

# Investigation of the Setting Behaviour of Mechanically Biased Piezoelectric Ultrasonic Transducers

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ICU 2025, Paderborn, Germany, 25th September 2025





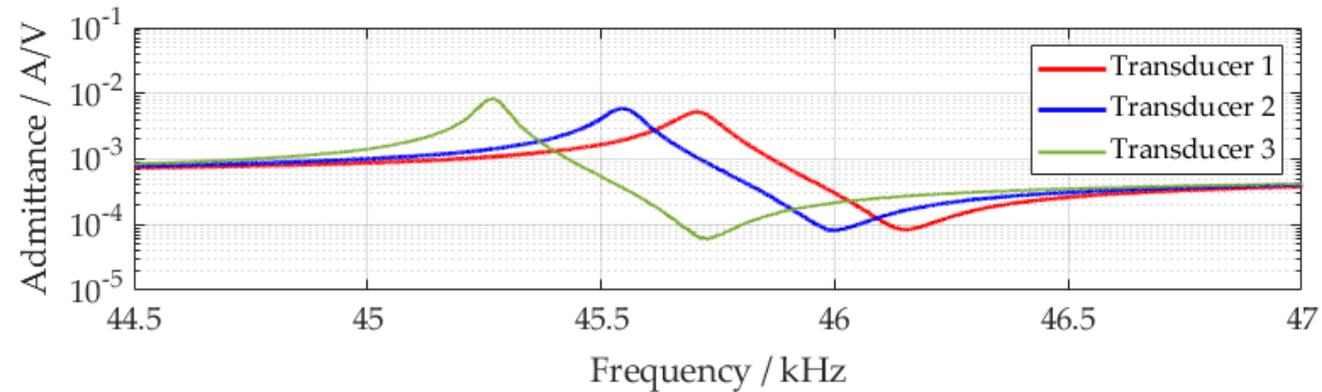
# Outline

- Motivation
- Transducer Setup
- Failure Mode and Effects Analysis
  - Geometry
  - Contact Stiffness
  - Preload Losses and Homogeneity
  - Assembly
- Conclusions



## Motivation

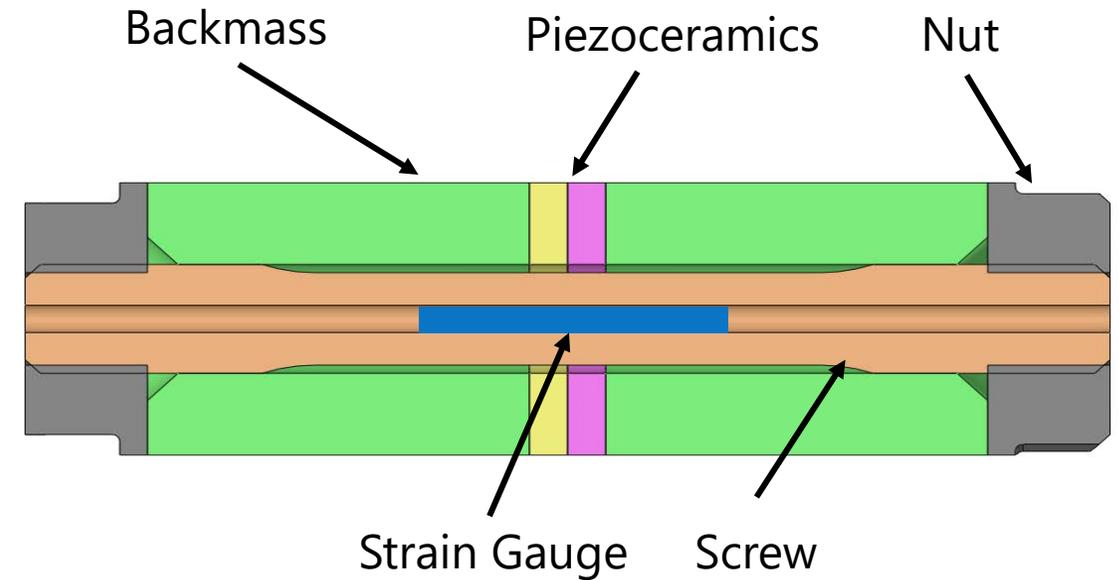
- Frequency deviation observed in nominally identical transducers:  $\approx 450$  Hz.
- Resonance variation reduces process stability and efficiency in industrial use.
- Main hypothesis: preload and screw setting behaviour are key factors.





