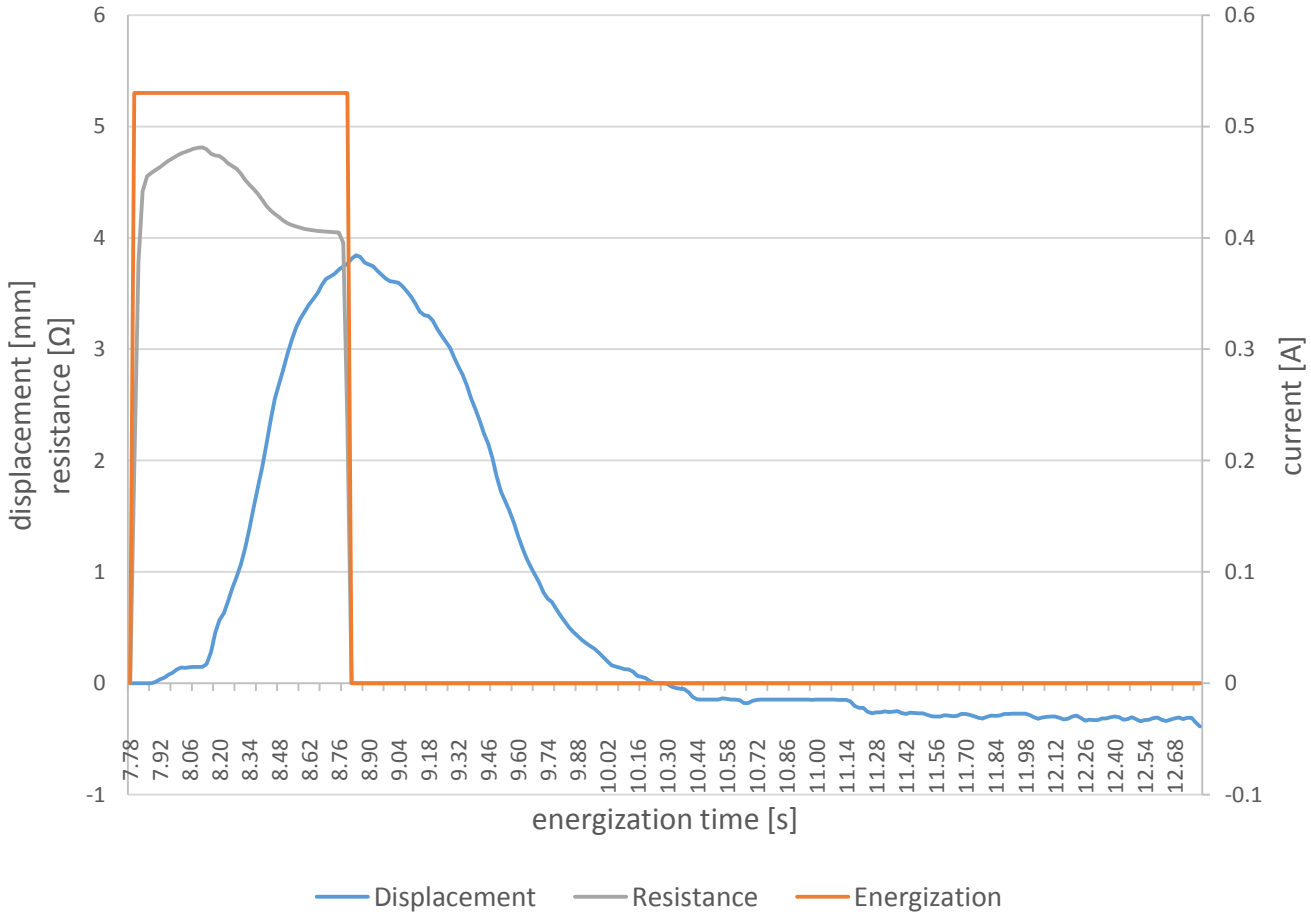
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**Example of an activation cycle:**

