

# TIME-DEPENDENT MATERIAL CHARACTERISTICS OF PRESTRESSED PIEZOELECTRIC CERAMICS IN LANGEVIN TRANSDUCERS

**Claus Scheidemann**, Tobias Hemsel, Walter Sextro  
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# Outline

- Motivation
- Experimental and Measurement Setup
- Prestress Dependence
  - Experimental Results
  - Simulation Results
- Conclusion and Outlook





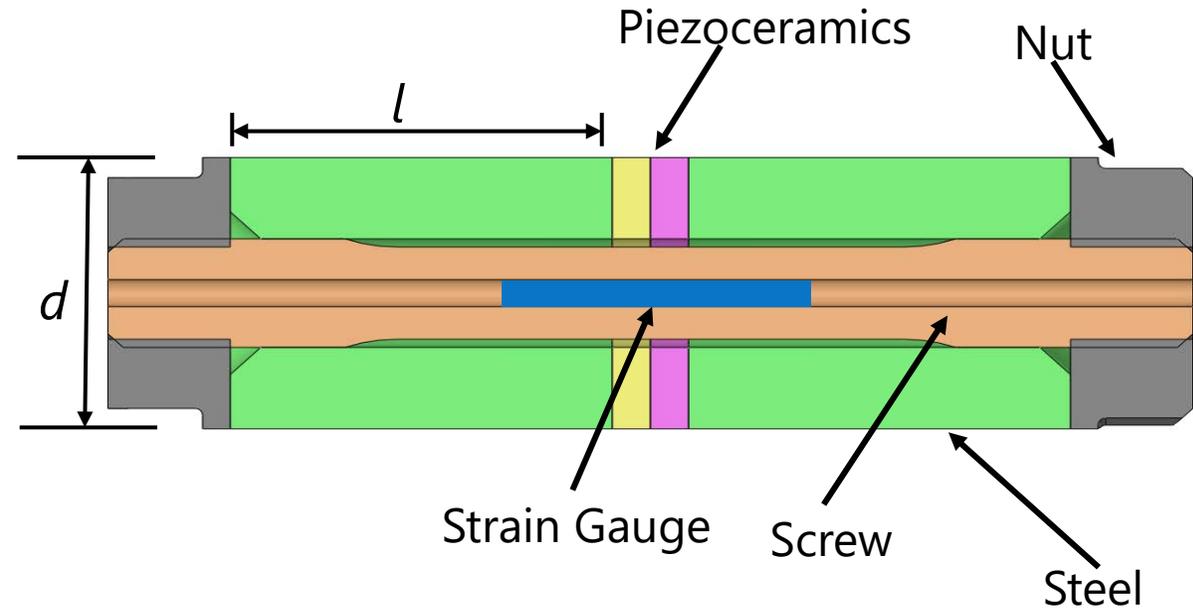
## Motivation

- Design of new transducers: time consuming iterative process of simulation, prototyping and experiments
- Standard determination of complete set of material parameters: 4 test samples are required
- Manufacturer data sheets: Small signal characteristics for free vibration only
- New approach: Measurements on a single probe (same geometry as used in device), considering driving conditions (temperature, prestress, high power, vibration under load)



## Experimental Setup

- Symmetrical transducer
- Ceramic rings 20 x 8 x 2.5 mm<sup>3</sup>
- $l$  optimized to achieve a homogeneous normal stress distribution in the piezoceramics
- Different prestress levels (measured by strain gauge)

