Dynamische Modellierung einer aktiven Lagerung basierend auf dielektrischem Elastomeraktor

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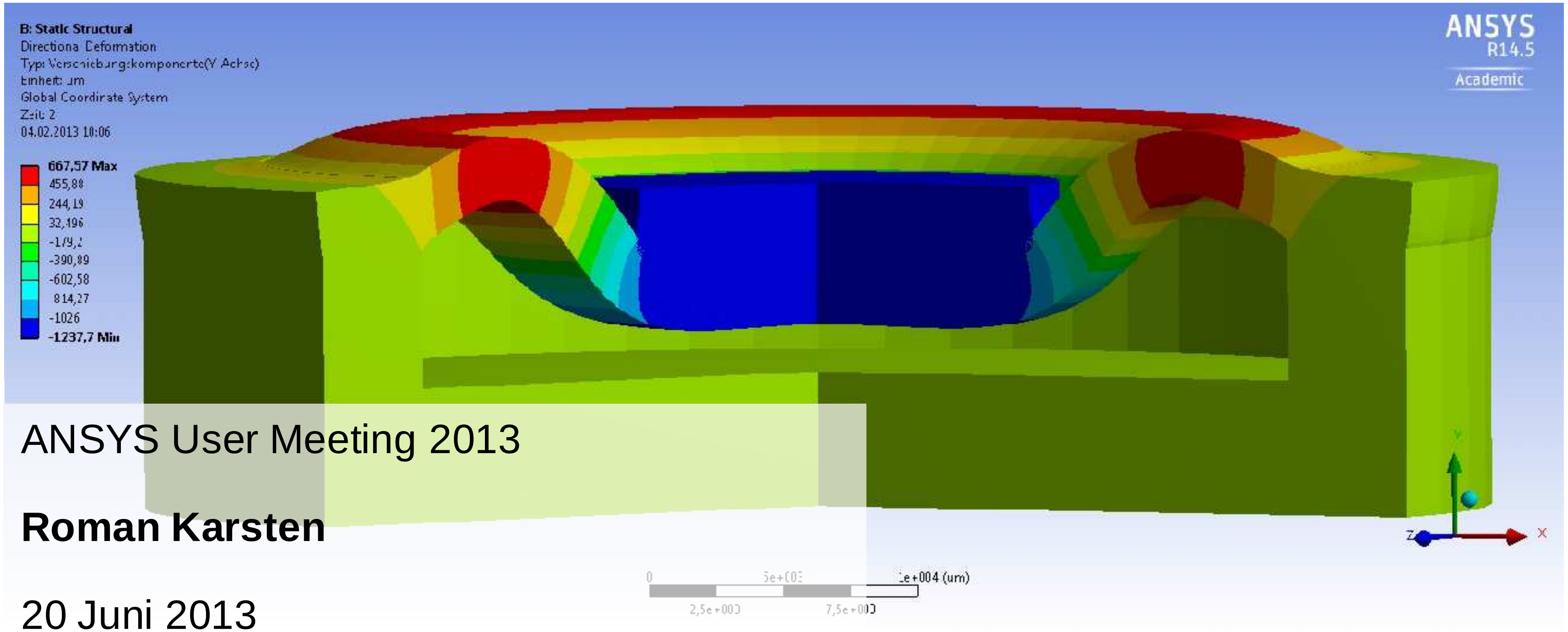

ANSYS User Meeting 2013

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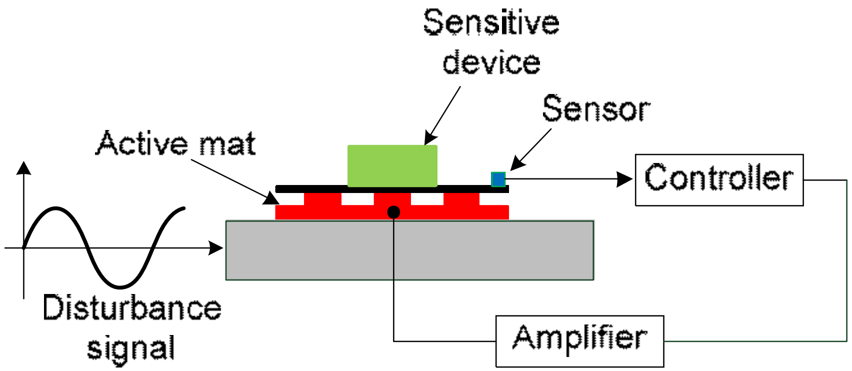
Outline

- Motivation
- Working principle of dielectric elastomer stack actuator (DESA)
- Application active suspension based on DESA
- Transient simulation of the suspension
- Harmonic simulation of the suspension
- Conclusion

Motivation
Active vibration control

- Passive isolation in low frequency range (0 – 100 Hz) is limited
- Active suspension is necessary to protect sensitive devices from vibrations
- Active suspension produces inverse deflection to disturbing vibration



Motivation

Active suspension based on Dielectric Elastomer Stack Actuator (DESA)

