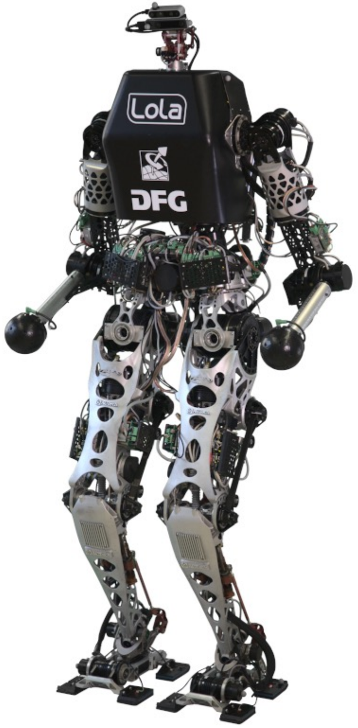
Identification of Material Properties for Resins used in SLA 3D Printing

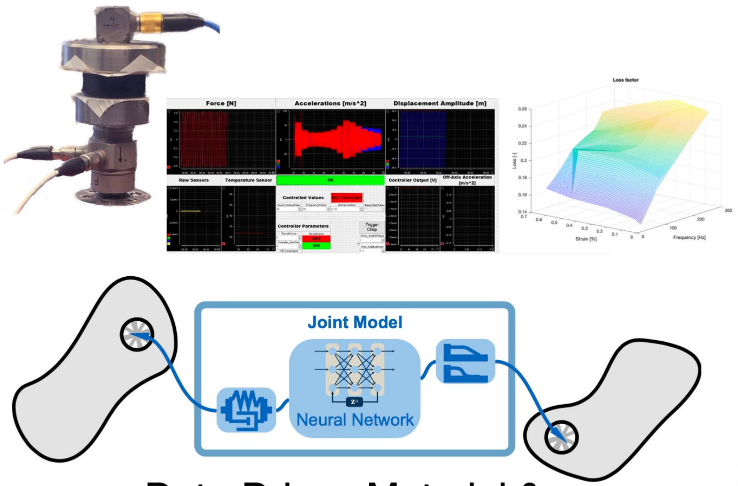
T. Slimak, F. Trainotti, D.J. Rixen

#15019

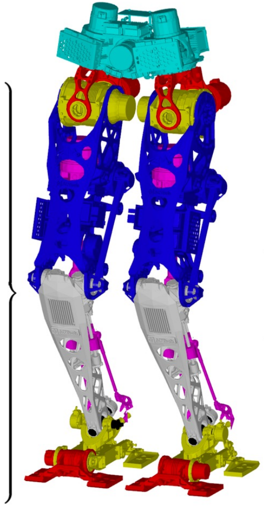
IMAC-XLI Conference, February, 2023

LOLA Motivation

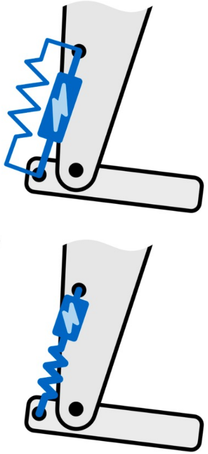




Data-Driven Material &
Component Analysis



Flexible Multibody
Simulation using ExuDyn



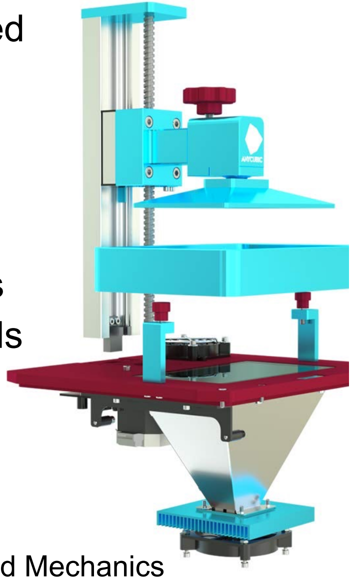
New Ankle
Designs

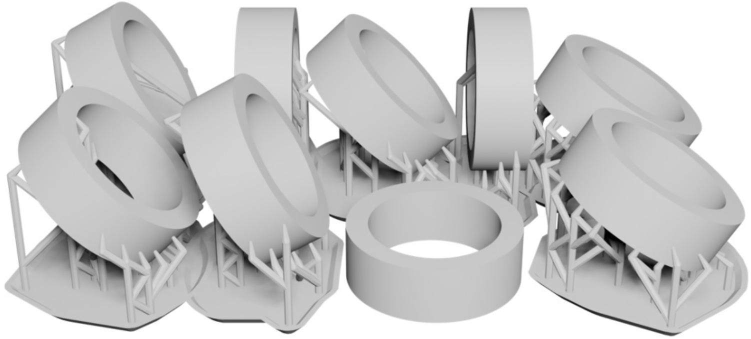
Stereolithography (SLA) 3D Printing

- Targeted photochemical process cross-links liquid monomers to form solid polymer objects

- Various filler materials used to achieve different mechanical properties

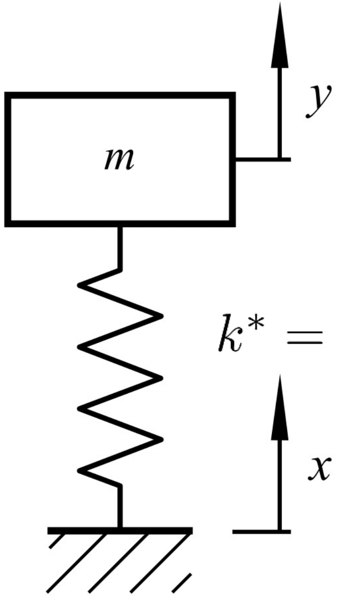
- Large number of manufacturing parameters which effect resulting solids