Wire diameter: 0,15mm

Activation pattern: Block (5V, 0,53A)

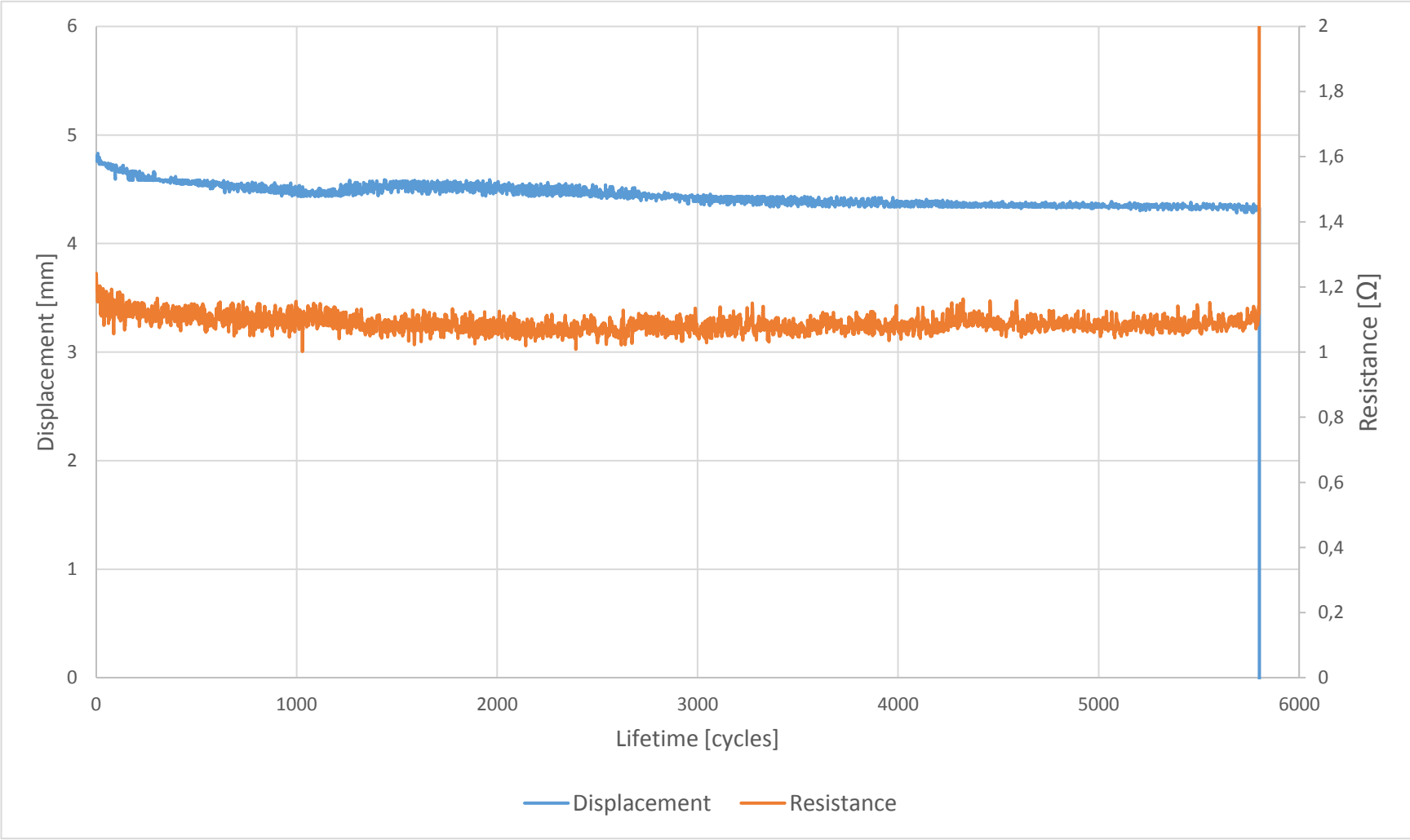
Activation frequency: long



# 5. IMPACT OF ACTIVATION STRATEGIES ON SMA-BEHAVIOR

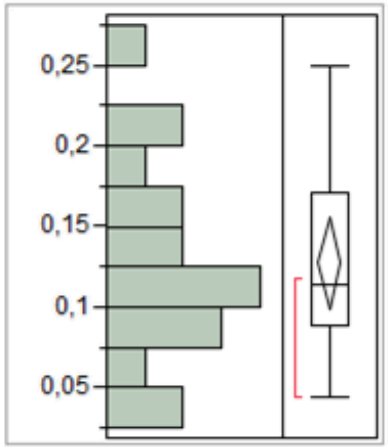
| Experimental results | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Factors | | | Response | | | | |
| Exp. No. | Activation Pattern | Activation frequency | Wire diameter [mm] | Relative displacement | Relative displacement reduction | Displacement reduction [mm] | Lifetime [cycles] | Resistance increase [Ω] |
| 1 | block | long | 0,3 | 4,82% | 66,69% | 3,19 | 6381 | 0,09 |
| 2 | block | long | 0,15 | 3,71% | 42,30% | 1,55 | 28388 | 0,02 |
| 3 | block | optimum | 0,3 | 4,83% | 9,22% | 0,44 | 5415 | 0,01 |
| 4 | block | optimum | 0,15 | 3,40% | 41,55% | 1,60 | 32062 | 0,18 |
| 5 | block | short | 0,3 | 4,76% | 0,57% | 0,03 | 8225 | 0,02 |
| 6 | block | short | 0,15 | 3,75% | 35,64% | 1,34 | 28264 | 0,10 |