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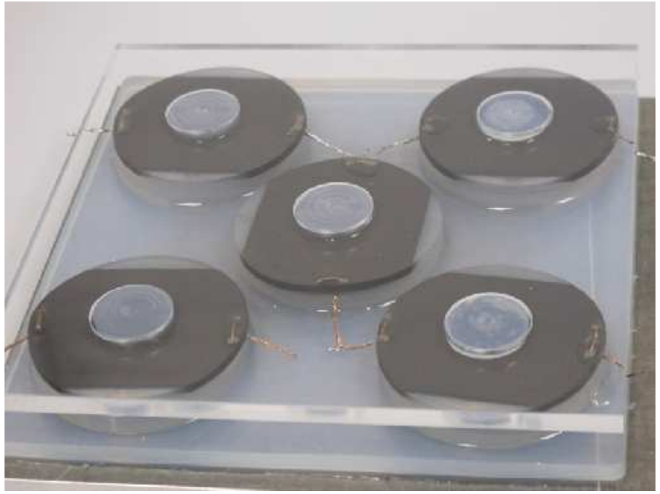
Aims of research:

- Development of active suspension for isolating laboratory equipment from disturbing vibrations
- Active vibration cancelation in low frequency range up to 50 Hz
- Passive isolation at higher frequencies



Aims of FEM simulation:

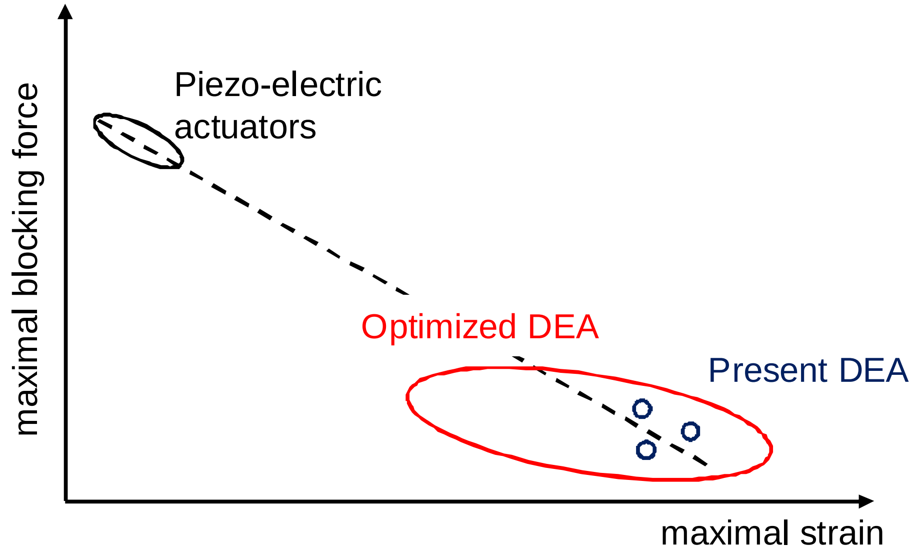
- Shape optimization for better vibration isolation

- Size: 140 mm x 140 mm x 20 mm
- 5 Dielectric elastomer stack actuators (DESA)
- Weight of each DESA 5.16 gram
- Isolated mass: up to 500 gram

Motivation
Dielectric elastomer stack actuator (DESA)

Advantages of DESA:

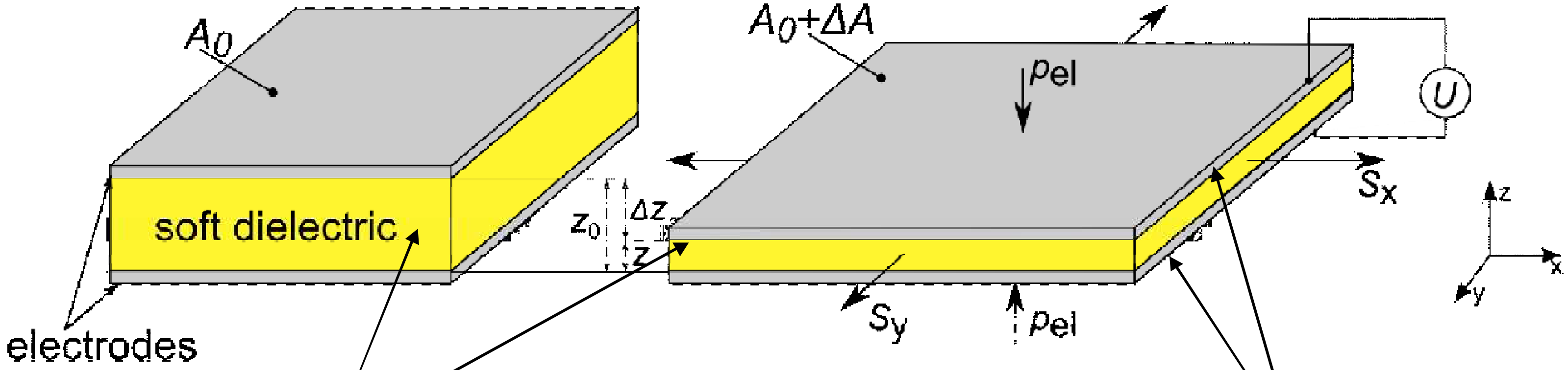
- Inexpensive
- Formable
- Light weight, density 1 g/cm³
- High strain: 20 %
- Combination of passive and active features



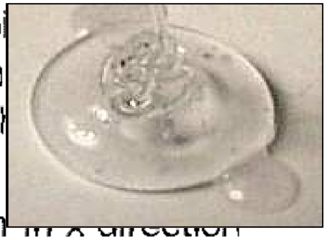
Disadvantages of DESA:

- Low forces: some N
- High driving voltage: up to 1000 V

Dielectric elastomer actuator (DEA)
Working principle



p_{el}	electrostatic pressure
$\varepsilon_0 \cdot \varepsilon_r$	permi…
U	drivin…
z	film t…
z_0	initial…
$S_x = \frac{x}{x_0}$	strain in x direction
$S_y = \frac{y}{y_0}$	strain in y direction
A	transducer area
A_0	initial transducer area
Y	Young's Modulus