Experimental Characterization Techniques

Transmissibility-based Uniaxial Shaker Characterization



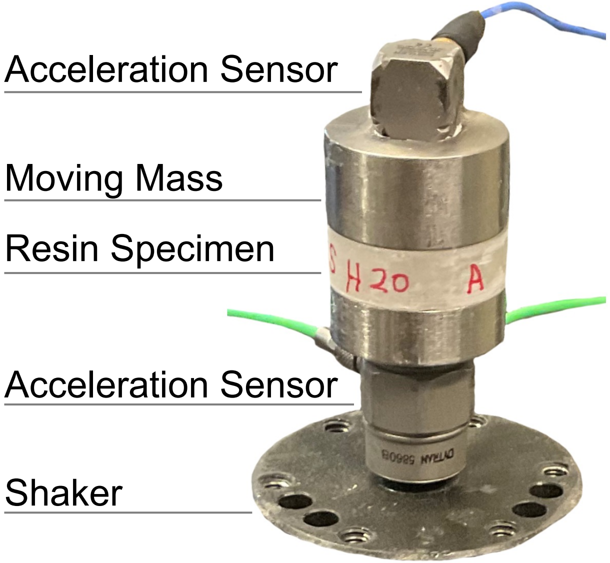
- Can determine frequency and amplitude dependent stiffness
- Damping below the noise floor

$$m\ddot{y} + k^*(y - x) = 0$$

$$k^* = k' + ik'' = k'(1 + j\eta)$$

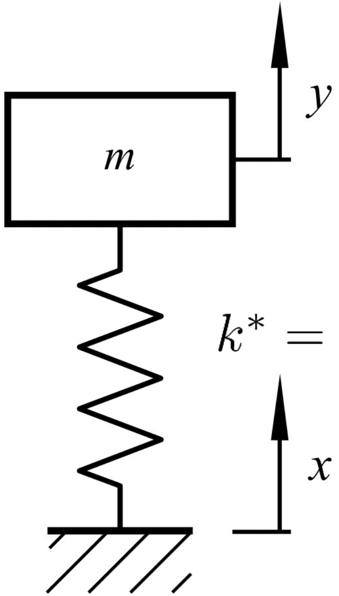
Assuming:

- Single DoF uniaxial motion
- Shaker mass >> Moving mass



Experimental Characterization Techniques

Transmissibility-based Uniaxial Shaker Characterization (Theory)



$$m\ddot{y} + k^*(y - x) = 0$$

$$k^* = k' + ik'' = k'(1 + j\eta)$$

Linearized Sweeps

Transmissibility: $T = \frac{y}{x} = \frac{\ddot{y}}{\ddot{x}}$

$\mathrm{k'[N\backslash m]}$	$\eta[-]$
$\mathrm{real}\left(\frac{-\omega^2 mT}{1-T}\right)$	$\mathrm{imag}\left(\frac{-\omega^2 mT}{1-T}\right)\frac{1}{k}$

