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Structural Design with Joints for Maximum Dissipation

M. Stender, Dynamics Group, Hamburg University of Technology, Germany

A. Papangelo, Department of Mechanics, Mathematics and Management, Polytechnic Bari, Italy

M. Allen, Department of Engineering Physics, University of Wisconsin, USA

[1]M. Brake, Component Science and Mechanics, Sandia National Laboratories, USA

C. Schwingshackl, Dynamics Group, Imperial College London, UK

M. Tiedemann, Dynamics Group, Hamburg University of Technology, AUDI AG, Germany

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Agenda

- Motivation
- Model and joint formulation
- The optimization
- Conclusion

The major part of this presentation reports the results of the *Nonlinear Mechanics and Dynamics Summer Research Institute (NOMAD)* at Sandia National Laboratories in Albuquerque, New Mexico, 2015

Motivation

- Joints: *today*
  - Source of **nonlinearity**
  - Source of **uncertainty**
  - **No predictive models** available so far

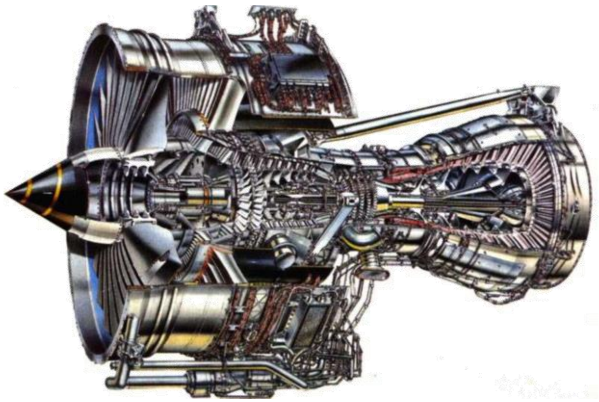
- Joints: *future*
  - **Major source of damping** in many applications
  - Intentional use of joints to
    - Increase efficiency and life fatigue
    - Decrease wear
    - Reduce mass

- The study
  - Assume a predictive joint model
  - Assess a minimal model including the joint
  - Optimize the dynamic response using joint parameters

design liability

↓

design parameter



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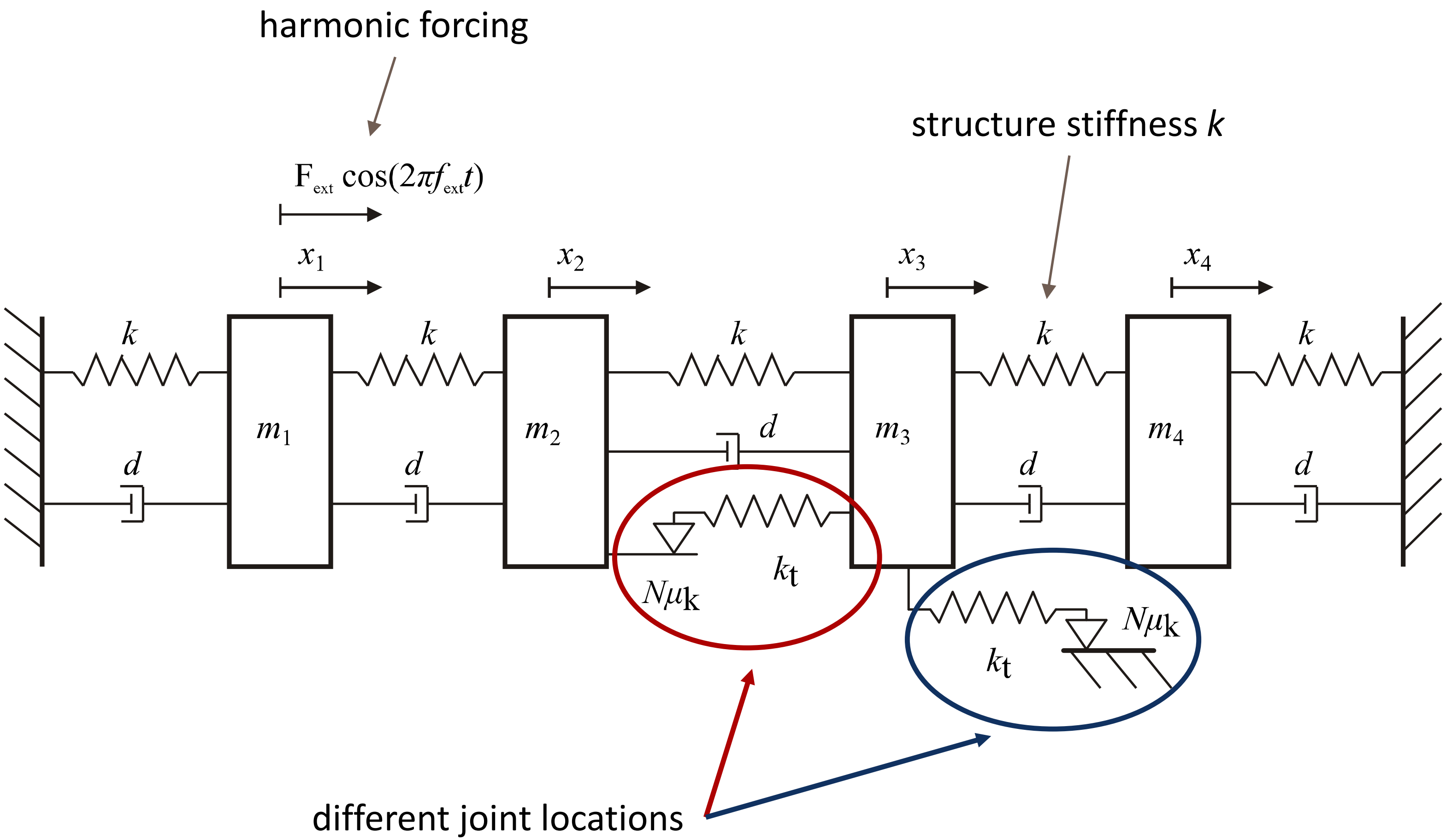
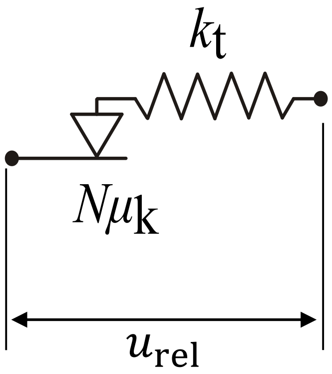
The model



