FUNCTIONALIZED STRUCTURAL COMPONENTS WITH ADAPTIVE STIFFNESS FOR SOFT ROBOTIC APPLICATIONS

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STRUCTURING

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   - Transfer into programmable materials

Motivation

Soft Robotics

- soft & compliant materials
- infinite degree of freedom

  → inherent safety, high flexibility/deformability

  → adaptation to obstacles + surroundings

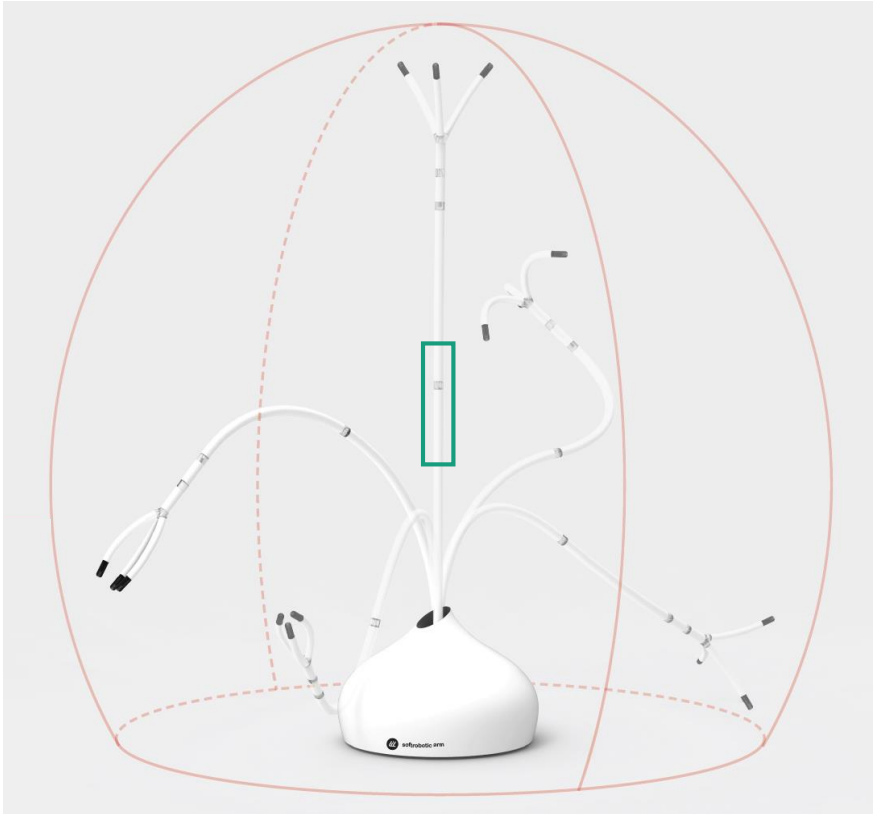
Deficit

- Lack of stiffness for sufficient loads

Aim

- **Structural components with adaptive stiffness control**

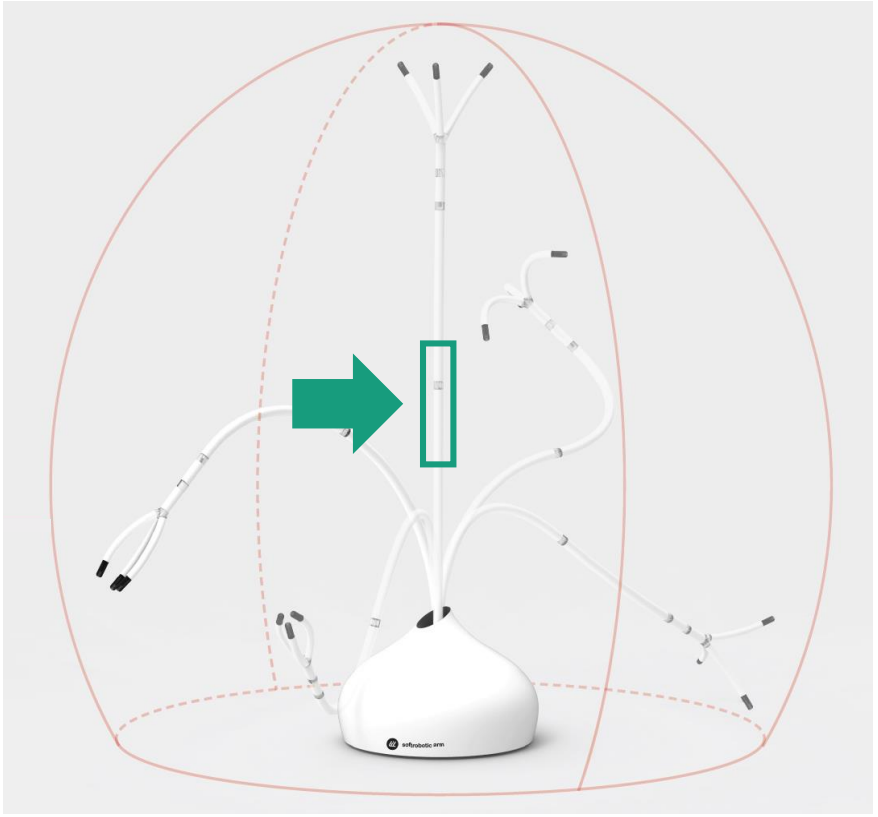
➡ load bearing capacity & flexibility + inherent safety