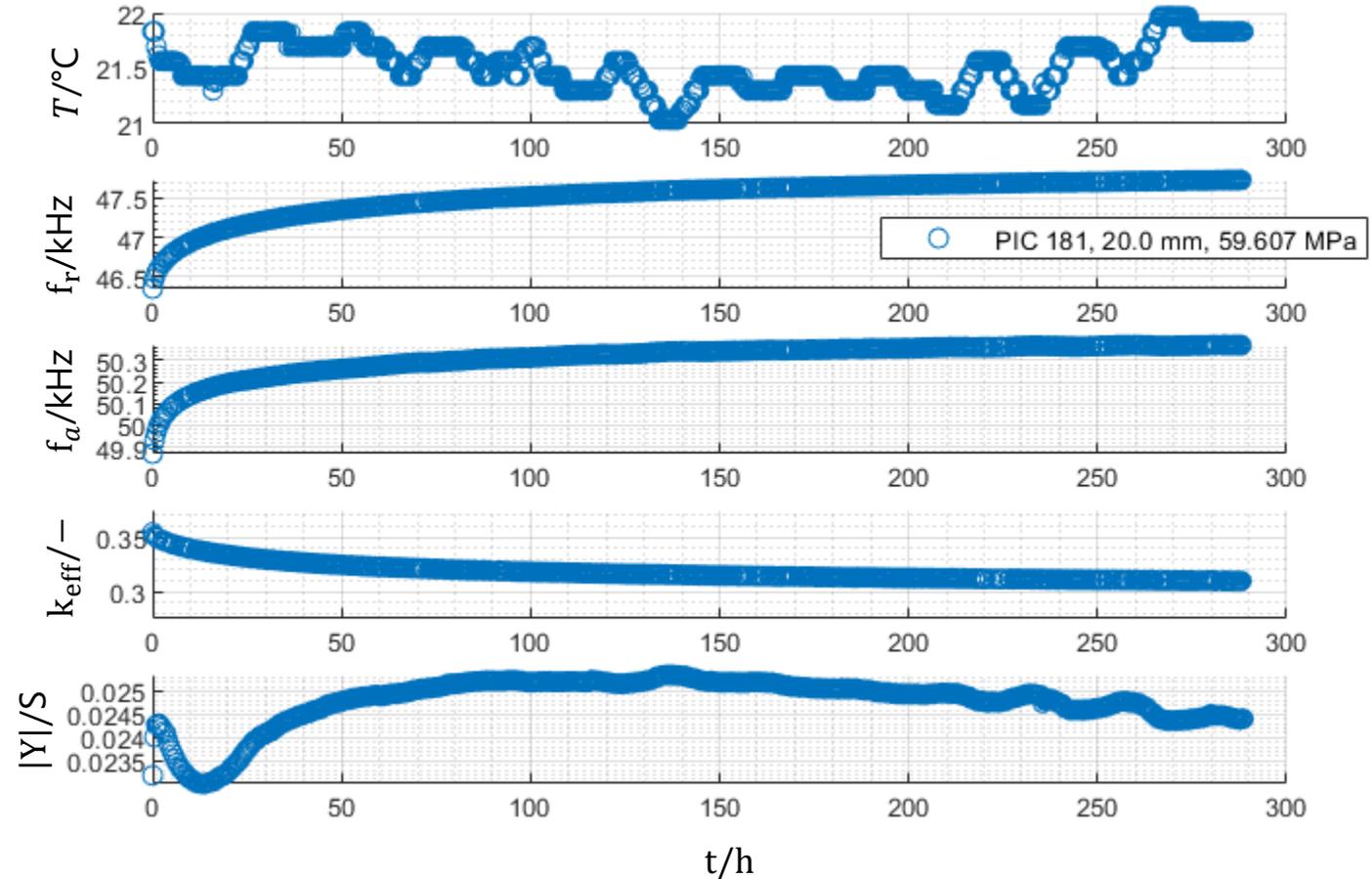




## Measurement Setup

### General Conditions

- Small signal excitation, free vibration
- Measurement of electrical admittance and temperature at different points of time after assembly
- Evaluation of admittance, resonance- and antiresonance frequency