Elastosil P7670 *Wacker Chemie*,
Young's Modulus: Y = 129 kPa

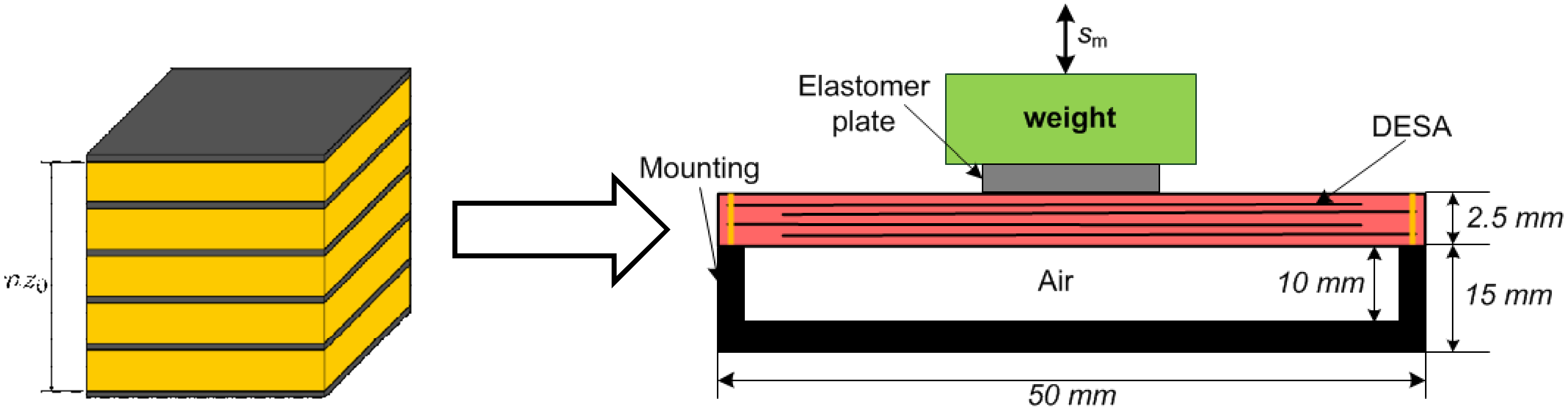
Electrostatic pressure

$$p_{el} = \varepsilon_0 \varepsilon_r \frac{U^2}{(z_0 - \Delta z)^2}$$

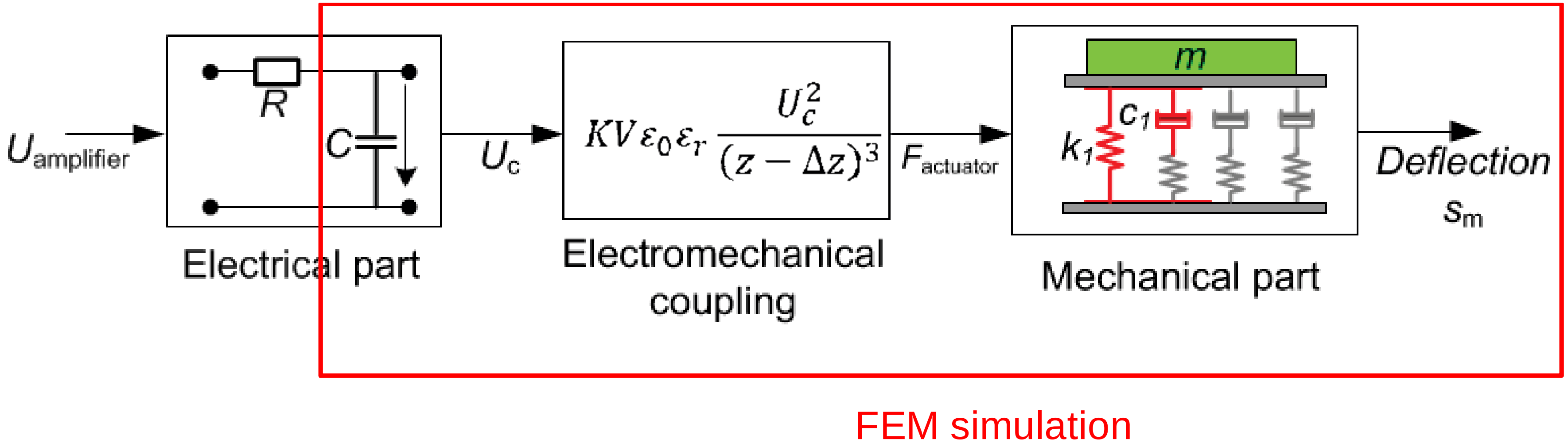
Graphite powder

Active suspension based on dielectric elastomer stack actuator (DESA)

actuator parameter		
Entire thickness	2,5	mm
Radius electrodes	20	mm
Thickness dielectric	43	µm
Thickness electrodes	7	µm
Number of layers	49	1



Dynamic Model of DESA



F	force	U	driving voltage	z_0	initial film thickness	k	stiffness constant	a	acceleration
$\varepsilon_0 \cdot \varepsilon_r$	permittivity	z	film thickness	V	volume of dielectric	c	damping constant	m	weight