Source: Boxberger, L.: Entwicklung eines adaptiven, kybernetischen Systems zur Mensch-Maschinen-Interaktion. (nicht veröffentlichtes Material) Masterarbeit. Hochschule für Technik und Wirtschaft Dresden, 2017

Requirements

- **reversible controllable stiffness *k*** stiff-state ←→ soft-state
- **high stiffness ratio *K* > 100**
- **Speed of stiffness variation *t* < 1 s**
- No permanent energy supply → triggerable
- Stiffness change without deformations & volume change
- Low complexity and workspace
- primarily adressed mode of stiffening: bending



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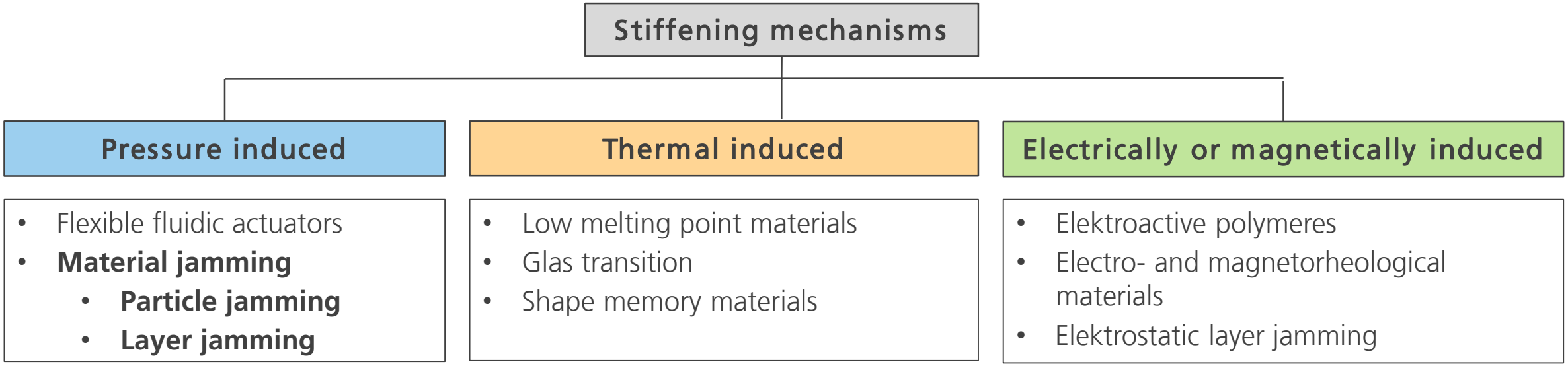
State of the Art



- No mature working solution so far

➡ **New and further developments required**

➡ **particle & layer jamming selected**

Concept description

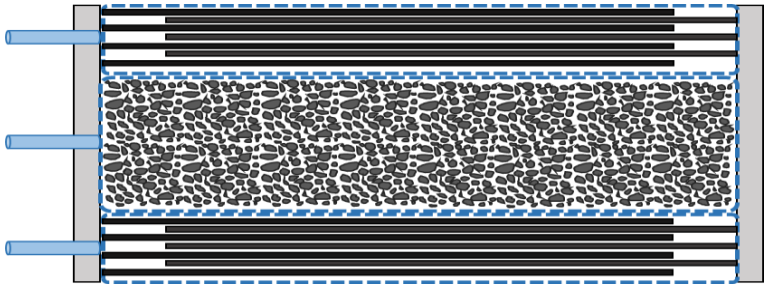
Concept description

Working principle

- Combination of particle and layer jamming
  - Particles + compression stress, – tensile stress
  - Layers – compression stress, + tensile stress