| 7 | straight line | long | 0,3 | 4,44% | 34,00% | 1,51 | 20442 | 0,01 |
| 8 | straight line | long | 0,15 | 2,82% | 15,59% | 0,34 | 39026 | 0,12 |
| 9 | straight line | optimum | 0,3 | 4,60% | 27,68% | 1,25 | 36412 | 0,01 |
| 10 | straight line | optimum | 0,15 | 2,58% | 32,87% | 0,82 | 54618 | 0,34 |
| 11 | straight line | short | 0,3 | 4,63% | 19,52% | 0,86 | 22313 | 0,05 |
| 12 | straight line | short | 0,15 | 2,96% | 43,04% | 1,15 | 84613 | 0,28 |
| 13 | exponential increase | long | 0,3 | 4,76% | 4,10% | 0,19 | 6089 | 0,01 |
| 14 | exponential increase | long | 0,15 | 2,30% | 32,99% | 0,64 | 16417 | 0,06 |
| 15 | exponential increase | optimum | 0,3 | 4,30% | 45,79% | 1,92 | 17331 | 0,03 |
| 16 | exponential increase | optimum | 0,15 | 2,03% | 12,53% | 0,15 | 20219 | 0,05 |
| 17 | exponential increase | short | 0,3 | 4,48% | 23,55% | 1,02 | 31049 | 0,04 |
| 18 | exponential increase | short | 0,15 | 2,42% | 33,80% | 0,79 | 43987 | 0,07 |