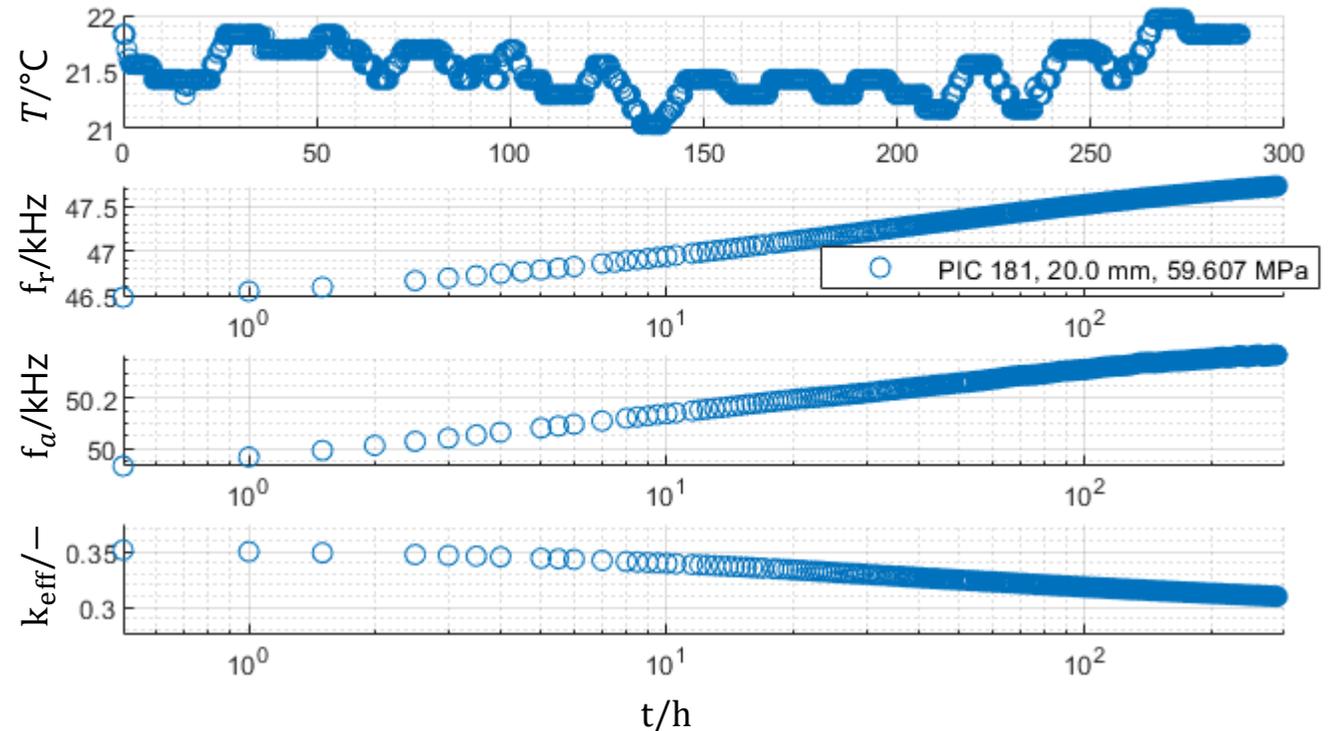




## Measurement Setup General Conditions

- Small signal excitation, free vibration
- Measurement of electrical admittance and temperature at different points of time after assembly
- Evaluation of admittance, resonance- and antiresonance frequency
- Decadal behavior
  - $f_r$  increases  $\sim 1\%$
  - $f_a$  increases  $\sim 0.25\%$
  - $k_{eff}$  decreases  $\sim 12\%$

➔ For reliable parameter identification the decadal time behavior must be considered!