harmonic forcing
structure stiffness k
F_ext cos(2πf_ext t)
x1
x2
x3
x4
k
k
k
k
k
m1
m2
m3
m4
d
d
d
d
d
Nμk
kt
kt
Nμk
different joint locations

The joint

- Single slider, LuGre formulation
  - Continuous representation
  - Exponential transition from stick to slip (→ micro-slip element)
  - $\mu_{\mathrm{k}} = 1$



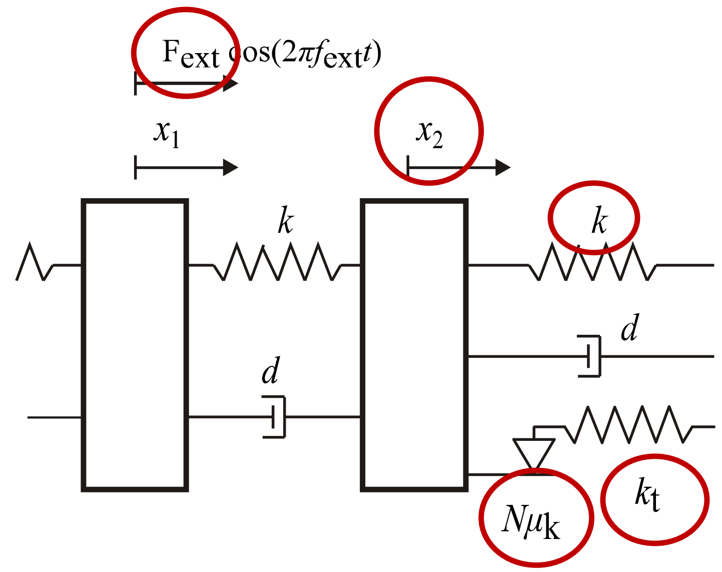
- Solver
  - Numerical continuation techniques (time-domain)
  - Continuation of the periodic solution (→nonlinear FRF)

- Limiting cases:
  - $\boldsymbol{\mu N} \to \mathbf{0}$: $W_{\mathrm{diss}} \to 0, F_{\mathrm{fric}} \to 0$ joint inactive, linear system
  - $\boldsymbol{\mu N} \to \infty$: $W_{\mathrm{diss}} \to 0, u_{\mathrm{rel}} \to 0$ adding the spring k_{t} in parallel, linear system
  - $\boldsymbol{k}_{\mathbf{t}} \to \mathbf{0}$: $W_{\mathrm{diss}} \to 0$ joint inactive
  - $\boldsymbol{k}_{\mathbf{t}} \to \infty$: pure sliding, no elastic response