## Example of displacement and resistance over lifetime:

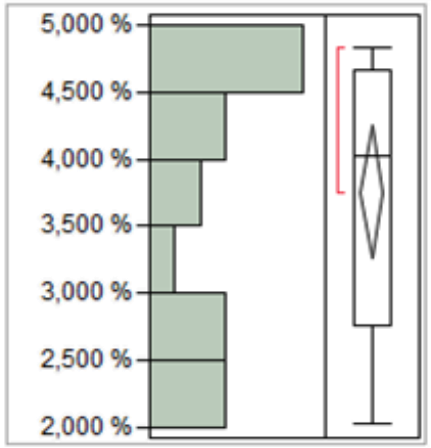


## Plausibility check:

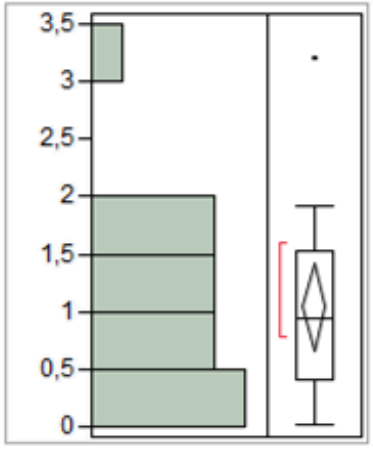
Activation frequency



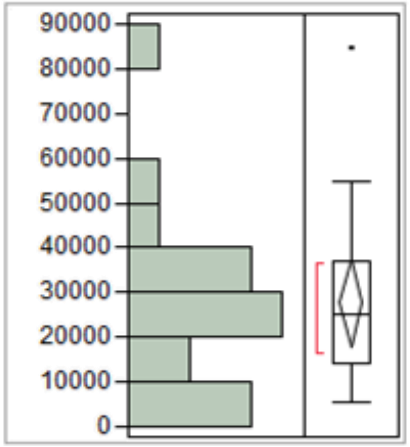

Relative displacement



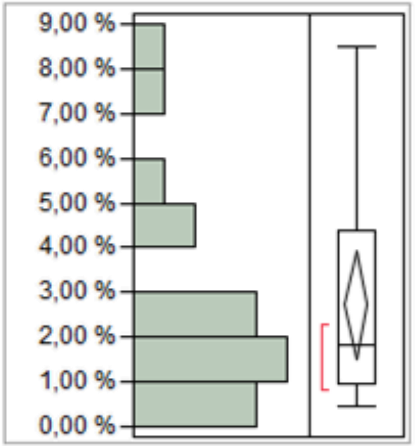