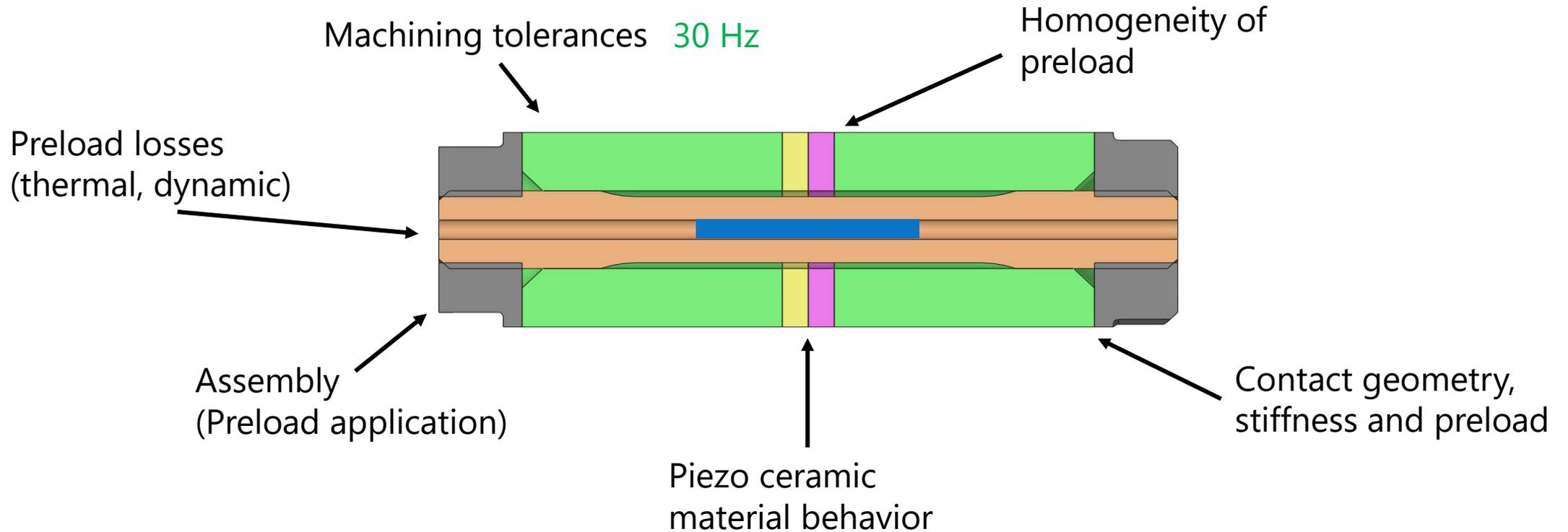
## Transducer Setup

- Bolt-clamped Langevin Transducer (BLT) construction
- Piezo rings preloaded between steel masses with a central screw and strain gauge.
- Preload ensures mechanical contact and influences piezoelectric parameters (e.g.  $d_{33}$ ).