Amplitude and Displacement Maps

$$k^*\underbrace{(y - x)}_{\Delta y} = \underbrace{-m\ddot{y}}_{F}$$

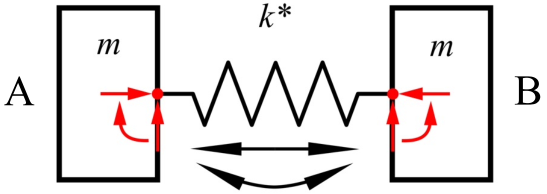
$$|k^*| = \frac{\hat{F}}{\hat{\Delta y}}$$

$$k' = |k^*|cos(\delta)$$

$F(t) = \hat{F}sin(\omega t + \delta)$ $\quad \Delta y(t) = \hat{\Delta y}sin(\omega t)$ $\quad \eta = \frac{k''}{k'}$

Experimental Characterization Techniques

Inverse Substructuring



- 6 DoF Characterization
- Can determine low material damping

Principle:

$$\underbrace{\begin{bmatrix} \mathbf{Z}^{\mathrm{J}}_{2_A2_A} & \mathbf{Z}^{\mathrm{J}}_{2_A2_B} \\ \mathbf{Z}^{\mathrm{J}}_{2_B2_A} & \mathbf{Z}^{\mathrm{J}}_{2_B2_B} \end{bmatrix}}_{\mathbf{Z}^{\mathrm{J}}_{2,2}} = \underbrace{\begin{bmatrix} \mathbf{Z}^{\mathrm{A}}_{2_A2_A} + \mathbf{Z}^{\mathrm{J}}_{2_A2_A} & \mathbf{Z}^{\mathrm{J}}_{2_A2_B} \\ \mathbf{Z}^{\mathrm{J}}_{2_B2_A} & \mathbf{Z}^{\mathrm{B}}_{2_B2_B} + \mathbf{Z}^{\mathrm{J}}_{2_B2_B} \end{bmatrix}}_{\mathbf{Z}^{\mathrm{AJB}}_{22}} - \underbrace{\begin{bmatrix} \mathbf{Z}^{\mathrm{A}}_{2_A2_A} & \mathbf{0} \\ \mathbf{0} & \mathbf{Z}^{\mathrm{B}}_{2_B2_B} \end{bmatrix}}_{\mathbf{Z}^{\mathrm{A|B}}_{22}}$$

Assuming rigid end-masses, no cross-coupling and massless spring

- Measure AJB
- Projection to virtual point + Integration
- Invert

$$\mathbf{Z}^{\mathrm{J}}_{22} = \begin{bmatrix} -\mathbf{Z}^{\mathrm{J}}_{2_A2_B} & \mathbf{Z}^{\mathrm{J}}_{2_A2_B} \\ \mathbf{Z}^{\mathrm{J}}_{2_B2_A} & -\mathbf{Z}^{\mathrm{J}}_{2_B2_A} \end{bmatrix}$$

pyFBS

Comparison of Characterization Techniques

Substructuring
- FBS friendly
- 6 DoF

Uniaxial Shaker
- Large amplitude and frequency range

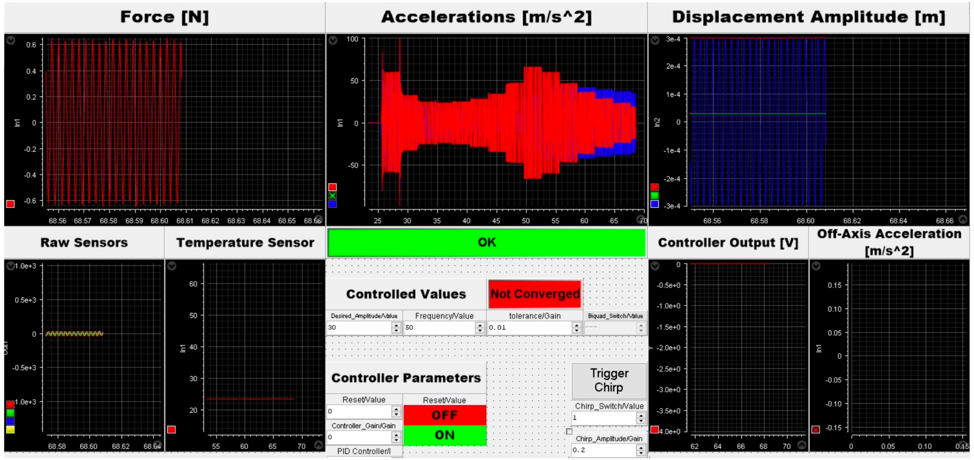
DMA/ Hydraulic Machines
- Expensive
- Extra parameters: preload, temperature, static
- Accurate, repeatable
- Only material level