Displacement reduction




Lifetime



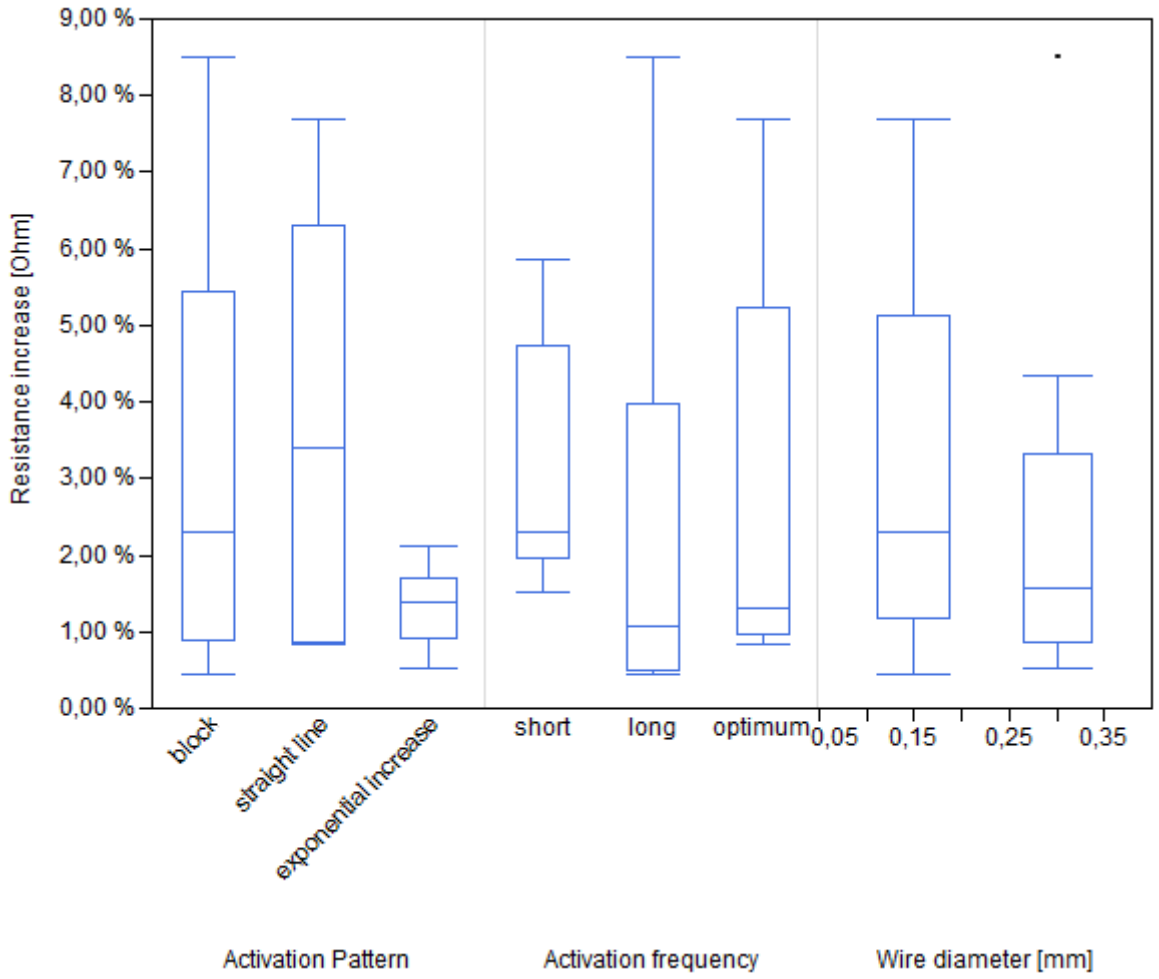

Resistance increase



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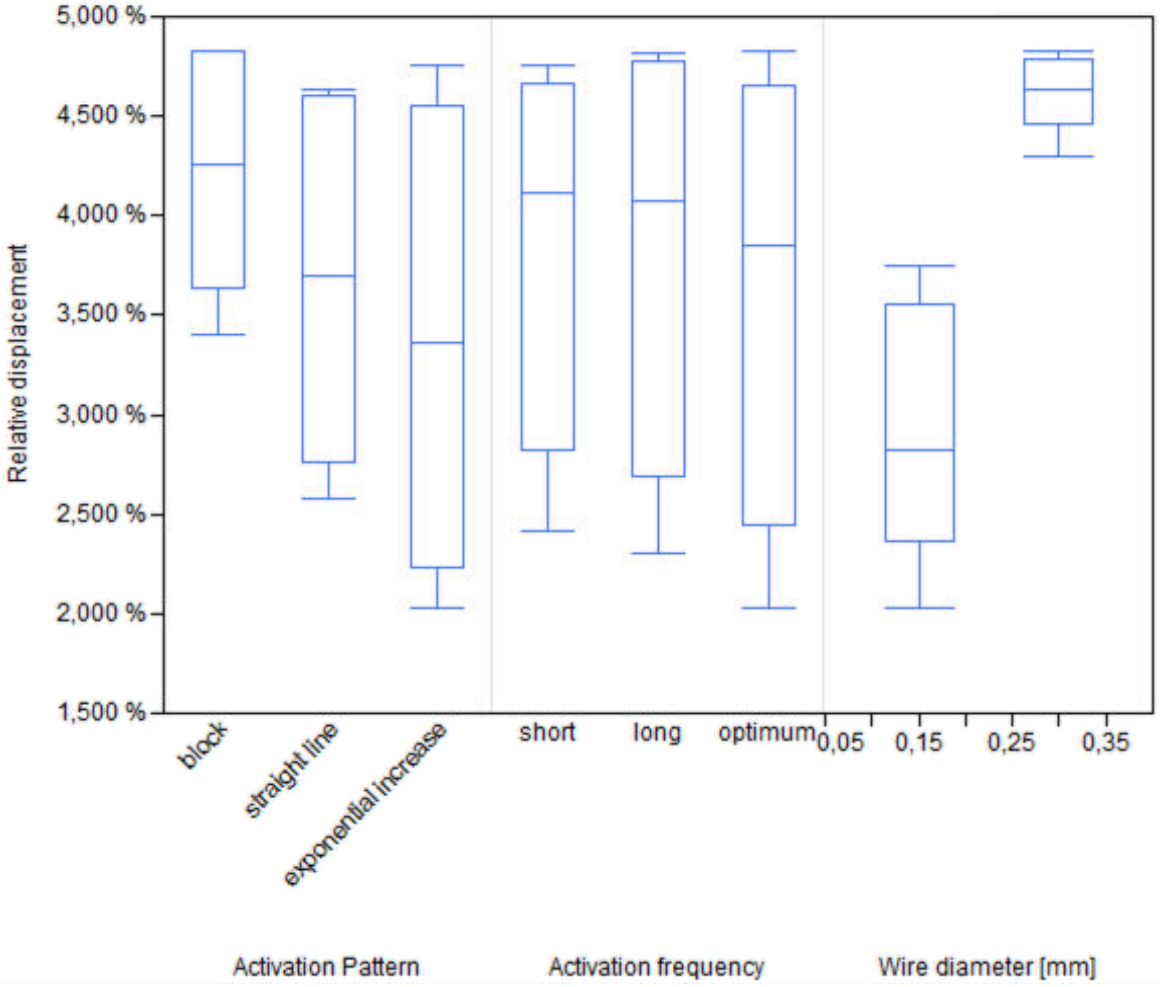
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## Impact of activation strategies on resistance increase