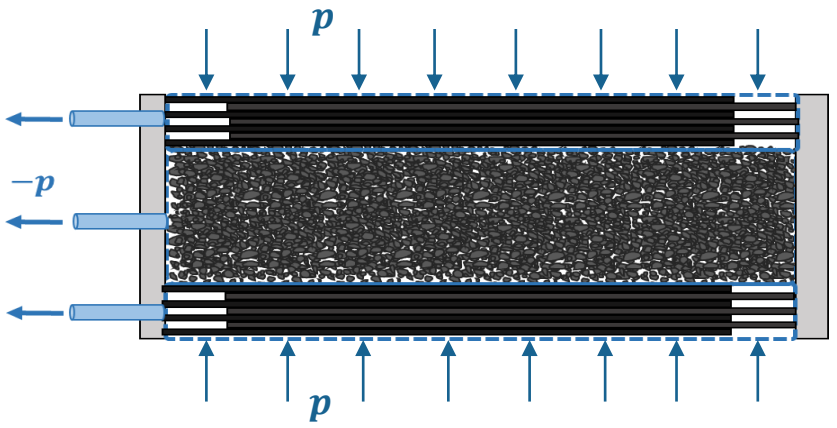
vacuum pump off

soft state



vacuum pump on

stiff state



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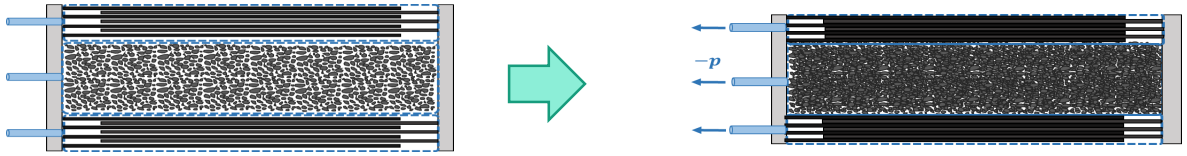
Concept description