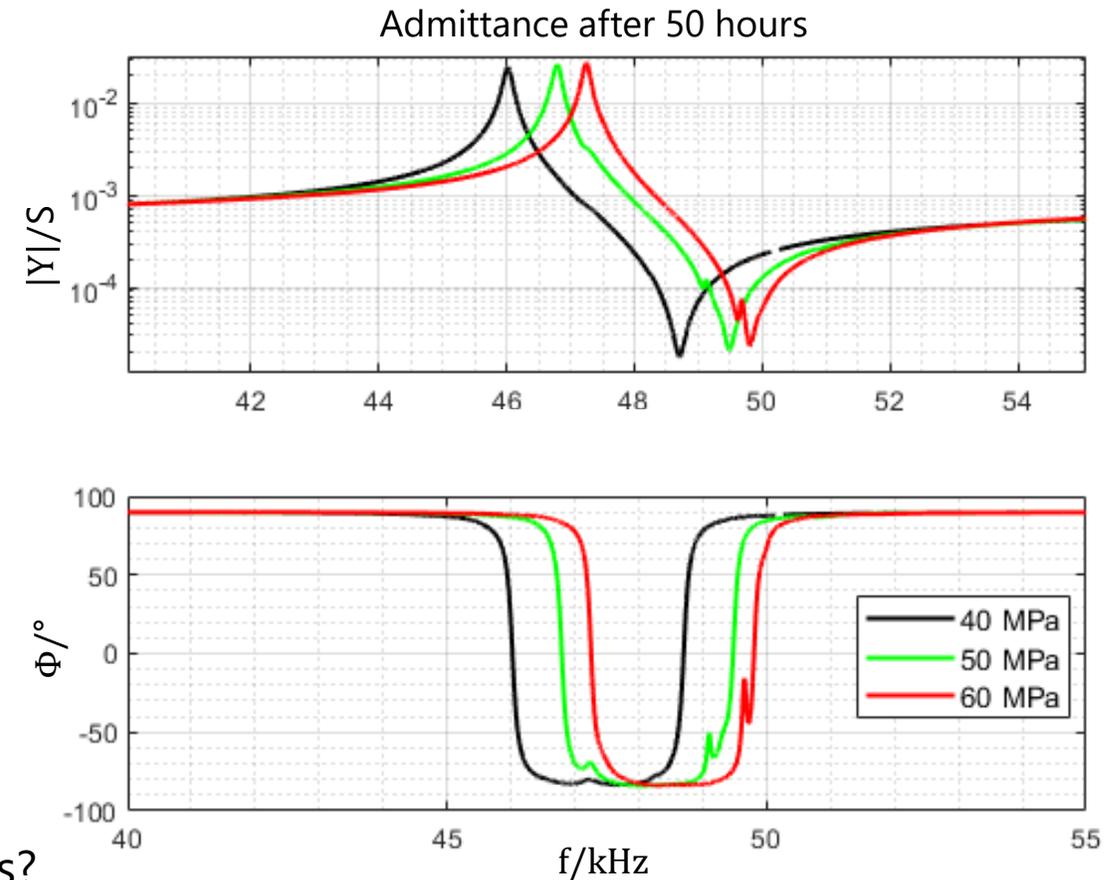




## Prestress Dependence Experimental Results

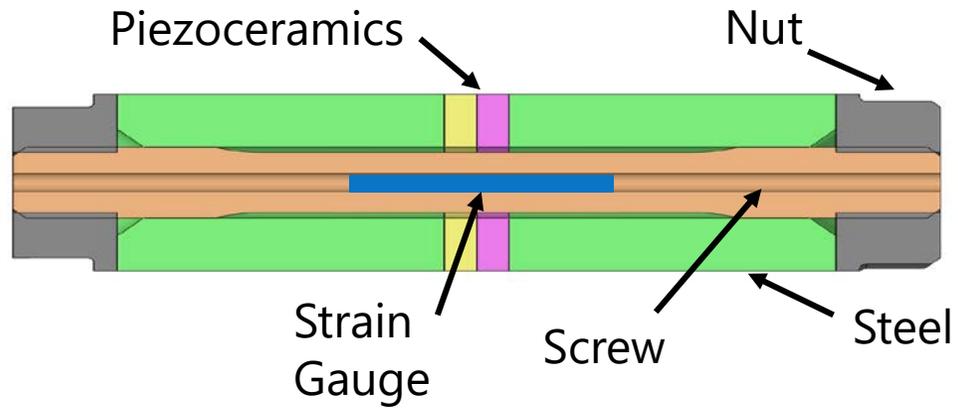
- Stepwise application of prestress, each measurement after 50 hours
- Resonance frequency increases ( $\sim 2.7\%$ )
- Anti resonance frequency increases ( $\sim 2.3\%$ )
- Electro-mechanical coupling decreases ( $\sim 5\%$ )
- Maximum admittance increases ( $\sim 13\%$ )

➔ How to extract material parameters from these results?



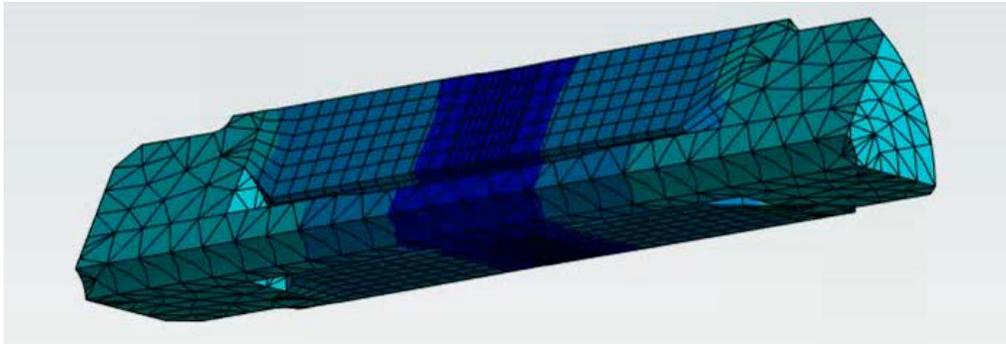


## Simulation Setup





## Simulation Setup



**Piezo Matrices**

$$\begin{array}{cccc|ccc}
 c_{11} & c_{12} & c_{13} & & & & e_{31} \\
 c_{12} & c_{11} & c_{13} & & & & e_{31} \\
 c_{13} & c_{13} & c_{33} & & & & e_{33} \\
 & & & c_{44} & & & e_{15} \\
 & & & & c_{44} & & e_{15} \\
 & & & & & c_{66} & \\
 \hline
 & & & & e_{15} & & \epsilon_{11} \\
 & & & e_{15} & & & \epsilon_{11} \\
 e_{31} & e_{31} & e_{33} & & & & \epsilon_{33}
 \end{array}$$