- **Goal: find the $N - k_{\mathrm{t}}$ combination that most effectively decreases the vibration level**

Dimensionless parameters

- Goal: study of qualitative dynamic behaviour
  → Introduction of dimensionless parameters
  - $\alpha = \frac{k_t}{k}$ (stiffness ratio)
  - $\beta = \frac{\mu_k N}{A}$ (force ratio)

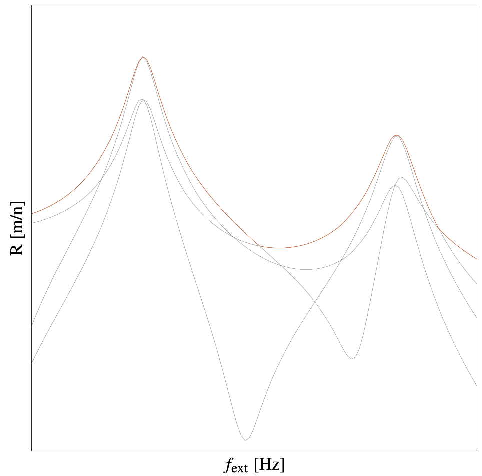


- Receptance

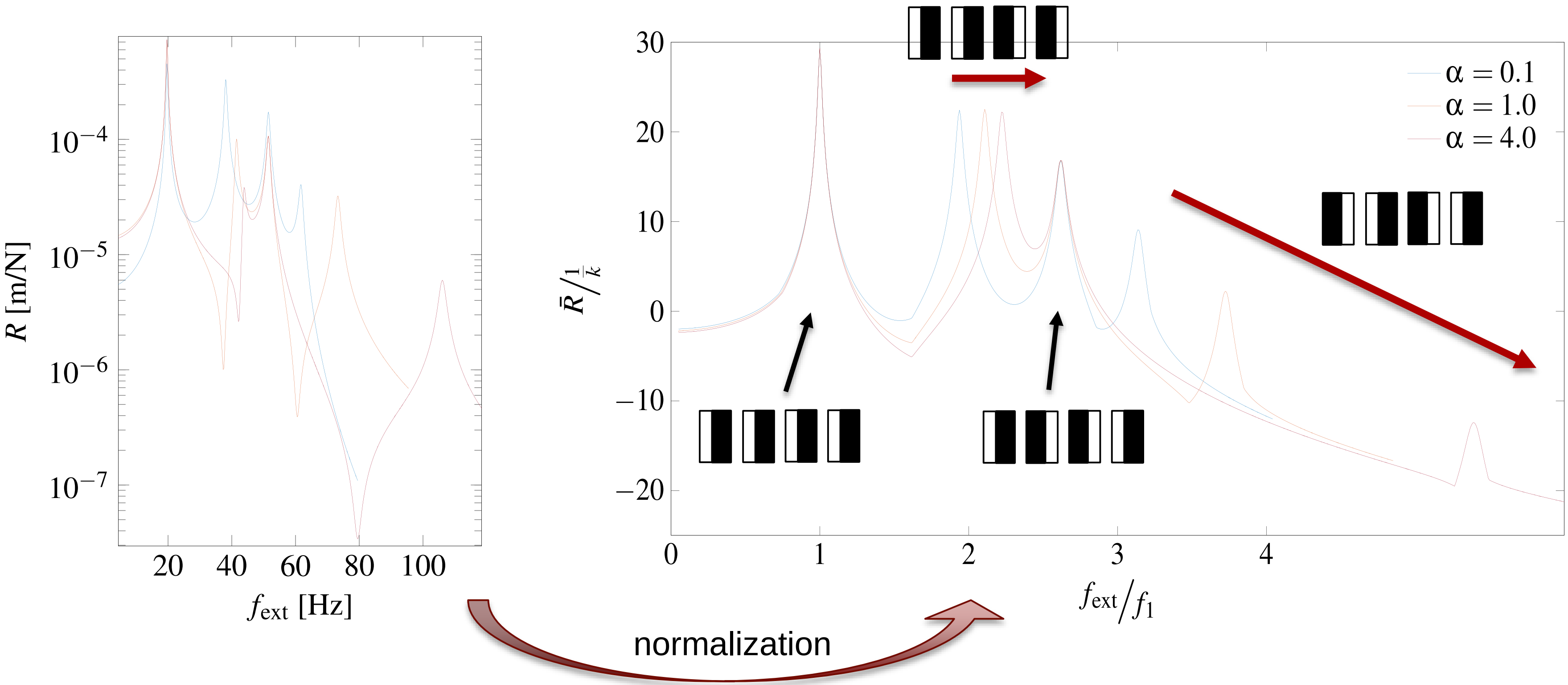
$$R_i = \frac{x_i}{A}, \quad i = 1, \dots, 4$$