Construction



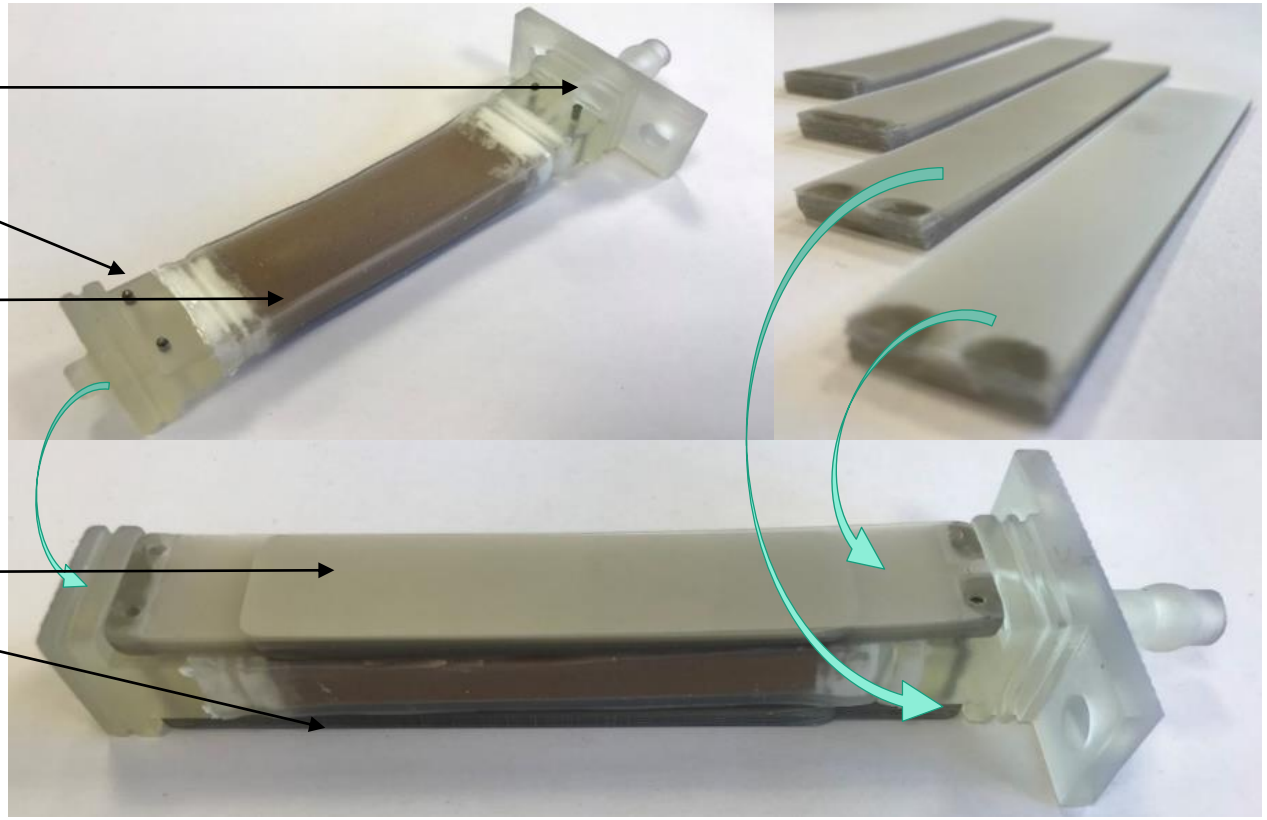
3D-printed parts

particle chamber

- coffee particles in silicone enclosure

layer bundle

- 41 PVC layers each
- layer thickness: 0,2 mm



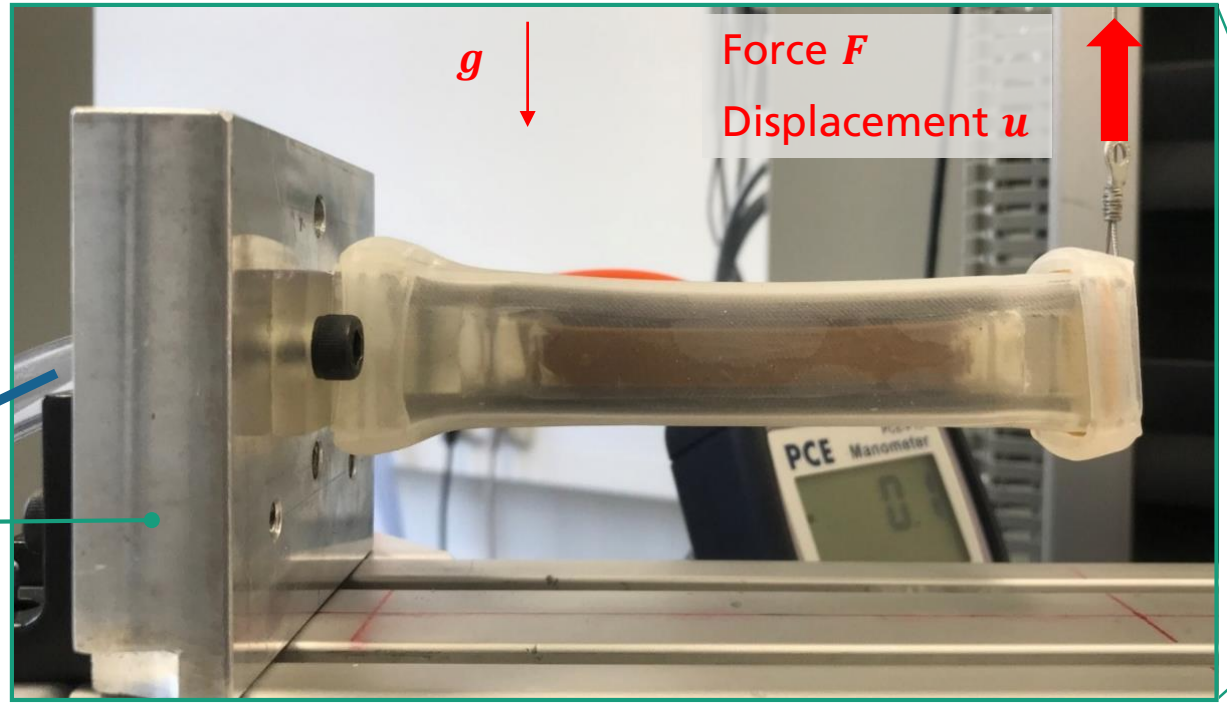
Mechanical characterization

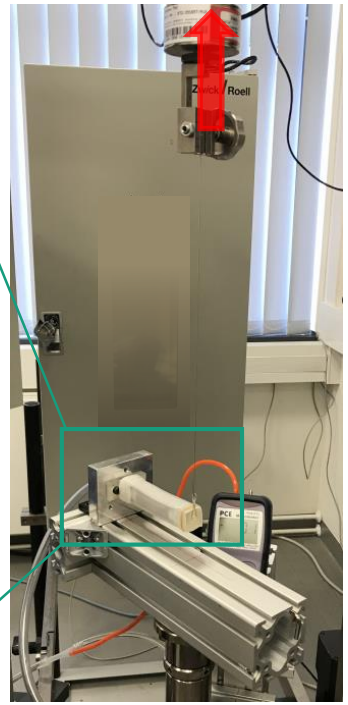
Mechanical characterization

Setup

- uniaxial testing machine (Zwick/Roell)