Driving voltage for DESA

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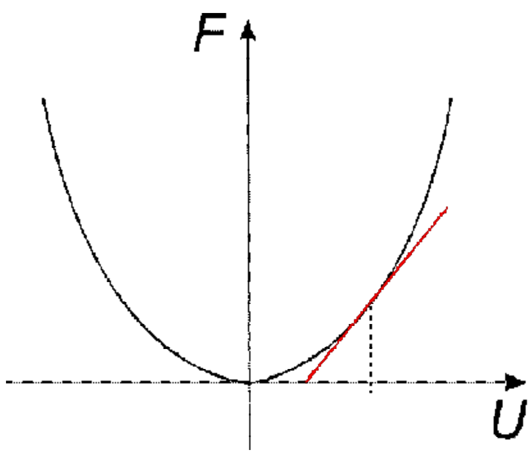
Active vibration control

→ positive and negative deflection of DEA necessary

$$(U_0 + U_1 sin(\omega t))^2 = U_0^2 + \frac{1}{2}U_1^2 + \underbrace{2U_0U_1}_{A_0} sin(\omega t) + \underbrace{\frac{1}{2}U_1^2}_{A_1} sin(2\omega t - 90°)$$

Approach

- High offset voltage: $\frac{A_0}{A_1} = \frac{2U_0U_1}{\frac{1}{2}U_1^2} = \frac{4U_0}{U_1}$
- Inverse function: Square root function



Driving voltage

- DC voltage: U_0 = 700 V
- AC voltage max.: U_1 = 300 V

FEM Simulation
Aims

- **Transient simulation of the active suspension**
  - Electro-mechanically coupled field simulation
  - Transient conditions
  - Theoretically achievable deflections of DESA

- **Modal / harmonic simulation**
  - Passive vertical transmissibility of the suspension
  - Determination of first resonance frequency of the suspension
  - Pre-stressed simulation

→ The result should be used for the shape optimization

FEM Simulation with ANSYS WB 14.5

2D axially symmetric simulation

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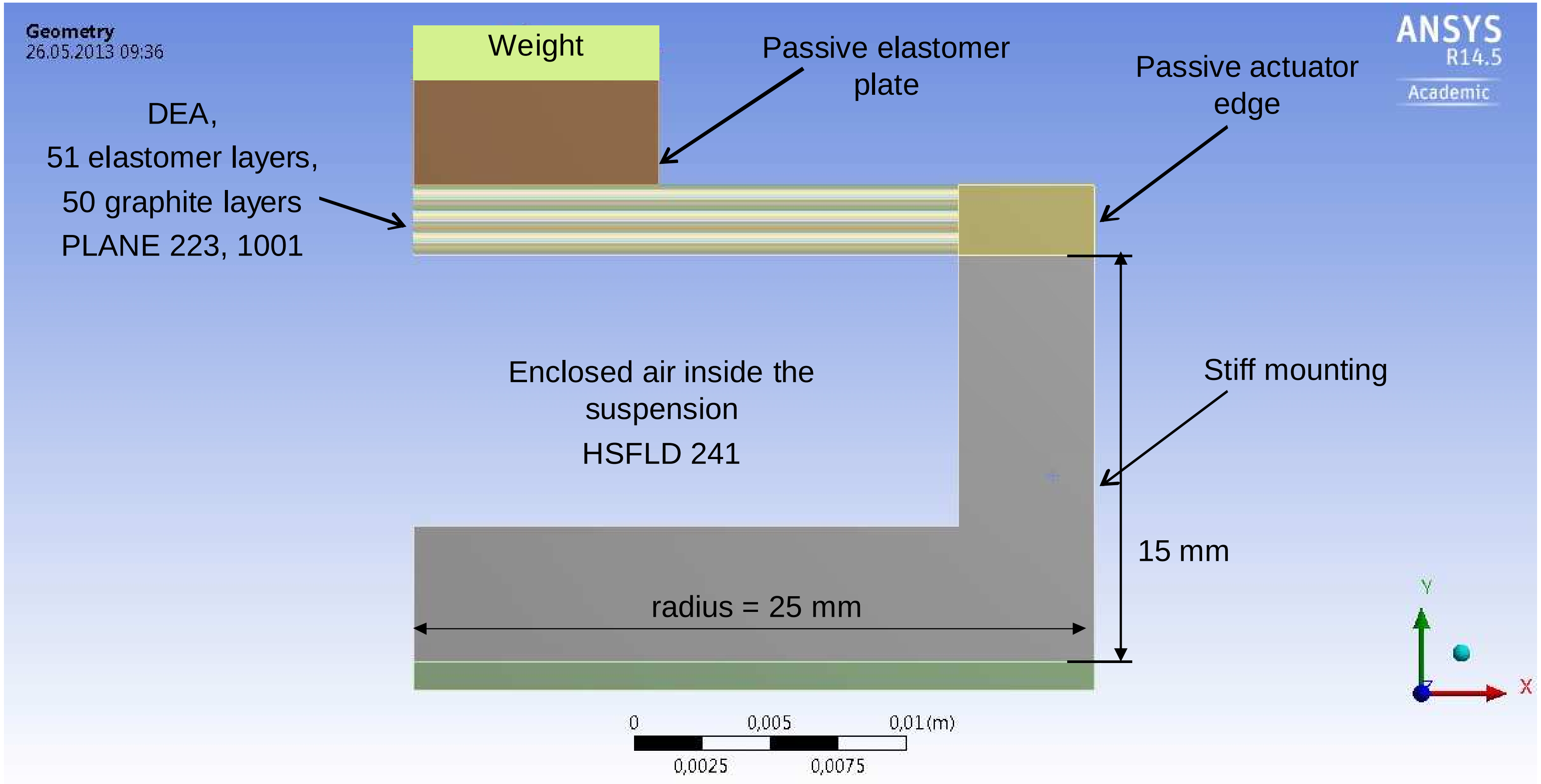
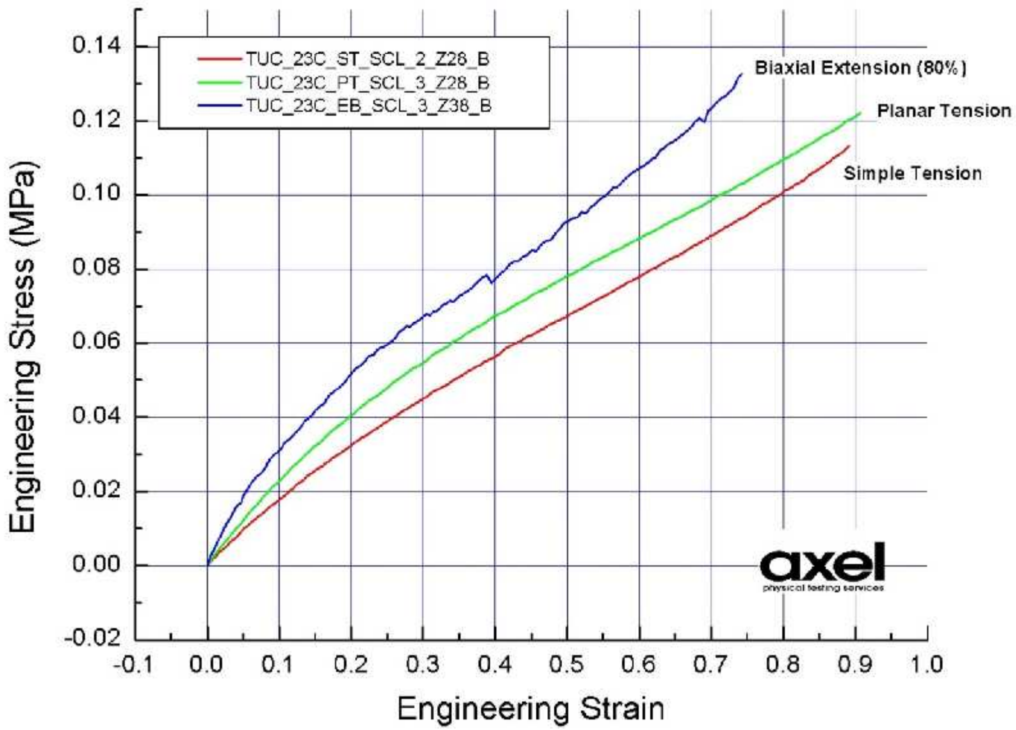