- Optimization
  - Reduce vibration level of structure
  - Procedure: minimize a *scalar cost value*
  - → Merging of receptances

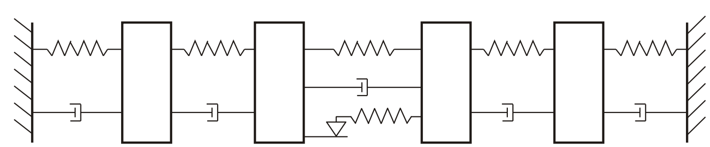
$$\bar{R} = \max_i(R_i)$$



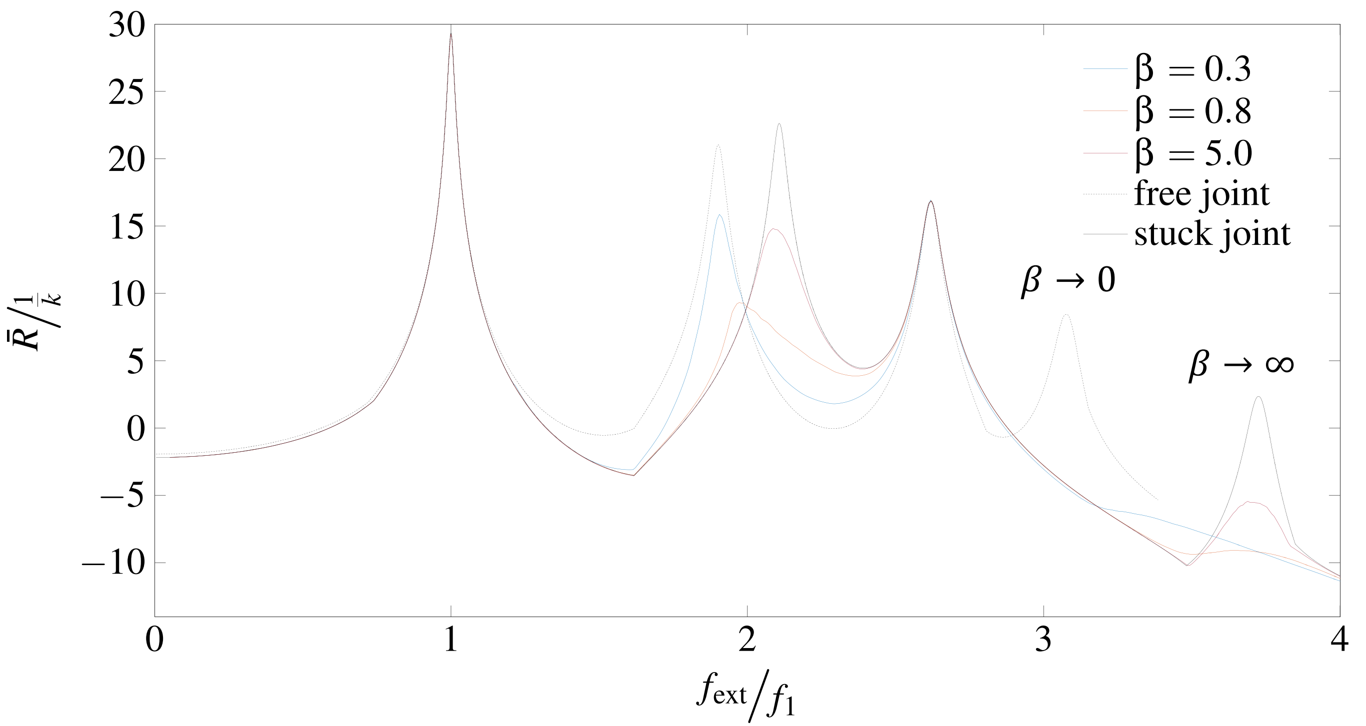
Parameter study on α, joint location a



- frequency shift of modes
- decrease of peak amplitudes as the system gets stiffer
- only 2nd and 4th mode affected