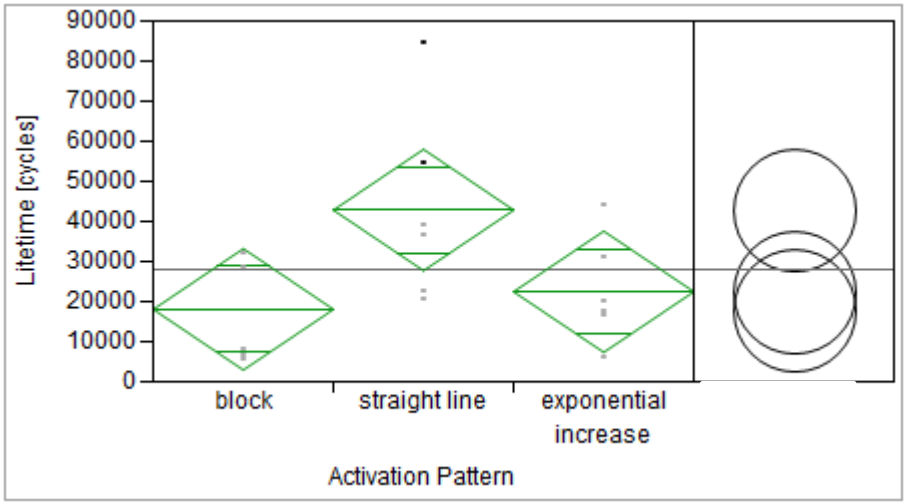
# 5. IMPACT OF ACTIVATION STRATEGIES ON SMA-BEHAVIOR

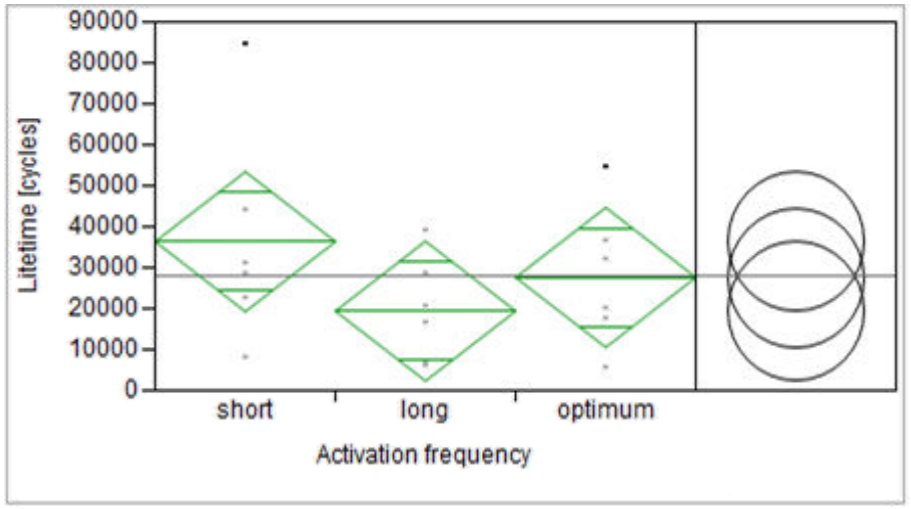
## Impact of activation strategies on relative