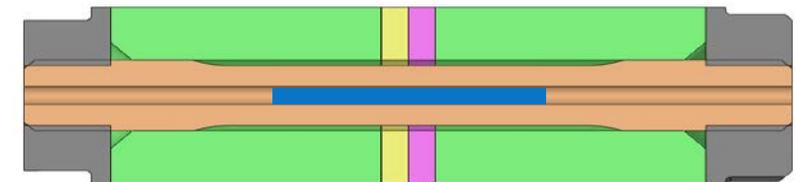
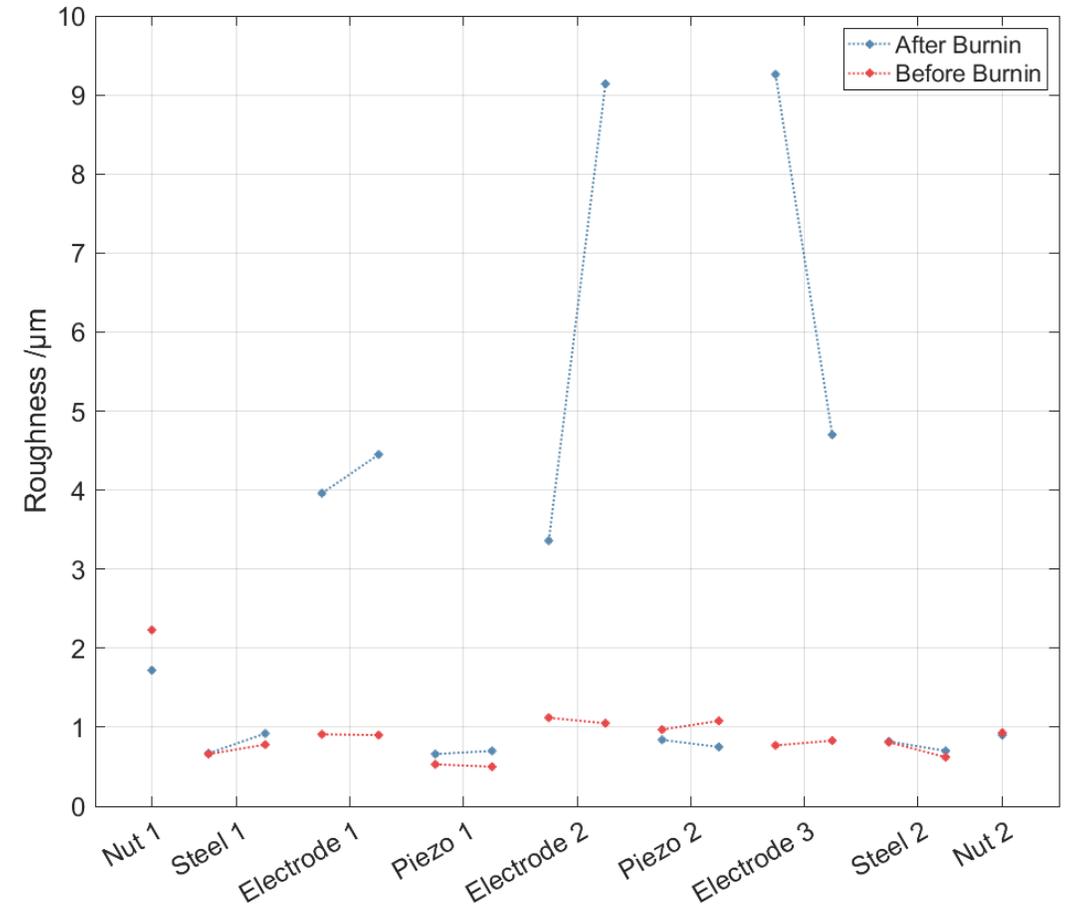
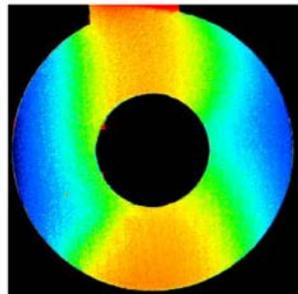
# Failure Mode and Effects Analysis: Which Effects Might Lead to Frequency Scattering?