Mechanical behavior of elastomer
Hyper elastic behavior

§ Coupled Element PLANE 223

- à hyper elastic behavior is not supported
- à Mechanical parameters of electrodes are unknown

TUC 23°C 100% Strain Summary



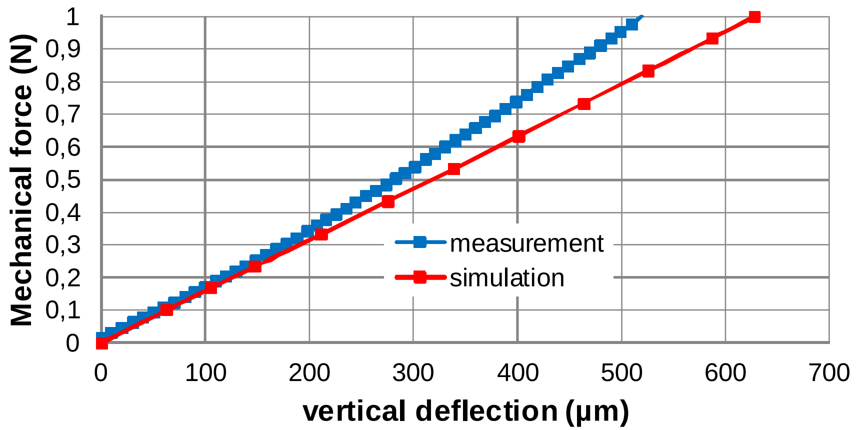
Elastosil P7670 *Wacker Chemie*

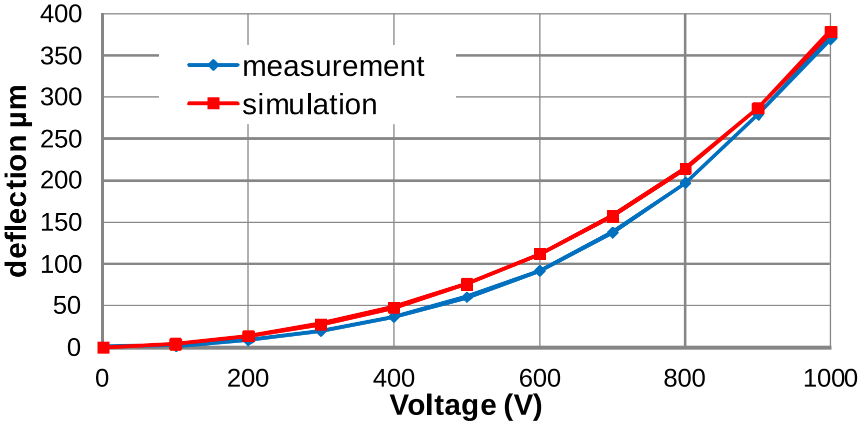
Static Simulation of DESA

Determination of constant Young's modulus

- Static simulation of active suspension
- Low deflection → constant Y-Modulus sufficient
- $Y = 300\ kPa$ for whole actuator
- Incompressible material $\vartheta = 0{,}49$