  → quasistatic bending stiffness $k = \frac{F}{u}$

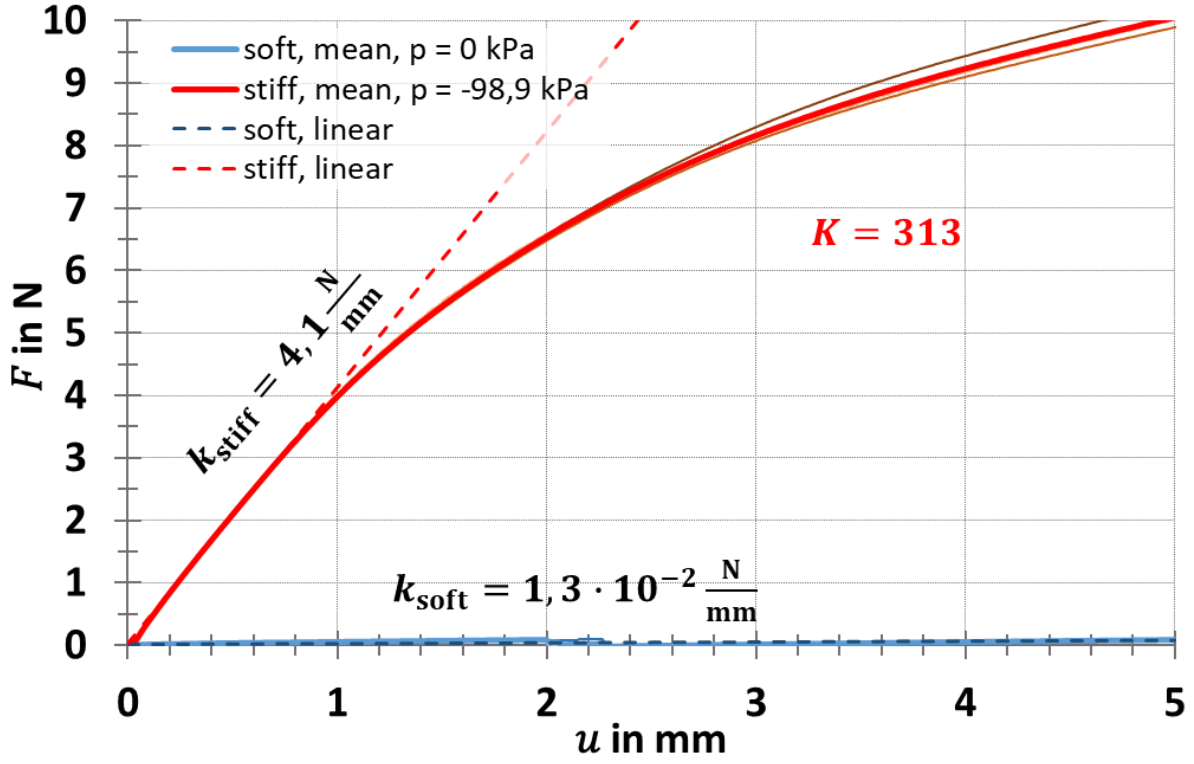


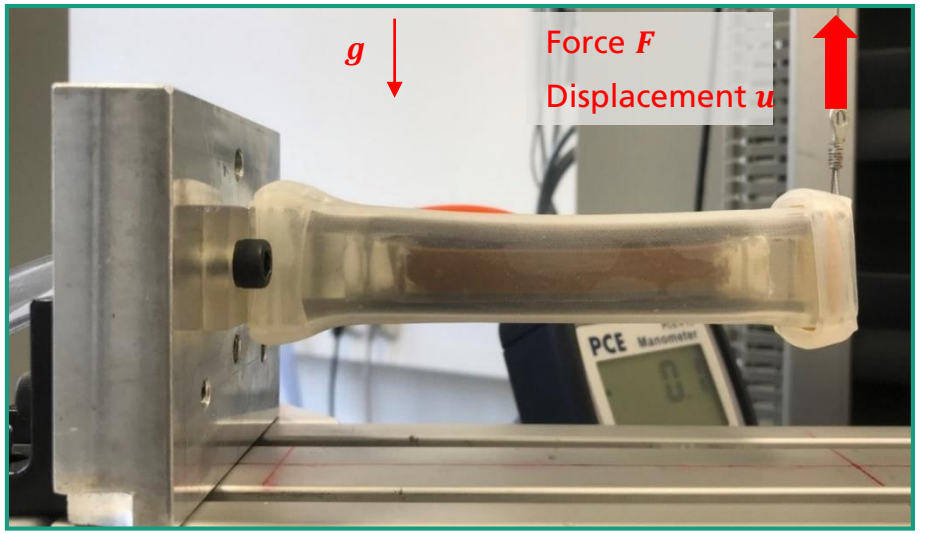


Mechanical characterization

Results

- high stiffness ratio $K > 300$





Properties of the structural component

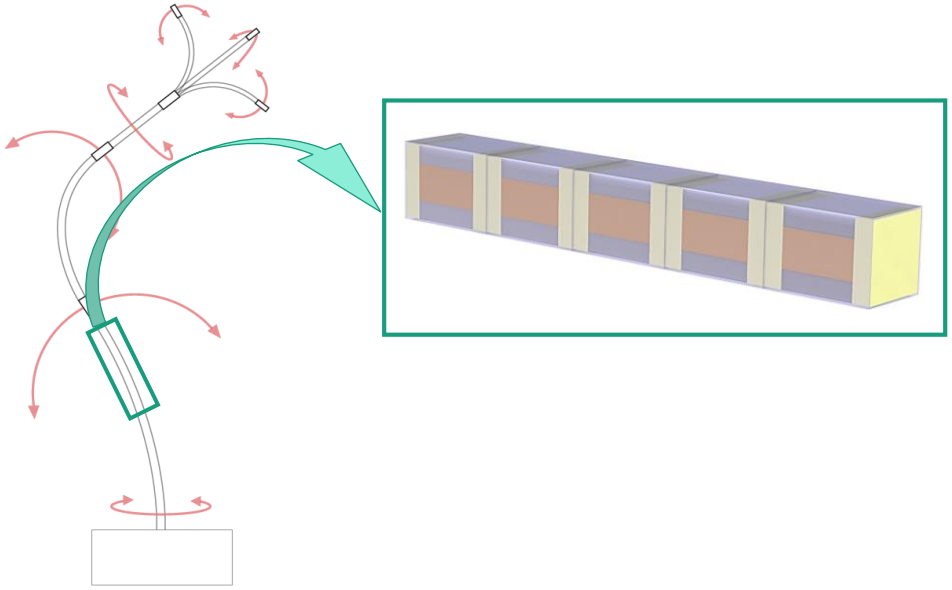
- reversible controllable **stiffness *k***
- high **stiffness ratio *K* > 300**
- Speed of stiffness variation ***t* < 1 s**