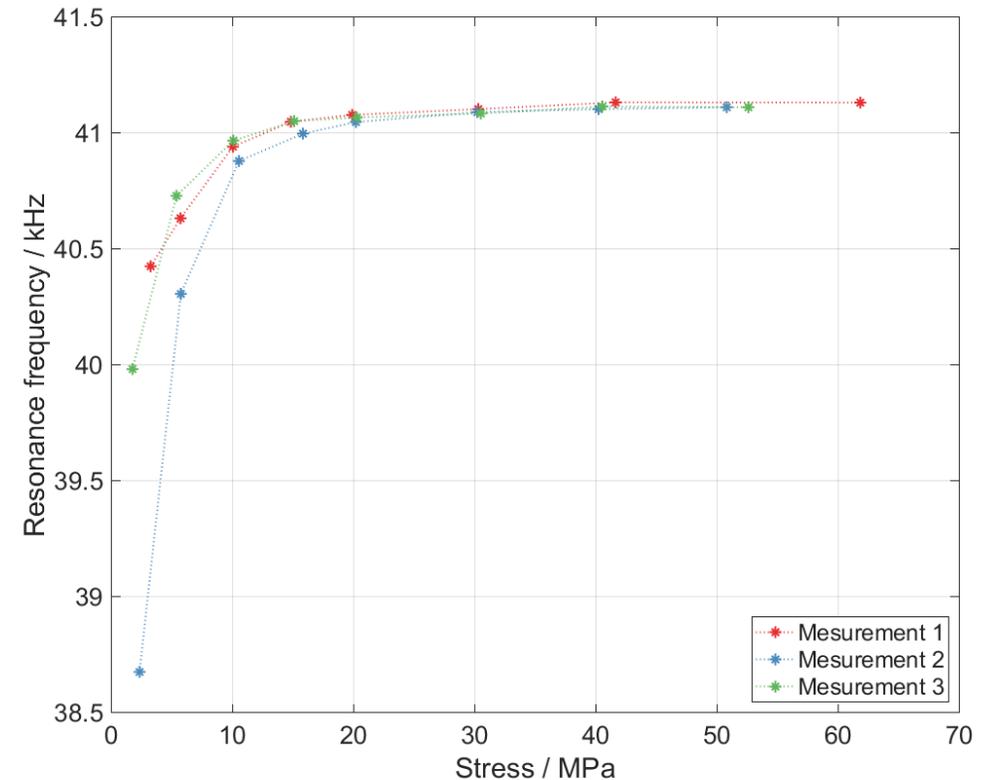
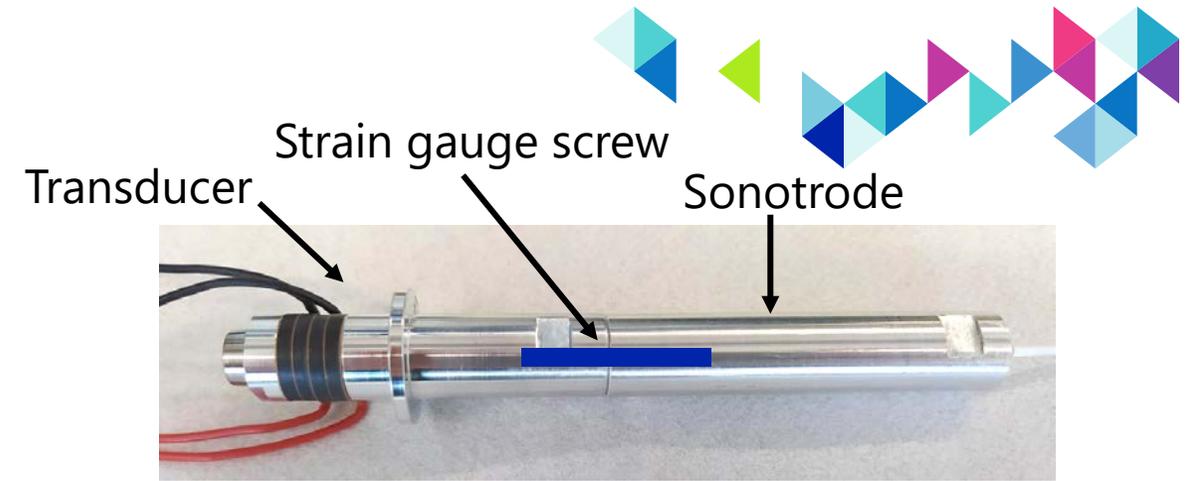
## Contact Geometry