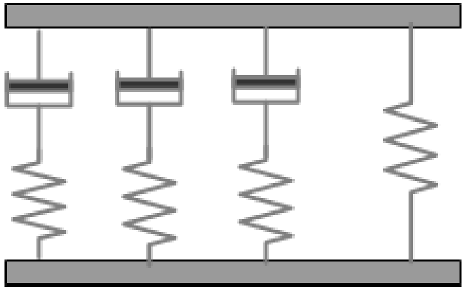
Static simulation vs. measurement



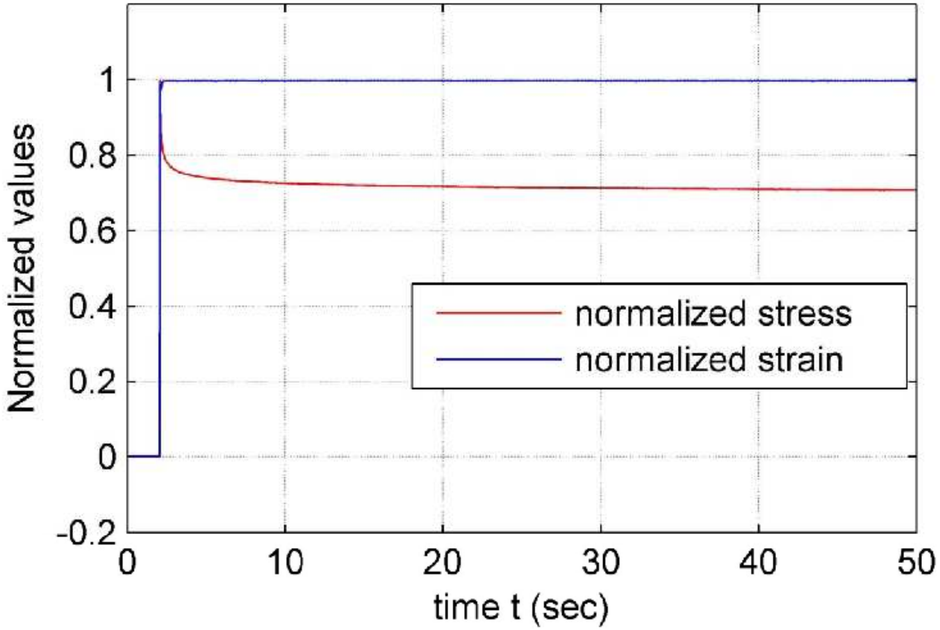


Mechanical behavior of elastomer
Viscoelastic behavior

Maxwell model



Relaxation measurement
Norm: ISO 3384



Prony parameter

$$\frac{K}{K_0} = \alpha_0 + \alpha_1 e^{-\frac{1}{\tau_1}t} + \alpha_2 e^{-\frac{1}{\tau_2}t} + \alpha_3 e^{-\frac{1}{\tau_3}t}$$

TB, PRONY, MATID, 1, 4, SHEAR
tbdata, 1, 0.1252, 0.02239, 0.07465, 0.3976, 0.03344, 32.18

TB, PRONY, MATID, 1, 4, BULK
tbdata, 1, 0.1252, 0.02239, 0.07465, 0.3976, 0.03344, 32.18

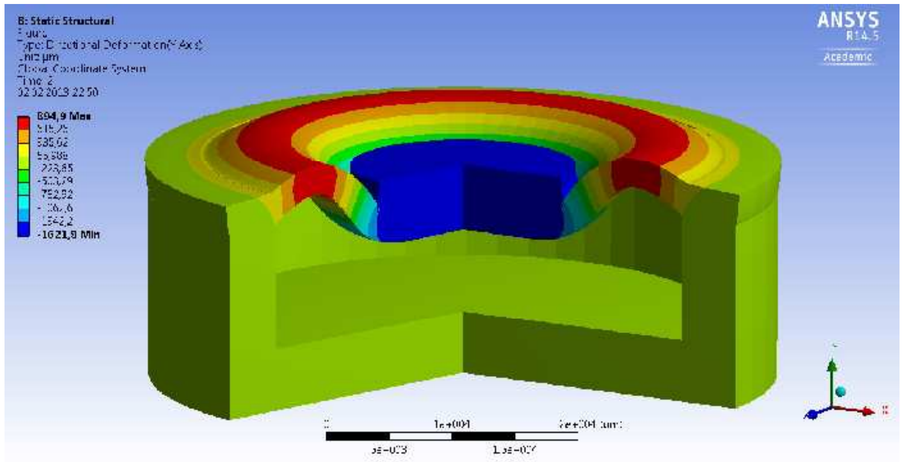
Parameters of real suspension based on DESA

Real actuator parameters		
Electrical resistance *R*	120	kΩ
Capacitance *C*	21,55	nF
Number of connected layers	32	
Mech. resonance frequency f_R (Load 50 gram)	33,2	Hz
Young's modulus *Y*	300	kPa