Also component-level
Cheap and fast

Amplitude variation (non-linearity)
1 DoF
Automatized

Implementation of Transmissibility Control

1. Live Butterworth bandpass filtering
2. Multi-rate discrete peak-picking to determine amplitude
3. Analytical integration and subtraction to determine strain
4. Adjustment of shaker excitation to reach desired motion
5. Automatized measurement procedures and failure detection



Analysis Overview

- Vertically and horizontally printed samples
- Large, middle and small samples
- 10, 15 and 20 minute curing time
- Radial and axial analysis

- 300 to 700 Hz excitation
- 0.005 to 0.025% strain

Issues During Measuring & Testing

- Printing consistent samples with correct geometries and no defects
- Attachment via cyanoacrylate
- Limited shaker force/power
- Excitation of shaker/table eigenfrequencies

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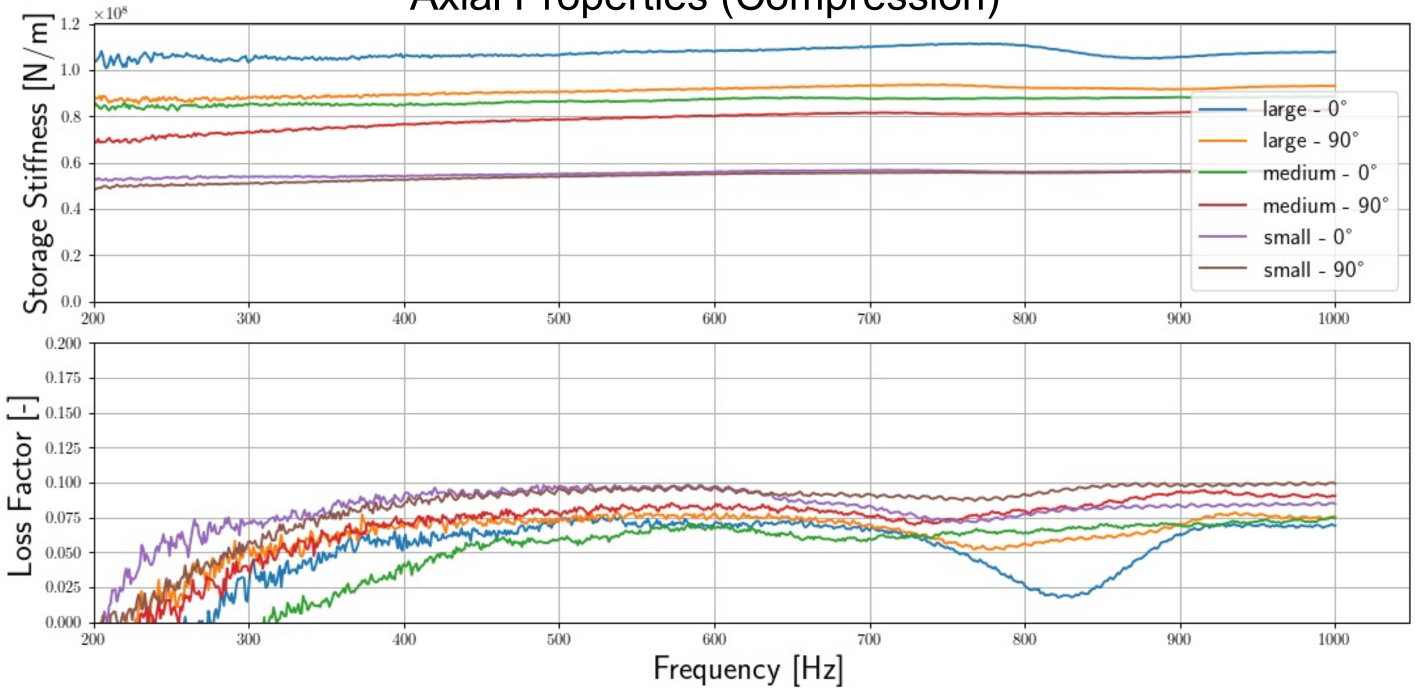
Department of Mechanical Engineering
Technical University of Munich