- No permanent energy supply needed
- Stiffness change without deformations & volume change
- mechanical properties for each pose referencable

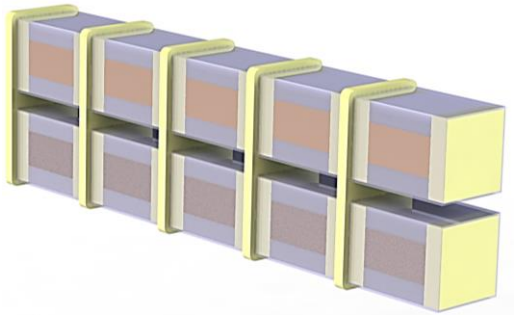
Further investigations

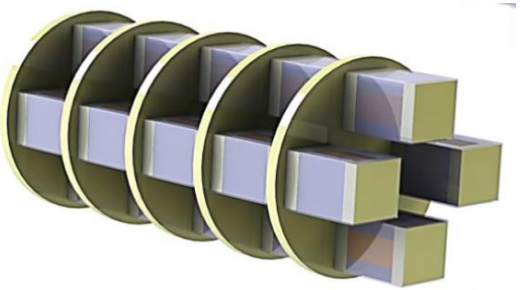
Further investigations

Transfer into robotic context

- Segmentation & scaling







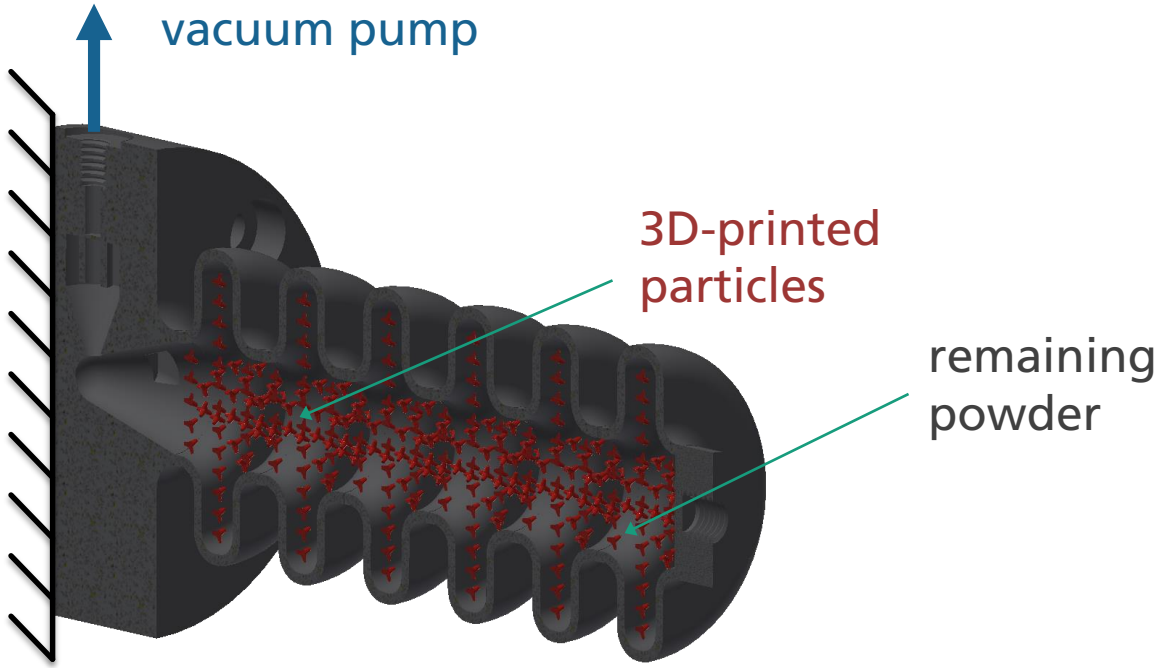
- Building of an segmented robotic arm
- Transfer into programmable materials