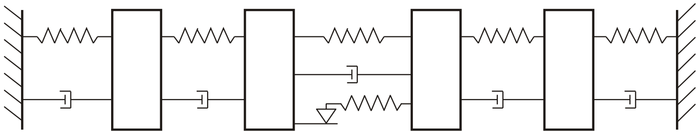


Parameter study on β, joint location a



- linear limits representing $\beta \rightarrow 0$ and $\beta \rightarrow \infty$
- lowest peak amplitude in between the linear limits

- **→ what is the best combination of α and β to reduce the 2nd peak amplitude?**



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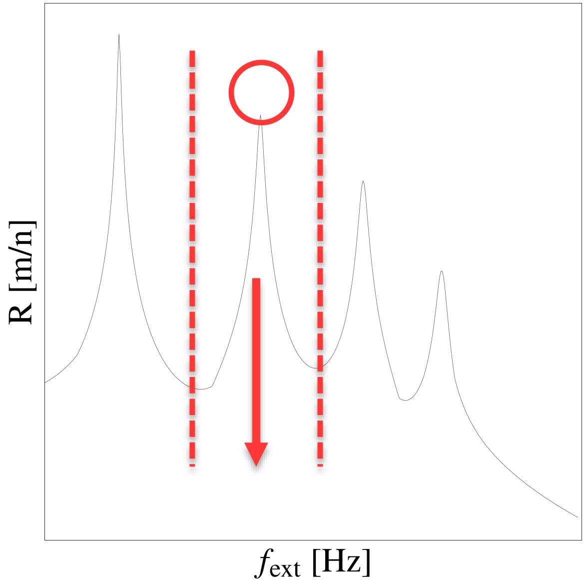
The optimization problem

- **Cost function:**
  - Merged receptance $\bar{R}$ within frequency interval $[f_\mathrm{l}, f_\mathrm{u}]$ *at peak of 2nd mode*