displacement



# 5. IMPACT OF ACTIVATION STRATEGIES ON SMA-BEHAVIOR

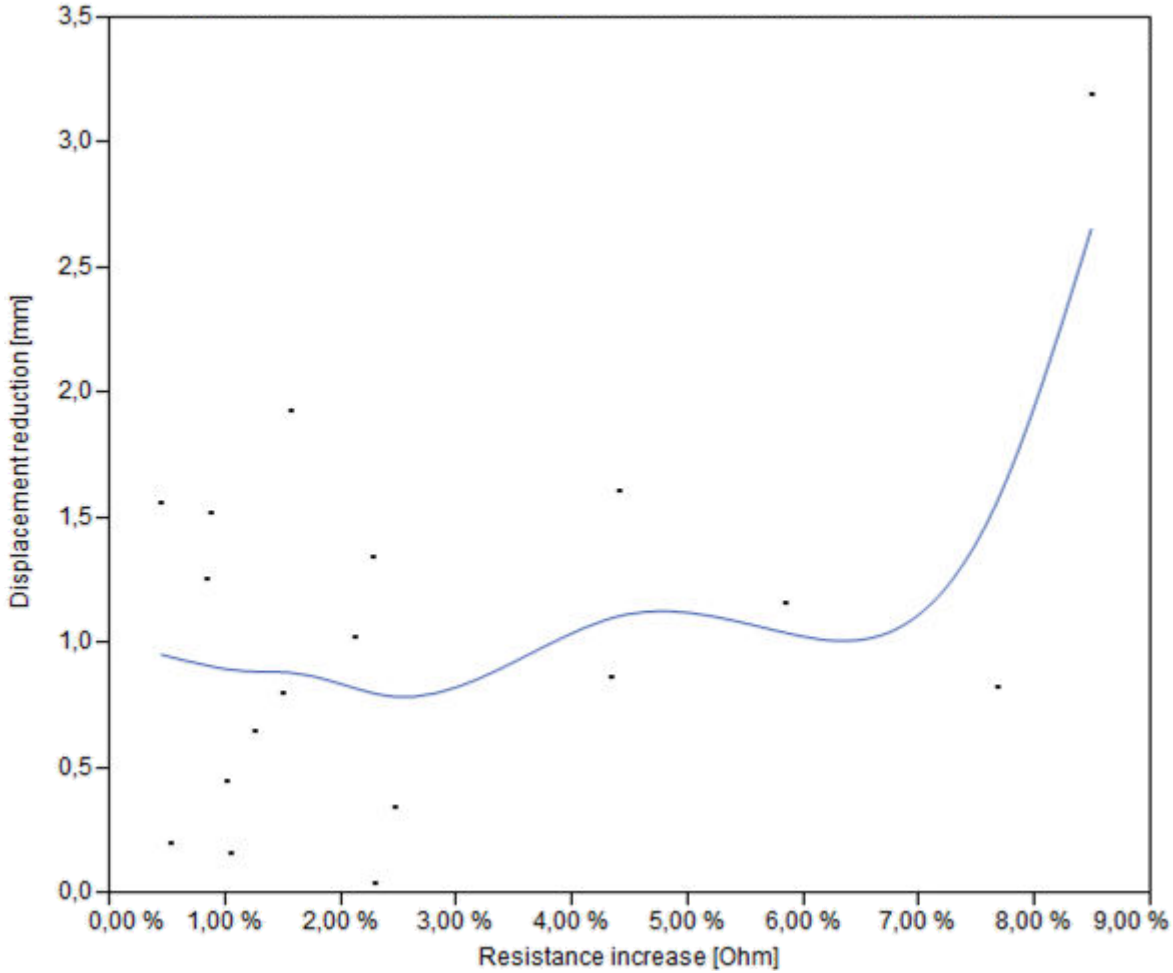
## Pairwise comparison of lifetime and activation parameters