- Measurements with a profilometer before/after assembly & operation
- Solid steel parts and piezos: no relevant change
- Electrodes difficult to evaluate due to deformation
- Result: insignificant influence on frequency deviation



## Contact Stiffness Experimental

- Preload of metal parts influences longitudinal resonance frequency
  - Clear effect at very low preload ( $< 10$  MPa)
  - At operating preload ( $\sim 40$ – $50$  MPa): saturation of effect
    - (5 Hz/MPa)
- Irrelevant for static preload, but how about dynamics?

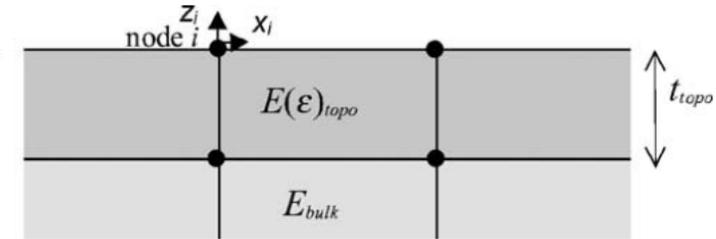




# Contact Stiffness Simulation (FE)

- Contact stiffness depends on roughness & preload.
- Contact stiffness is represented by a layer with variable Young's modulus.

$$\frac{E_{\text{topo}}(\varepsilon_z)}{E_{\text{bulk}}} = \frac{A_r(z)}{A_n}$$



[Sellgrent et al. 2003]

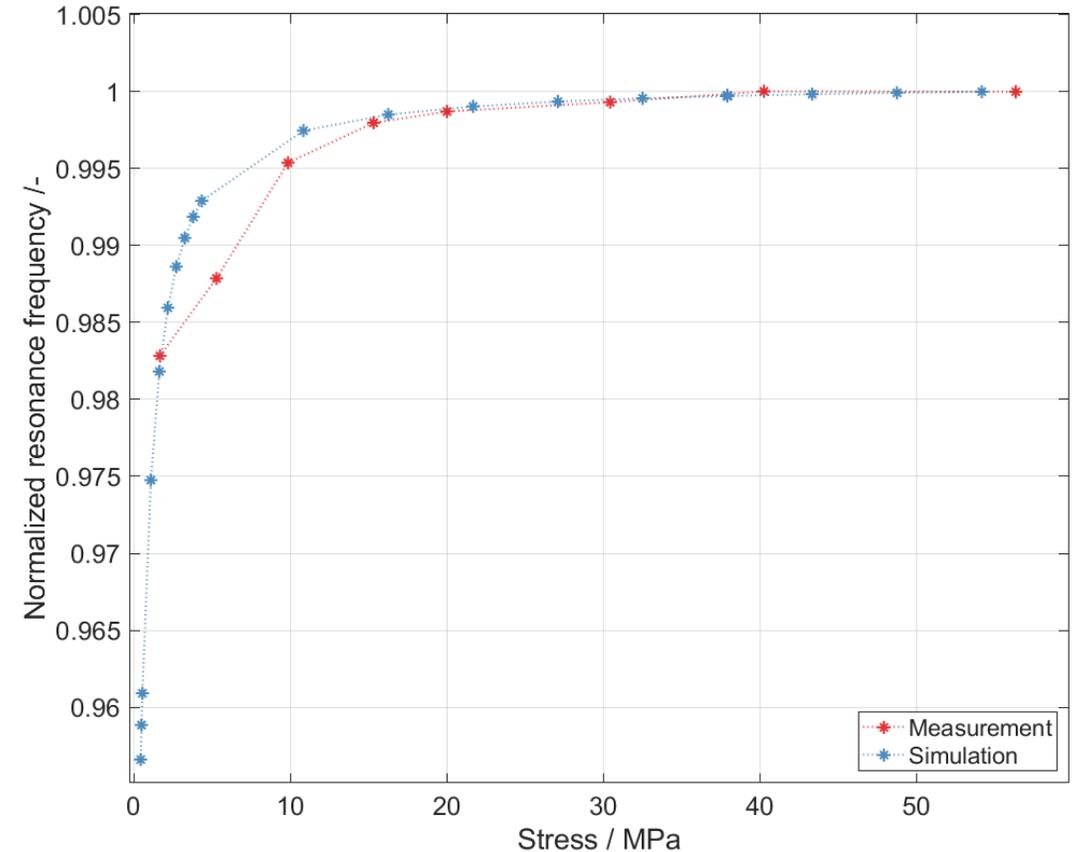
- Ratio of real to nominal contact area depends on surface roughness and normal force.