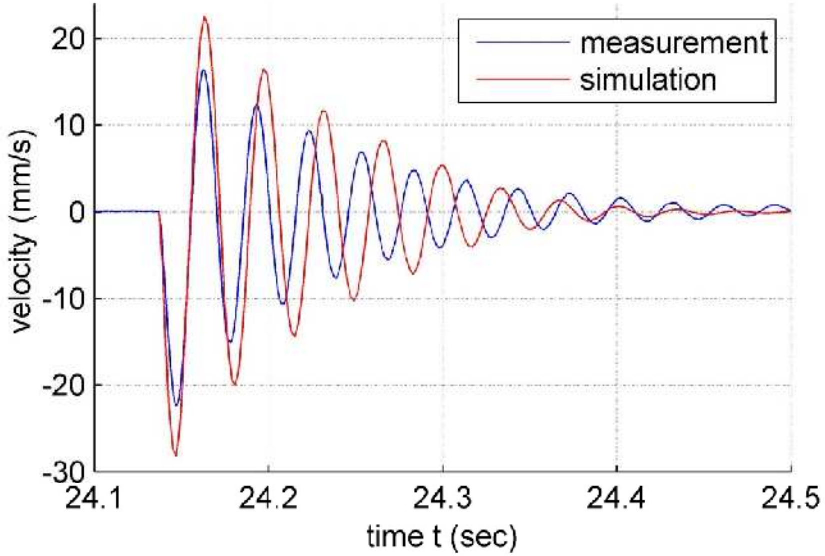
Transient simulation

Step excitation

- Excitation step: $U = 1000\,V$
- Load: *M = 50 gram*
- Measurement of load velocity with vibrometer *Politec OFV 3001*



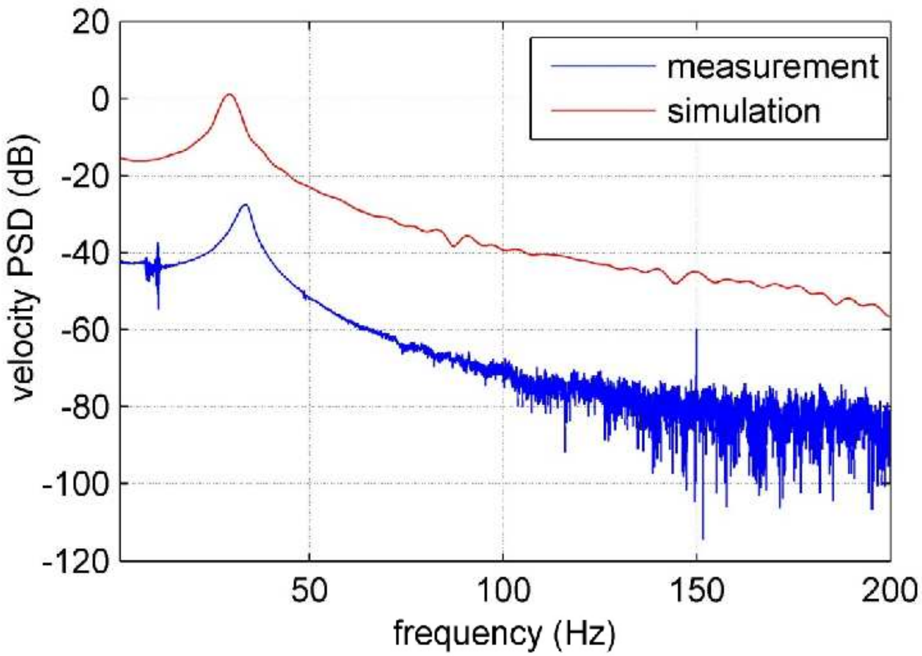
Output of the voltage step excitation



Transient simulation
Step excitation

- Excitation step: $U = 1000\,V$
- Load: *M = 50 gram*
- Measurement of load velocity with vibrometer *Politec OFV 3001*

Power spectrum density (PSD) step excitation



Transient simulation
Sine excitation

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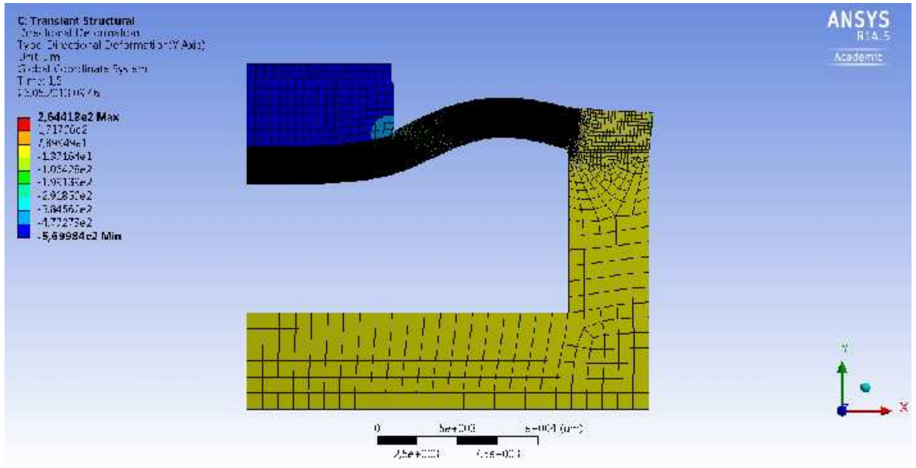
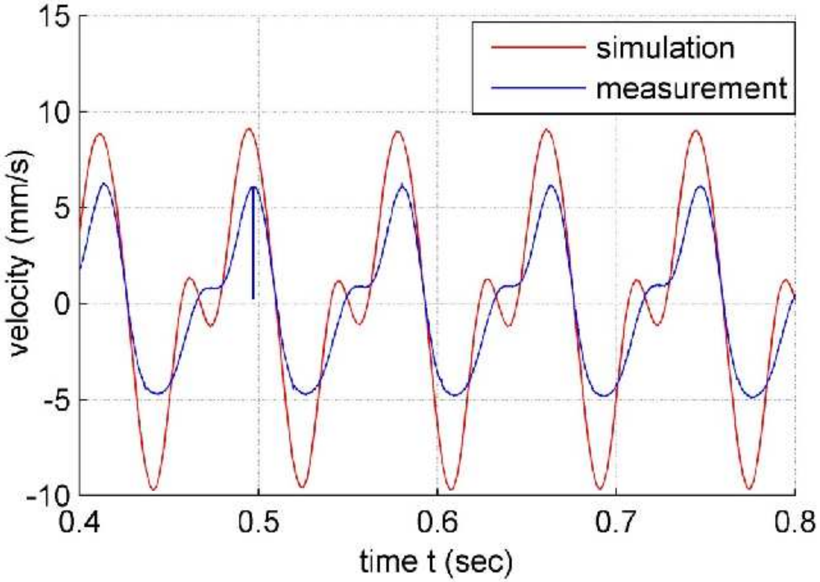
- Excitation: $U = 700V + 300V \sin(12Hz * t)$
- Load: *M = 50 gram*
- Measurement of load velocity with vibrometer *Politec OFV 3001*