- Modal analysis:  
Calculation of resonance- and antiresonance frequency
- Harmonic analysis:  
Calculation of admittance

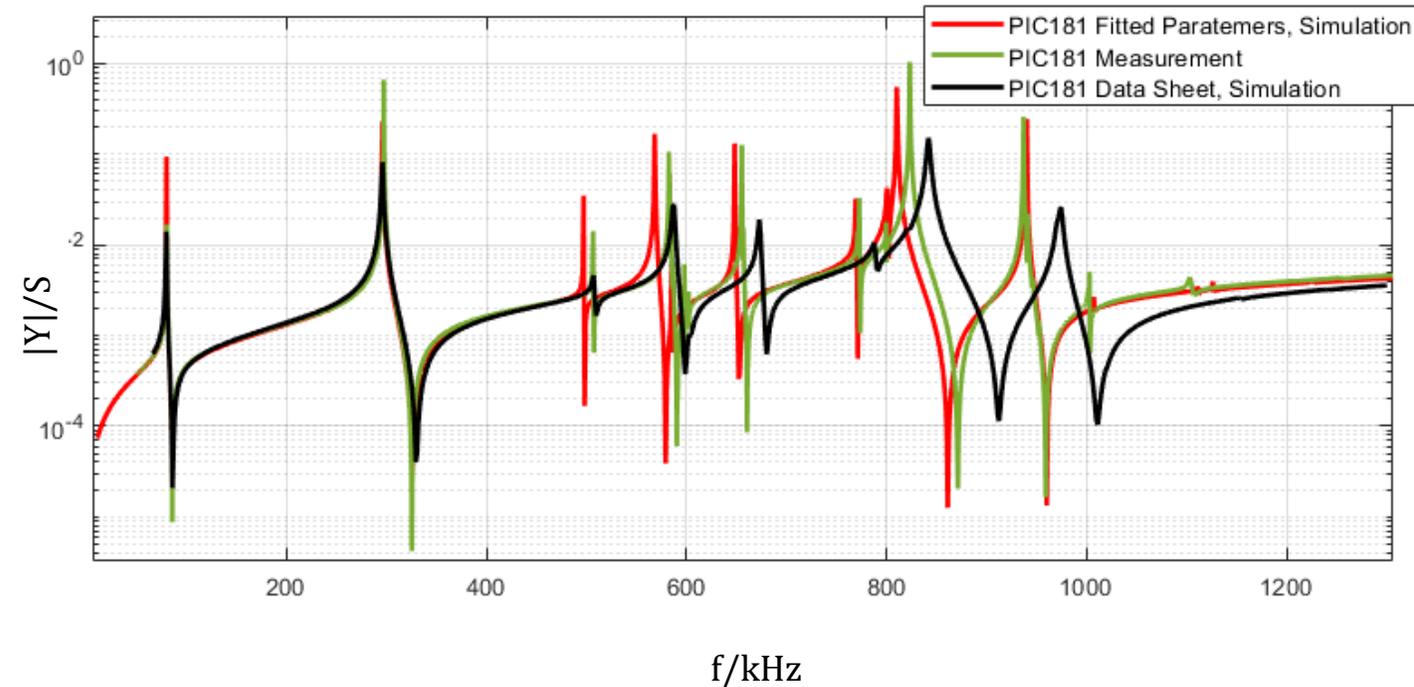
- Successively parameter fitting (fminsearch):
  1.  $c_{33}$  for resonance frequency
  2.  $d_{33}$  for antiresonance frequency
  3.  $\epsilon_{33}$  for admittance