Substructuring Results

Axial Properties (Compression)



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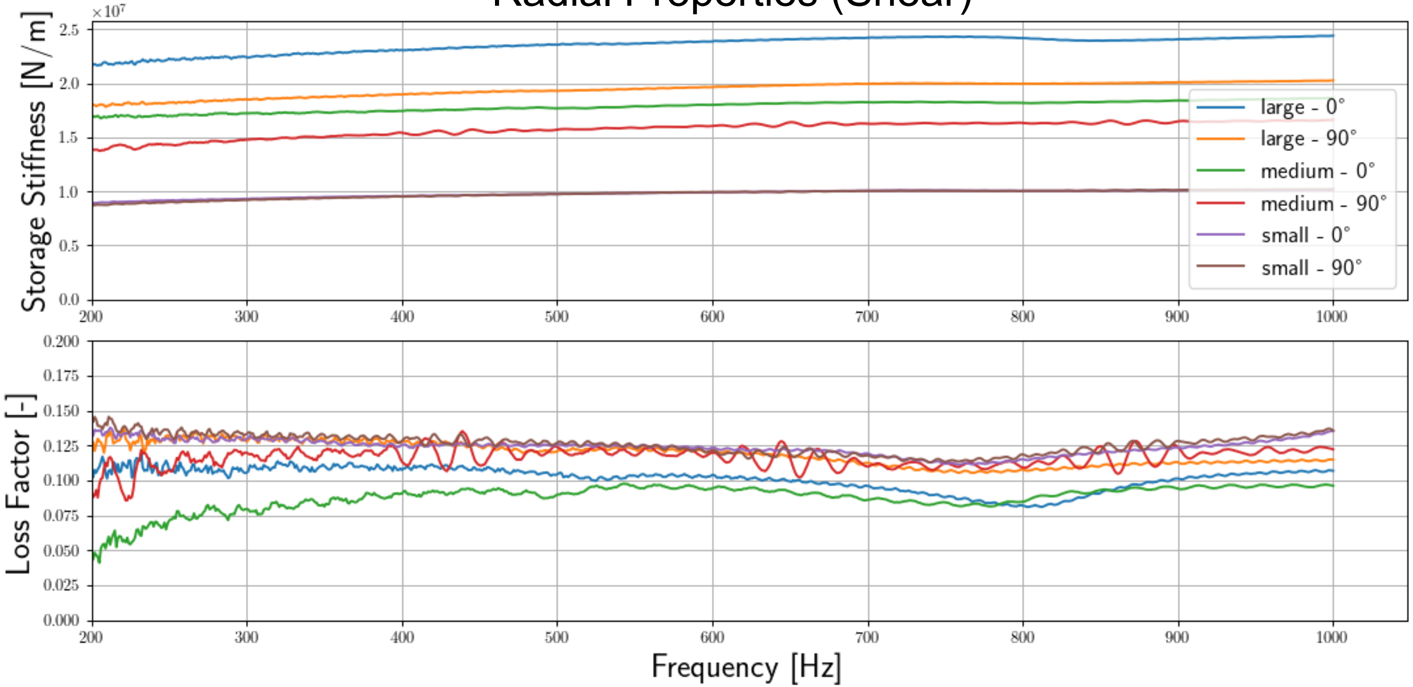
Substructuring Results