Transfer into programmable materials

Transfer into programmable materials

concept description

- powder-bed fusion → AM-parts with adaptive stiffness
- scalable structures with locally adjustable stiffness properties

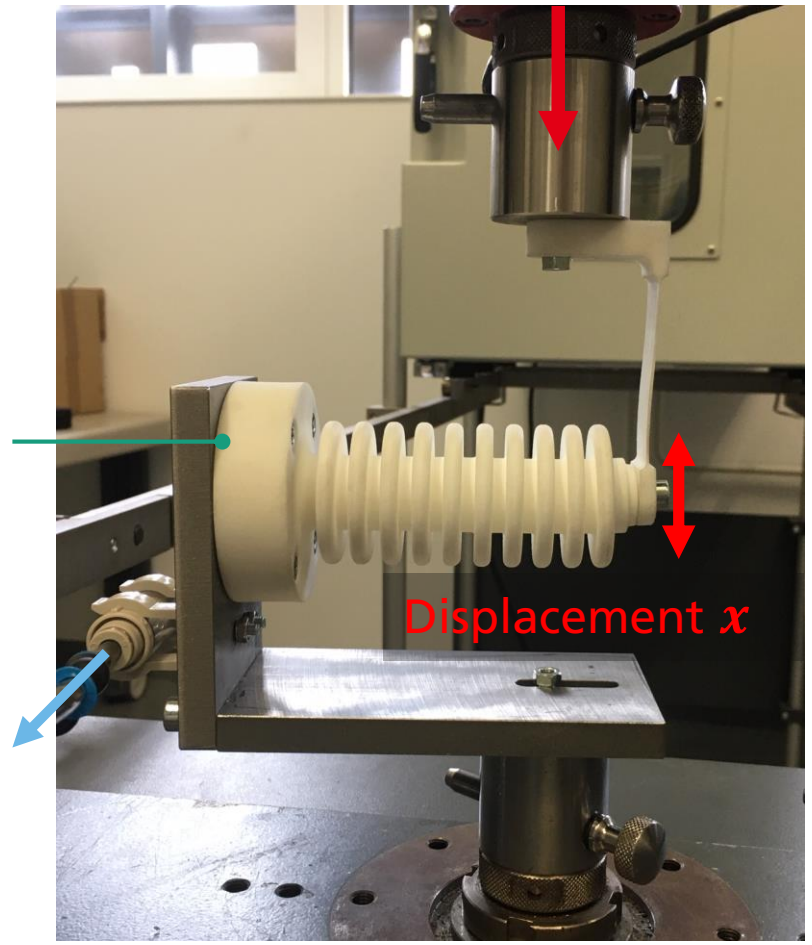


Mechanical characterization

Setup

- proof-of-concept
- Material: Polyamide
- uniaxial testing machine (Zwick/Roell)