## Simulation Preparation

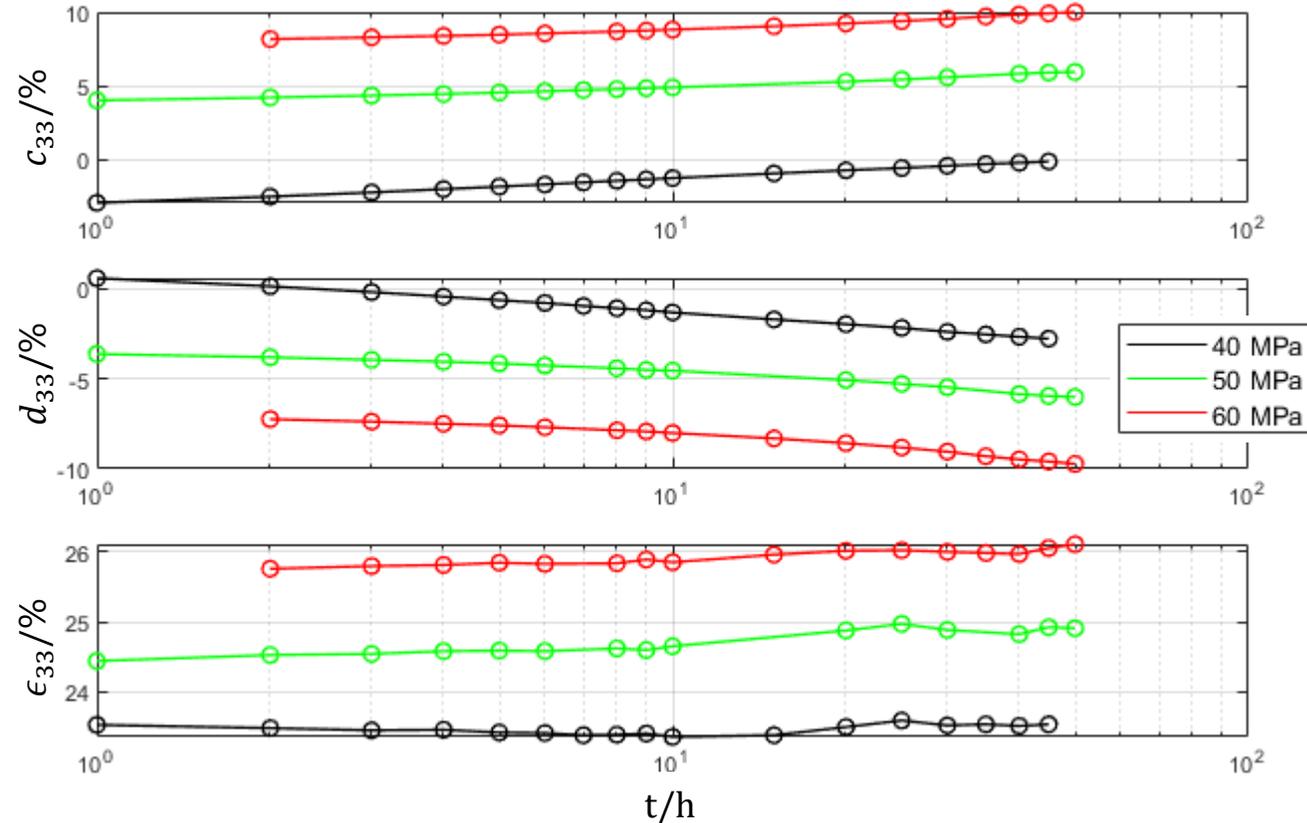
- Piezo rings were measured under free vibration
- Creation of an FE model in Ansys of the ring and simulation of the admittance with data sheet parameters
  - Stiffness of the thickness mode is too high
- Fitting material data to measurements gives a more realistic parameter set





# Simulation Prestress Dependence

- Prestress applied in three steps
- Identified changes are nearly linearly proportional to the prestress
- Decadal behavior is also observed in the determined parameter changes
- For a reliable prediction of the material parameter changes, approximately 2 days should be considered





## Conclusion and Outlook

- Long-term measurements of prestressed transducers showed significant changes
  - Resonance- and antiresonance frequency increase over time with decadal behavior
  - The electro-mechanical coupling factor decreases
  - Admittance doesn't show a clear behavior
- For a better model-based simulation of the transducer, it is beneficial to fit the material parameter of the ceramic rings first
- The determined prestress-dependent parameter changes also show a decadal behavior
  - With higher prestress, the stiffness increases while the piezoelectric constant decreases.
- Investigate the influence of other material parameters (e.g.  $c_{11}$ )
- Further investigation of the time-dependent change in admittance and damping





# Thank you for your attention

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## Claus Scheidemann

Research Assistant

Dynamic and Mechatronics  
Faculty of Mechanical Engineering

**Telephone** +49 5251 60-1816  
**Email** claus.scheidemann@upb.de  
**Web** www.mb.uni-paderborn.de/en/ldm  
**Address** Warburger Str. 100, room P1.3.32