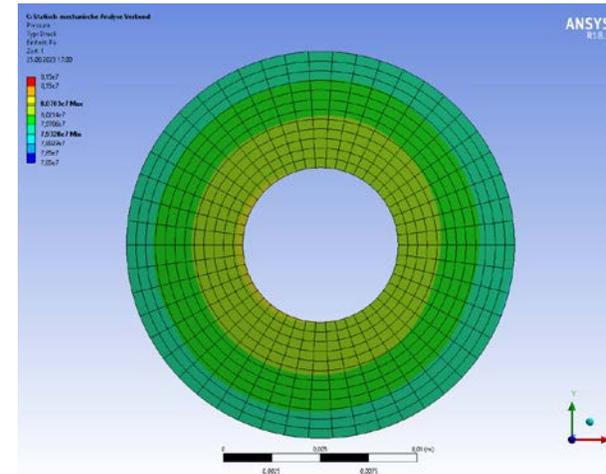
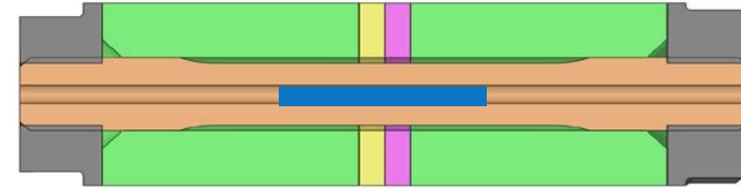
## Contact Stiffness Simulation (FE)

- Contact stiffness depends on roughness & preload
- Contact stiffness represented by a layer with variable Young's modulus
- Simulation aligns with experimental curves
- Dynamic load < 20 MPa!
  - In operation typically  $\pm 15$  MPa (150 Hz frequency shift, only in large signal excitation)



# Preload Homogeneity

- FE-simulation showed uniform stress distribution
- Pressure-sensitive films confirm this result:
  - No critical spots with overload or underload
  - Homogeneity is ensured