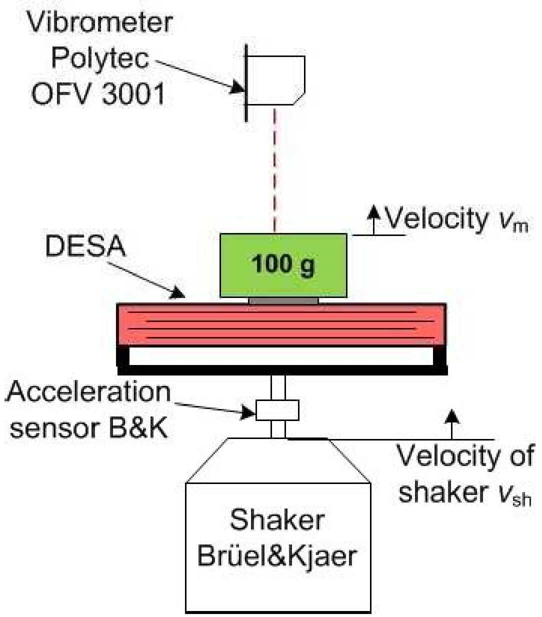
Velocity of load mass (50 gram)



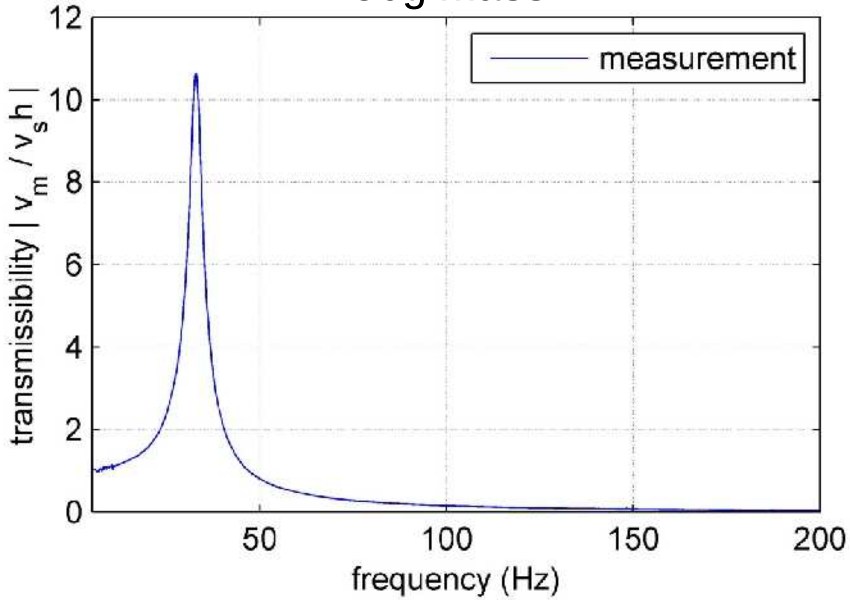
Modal / Harmonic Simulation

Passive transmissibility of the suspension

Set up for passive characterization of the suspension



Passive transmissibility of suspension, 50g mass



Load mass	10 g	20 g	50 g	100 g
Measurement f_R	66,2 Hz	48,9 Hz	33,2 Hz	22,8 Hz
Simulation f_R	67,26 Hz	49,8 Hz	33,6 Hz	23,4 Hz

Conclusion

- **FEM simulation allows to estimate the static and dynamic behavior of DESA**

- **Transient simulation**
  - Amplitude of the velocity is overestimated
  - Electrostatic nonlinear behavior is mapped
  - Frequency spectrum matches with measurement results

- **Modal simulation**
  - Dominant first resonance frequency is certainly determined

- **Deviations between simulation and measurement are present**
  - Electrical nonlinear effects are not regarded
  - Hyper elastic behavior is not regarded
  - Number of connected layers can change itself during the operation

Next steps

- Shape optimization of the suspension with FEM software

Thank you for your attention!

LOEWE

Exzellente Forschung für
Hessens Zukunft

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