$$\psi = \bar{R}_{\mathrm{peak\ 2}} \ \in [f_\mathrm{l}, f_\mathrm{u}]$$

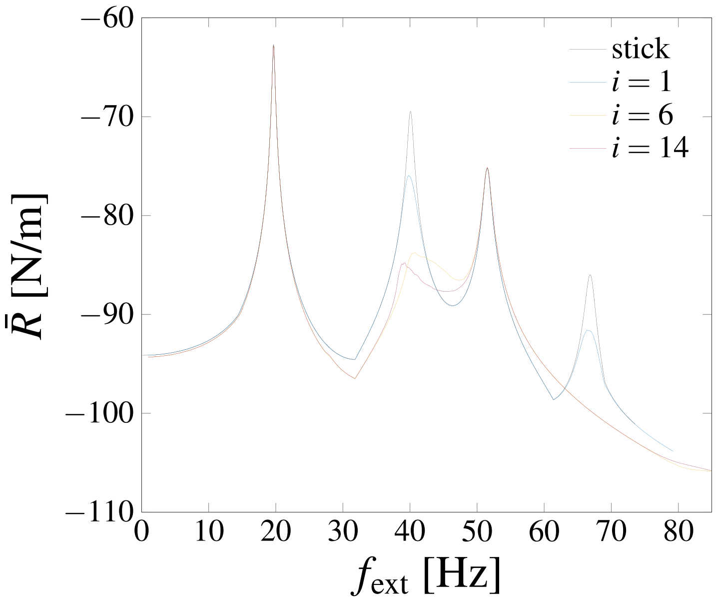


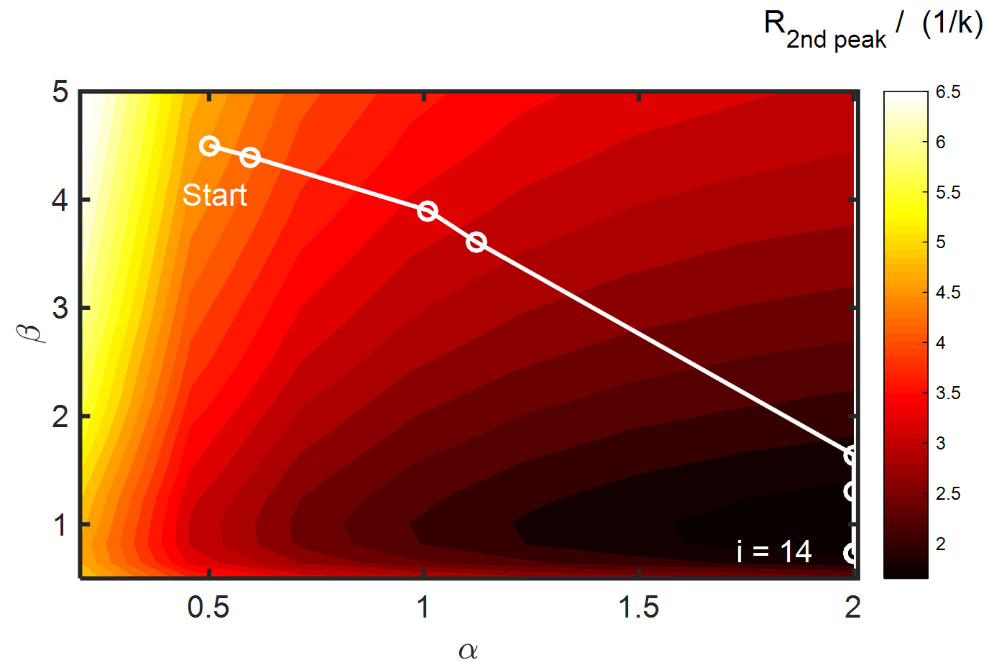
- **Optimization problem:**
  - Compute peak amplitude for parameter vector $[\alpha, \beta]^\mathrm{T}$
  - *Minimize peak amplitude by tuning of parameter vector*

$$\hat{\mathbf{p}} = \min_{\mathbf{p}}(\psi(\mathbf{p})) \ \in [\mathbf{p}_{\min}, \mathbf{p}_{\max}], \mathbf{p} = [\alpha, \beta]^\mathrm{T}$$

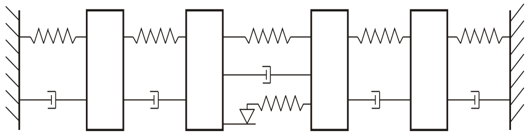
- **Optimization algorithm:**
  - MATLAB built-in `fmincon`
  - Sequential quadratic programming algorithm (sqp)
  - Computation of nonlinear receptances for every proposed parameter set