Preload distribution deviation < 1%

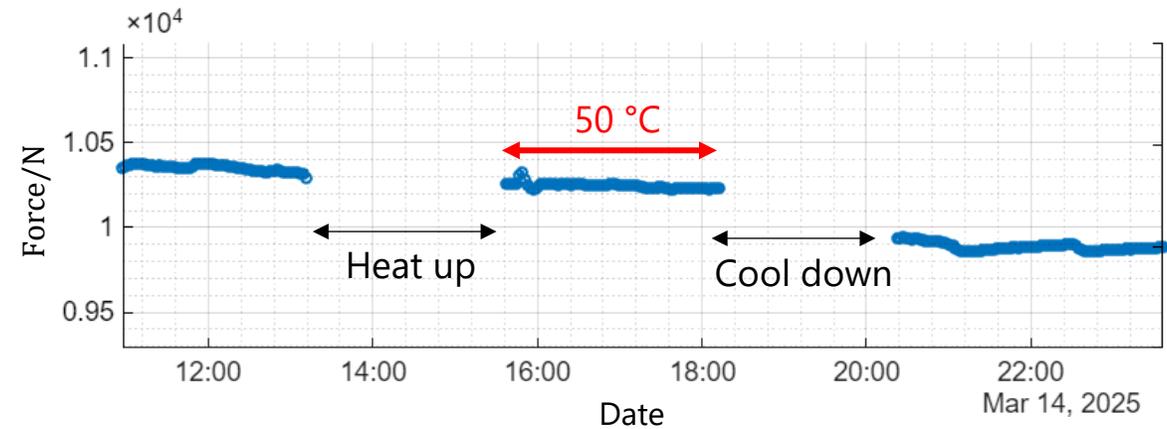


Pressure-sensitive film:  
homogeneous preload  
distribution



## Preload Losses: Thermal

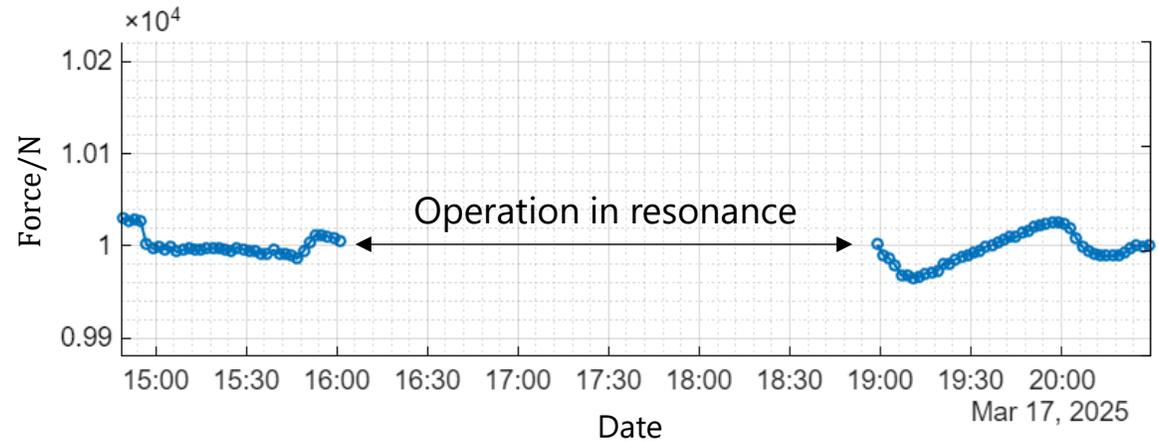
- Heat up to 50 °C → preload remains stable
- No thermal induced plastic deformation
- After cooling, preload decreases by 2-3 %  
→ 15 Hz frequency shift
- Material effect of the piezo?