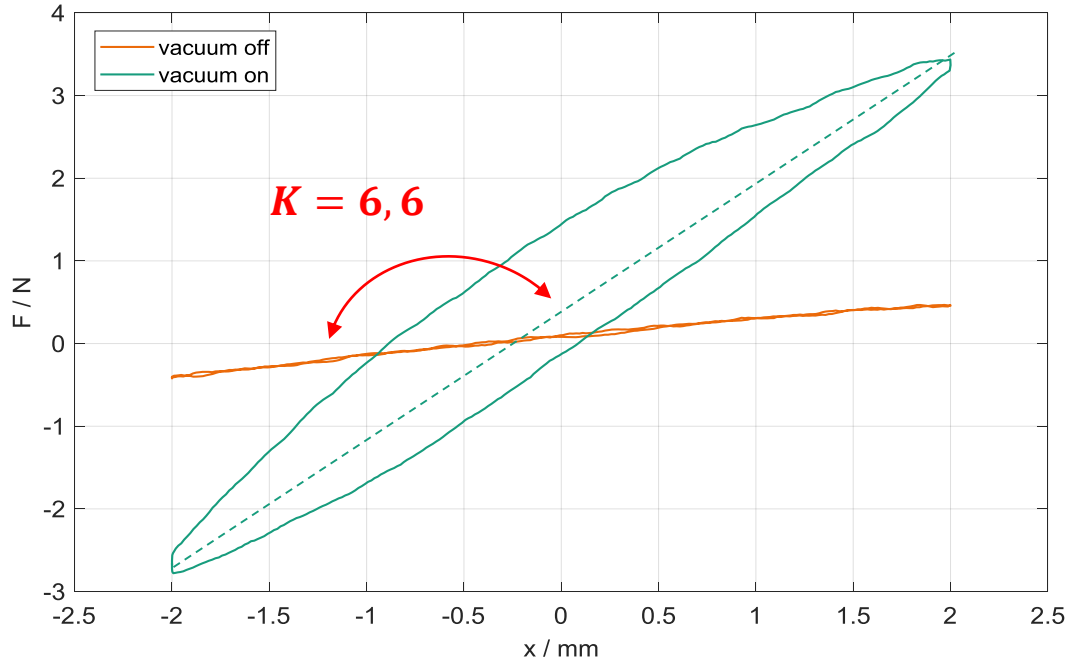
  → quasistatic bending stiffness $\boldsymbol{k} = \frac{\boldsymbol{F}}{\boldsymbol{u}}$

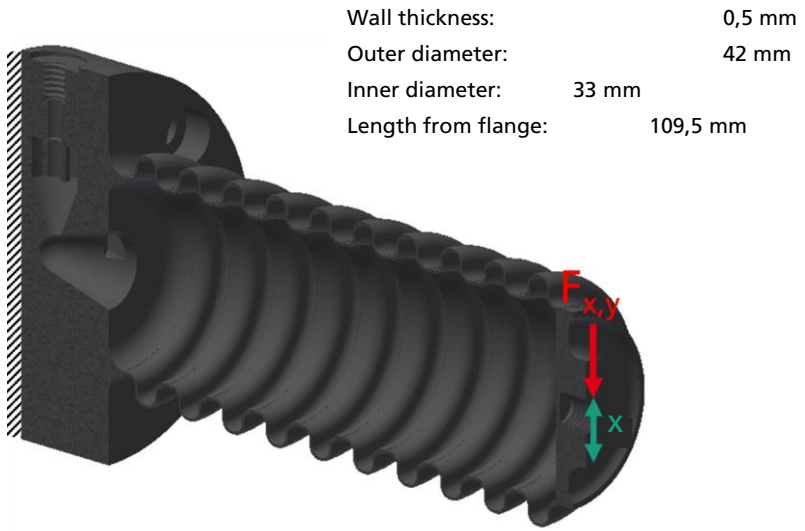


Mechanical characterization

Results

- Significant increase in stiffness $K > 6$
- Significant increase in hysteresis due to internal friction

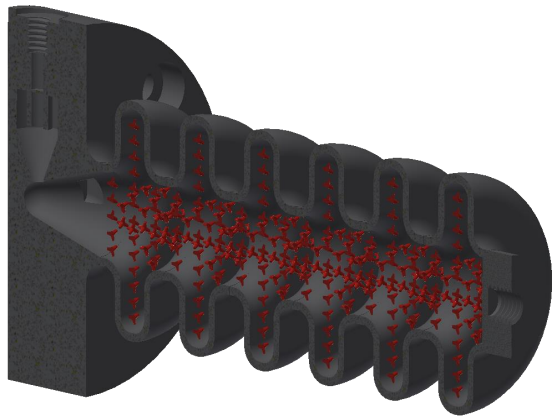




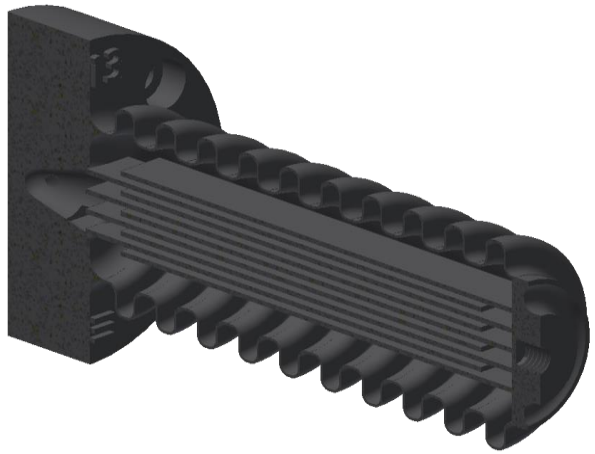
Transfer into programmable materials

Further investigations

- Further increase of effect using



3D-printed particles



layers

rods/fibers

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Fraunhofer CPM

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