# 5. IMPACT OF ACTIVATION STRATEGIES ON SMA-BEHAVIOR

## Dependency of displacement reduction and resistance increase

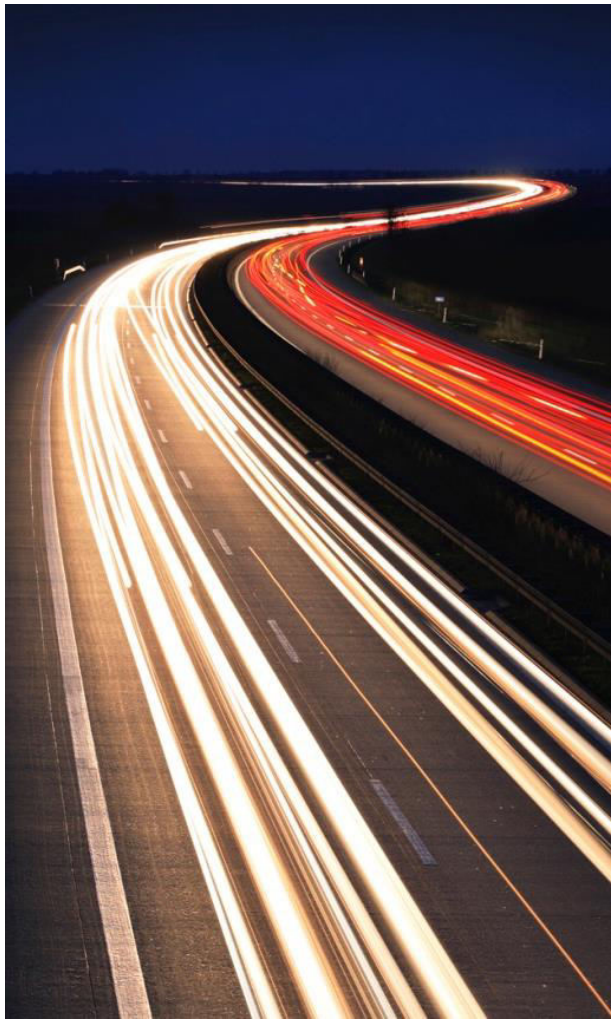


# 6. CONCLUSION AND OUTLOOK

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- Already known **coherences** were **confirmed** (e.g. dependency between resistance increase and displacement reduction). Furthermore the dependency of these parameters **over lifetime** was proofed.
- **Activation strategies** have a **smaller impact** on SMA-actuator performance than **structural** and **geometrical factors** (e.g. wire diameter).

- The **Activation model** is insufficient and requires further studies.
- Further interactions between **activation factors** and other **structural factors** (e.g. loading condition, environmental temperature) need to be investigated.
- Additional series of experiments are needed to **confirm** the determined **lifetimes**.






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