## Preload Losses: Dynamic

- Operation in resonance for over 2 hours  
→ no preload loss

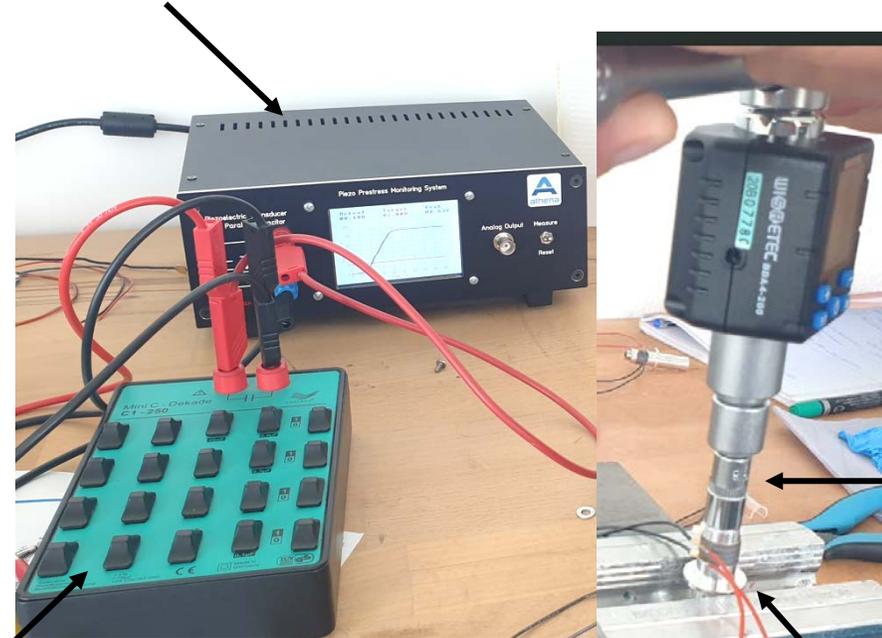




# Assembly Scatter

- Manual tightening →  $\pm 2.8\%$  preload scatter
- $\sim 15$  Hz shift

Preload measurement device



Parallel capacitance

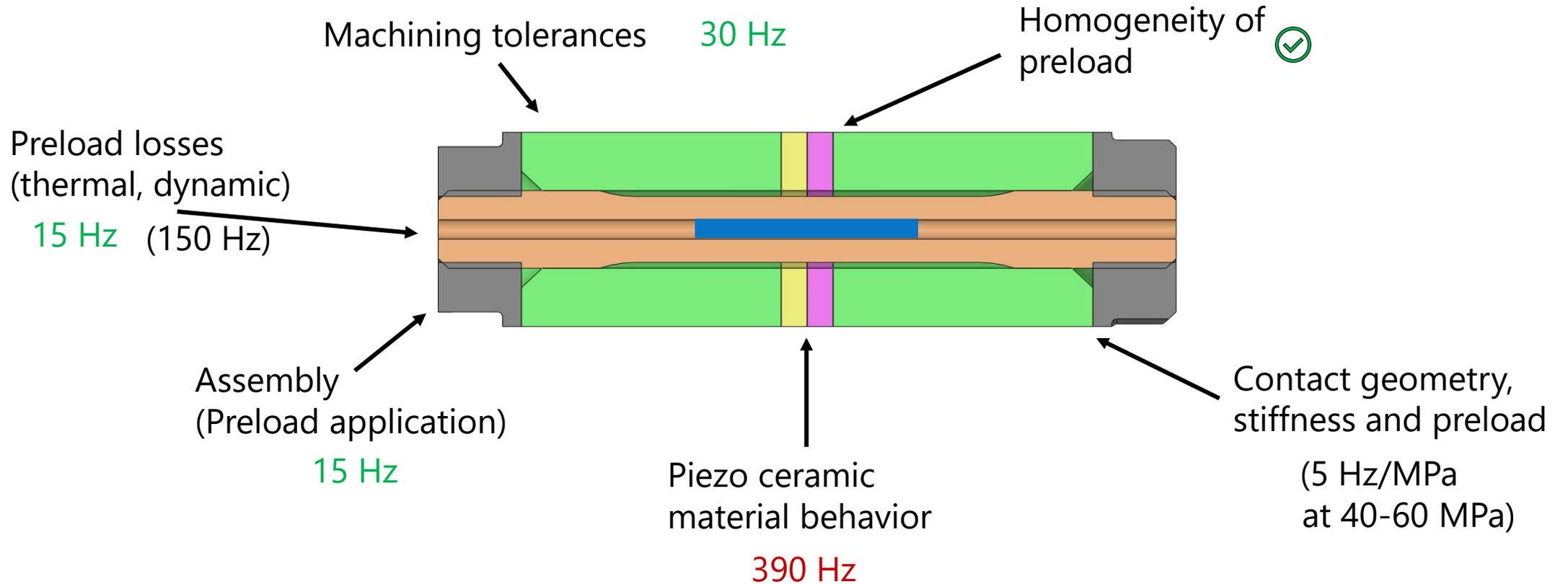
Wrench

Transducer





# Conclusions





# Thank you for your attention

This project has been funded by  
the Deutsche Forschungsgemeinschaft (DFG,  
German Research Foundation) – HE 2973/5-1

Funded by  
**DFG** Deutsche  
Forschungsgemeinschaft  
German Research Foundation

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