Optimization: results

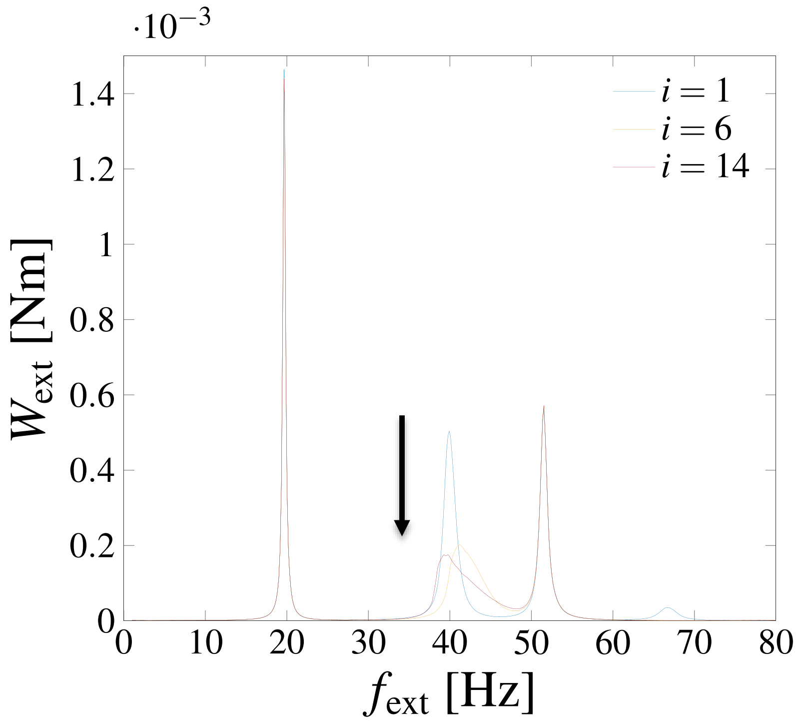


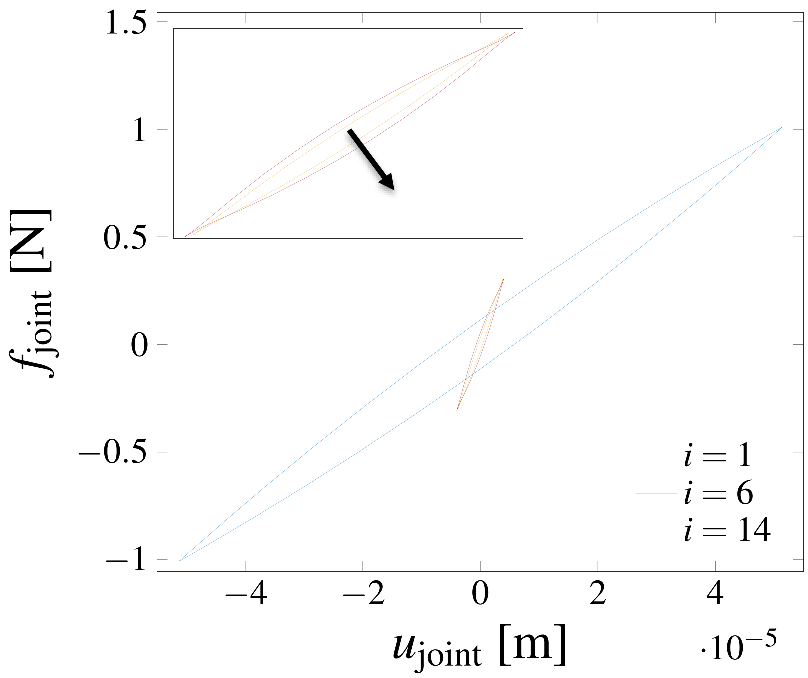


- strong shift of modes → constraint on mode shift(max. 2%)
- two generic optimization strategies
  - Increase of joint stiffness
  - Decrease of normal load
- decrease of 2nd peak amplitude by 63.8%