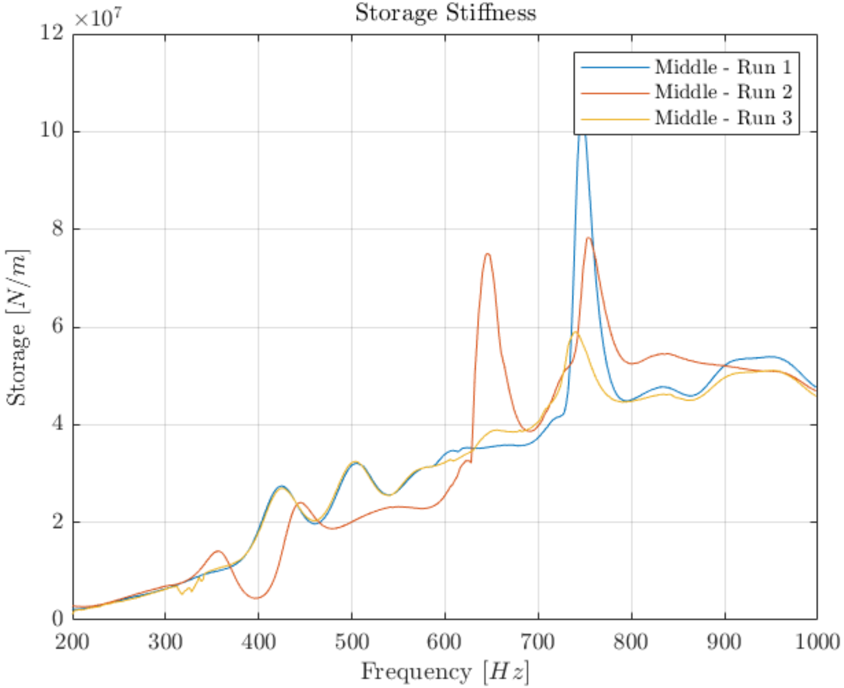
Radial Properties (Shear)

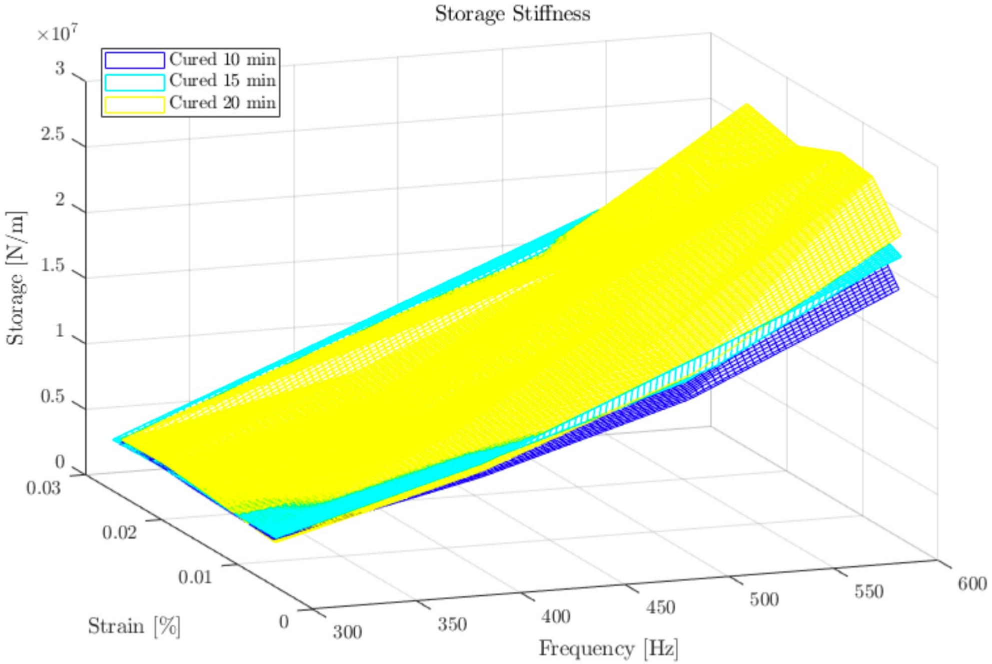


Decreased
X 5

Increased
X 1.5

Transmissibility Results





Outlook

- Explore the issues and repeatability
- Evaluate transferability to complex geometries
- Flexible resins

Takeaway Points

- Cheap and fast identification of material properties is possible
- SLA components are non-isotropic
- Manufacturing parameters have a large impact on material behavior

Thank you for your time

I’d be happy to answer any questions you might have

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