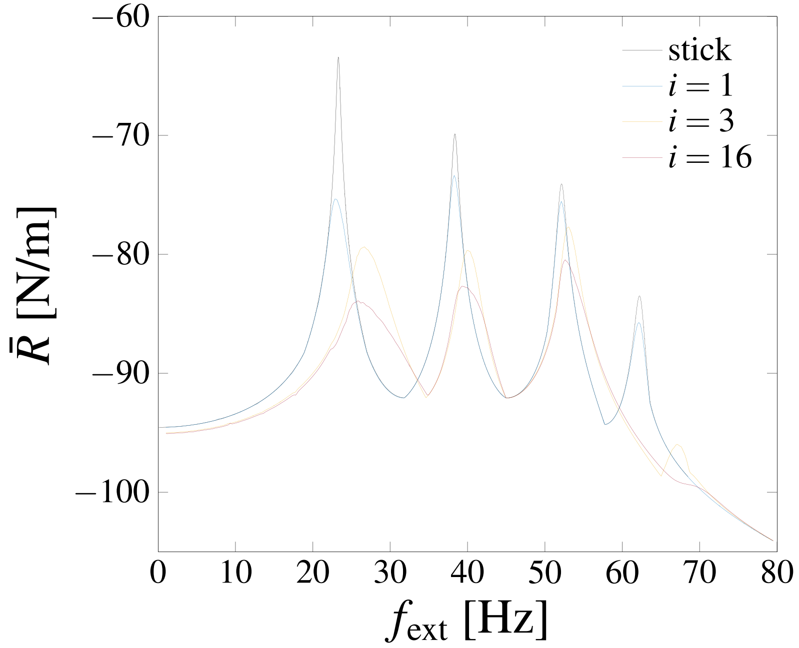
Work consideration

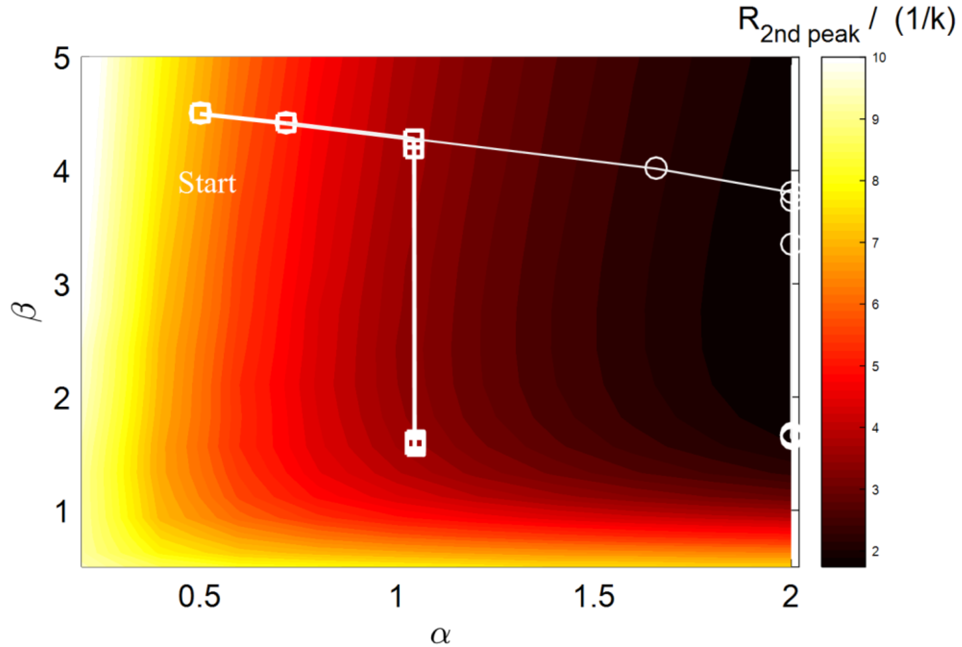




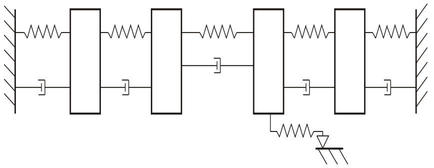
- 2 phases of optimization:
  - *Minimize the energy fed into the system*
  - *Maximize the dissipation in the joint*

Optimization: 'ground configuration'

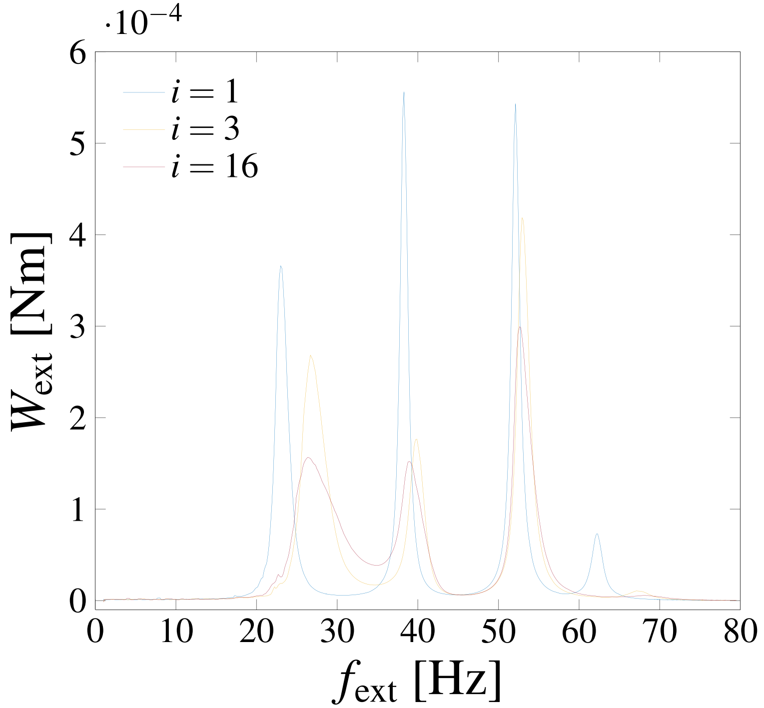




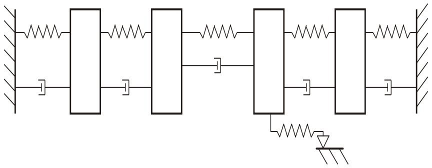
- Strong sensitivity to joint stiffness
- Reduction of peak amplitude by 77.3% w.r.t. stick response



Work consideration



- Every mode affected
- Increase of system response for every mode
- Major optimization strategy:
  - *Minimization of the energy fed into the system*
  - *Minimal impact of dissipation in joint*



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Conclusion

- Results
  - Optimization of a given structure by tuning joint parameters
  - *Significant improvement* of dynamic response possible
    - Potential of joint design
  - *Deep understanding* of the optimization mechanisms and physics behind
    - *Stiffness* introduced should not be neglected

- Challenges
  - Assess more than one joint in the structure → multiple minima
  - Apply procedure to more complex structures
  - Generate implications for new joints in terms of geometry and loading

→ **Need for predictive models**

Thanks for your attention!

Merten Stender

Dynamics Group, Hamburg University of Technology

merten.stender@tuhh.de
www.tuhh.de/dyn