NONLINEAR VIBRATION ANALYSIS OF TURBINE BLADED DISKS WITH MID-SPAN DAMPERS

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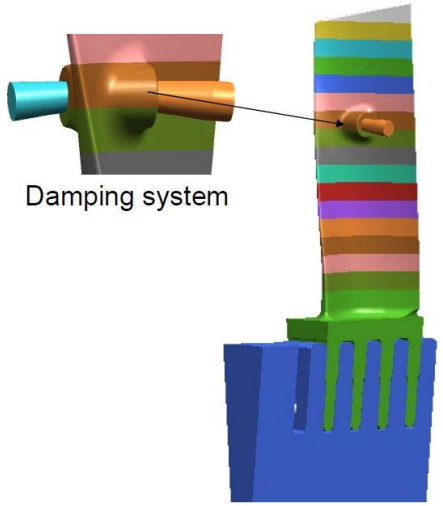
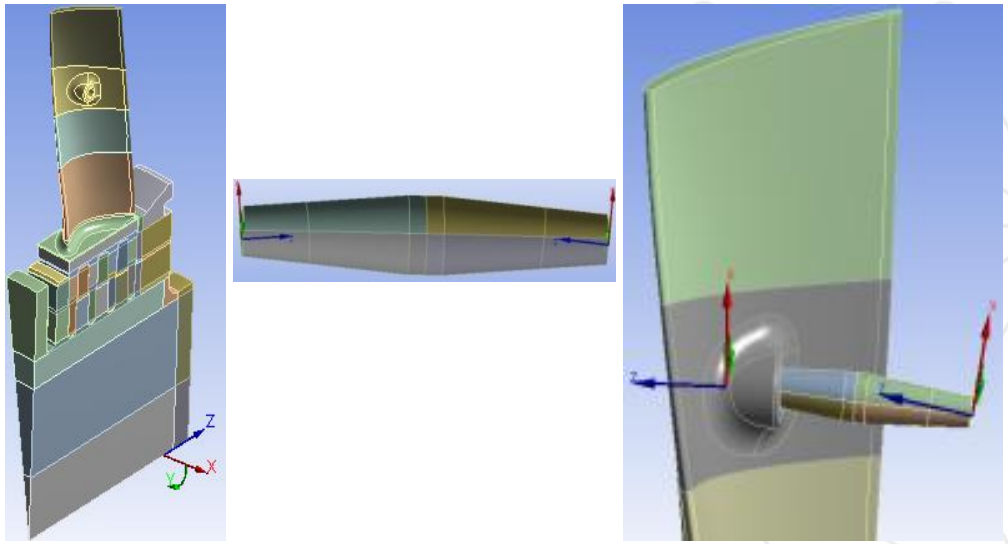
Objectives

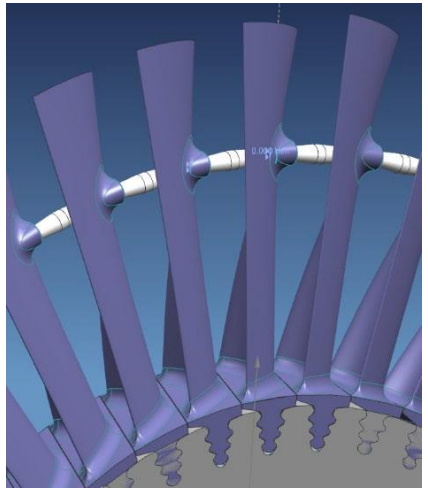
- Nonlinear forced response of bladed disks with friction contacts by using numerical methods
- Development of efficient and accurate numerical solvers validated by experimental setup
- Detailed investigation of variability phenomenon
- New methods for the dynamic response limits

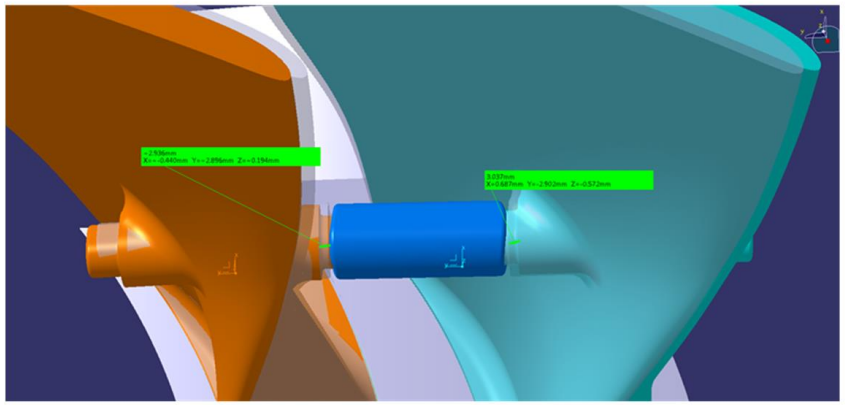
Mid-Span Dampers

- Collaboration with Baker Hughes
- Last stage blades of industrial steam turbines are exposed to high dynamic loading.
- Fatigue failure due to undesired vibrations.
- A special damper design, Mid-Span Dampers, is investigated.









Methodology and Dynamic Response

$$\mathbf{M}\ddot{\mathbf{q}}(t)+\mathbf{C}\dot{\mathbf{q}}(t)+\mathbf{K}\mathbf{q}(t)+\mathbf{f}_{nl}(\mathbf{q},\dot{\mathbf{q}},t)=\mathbf{f}_{ex}(t)$$

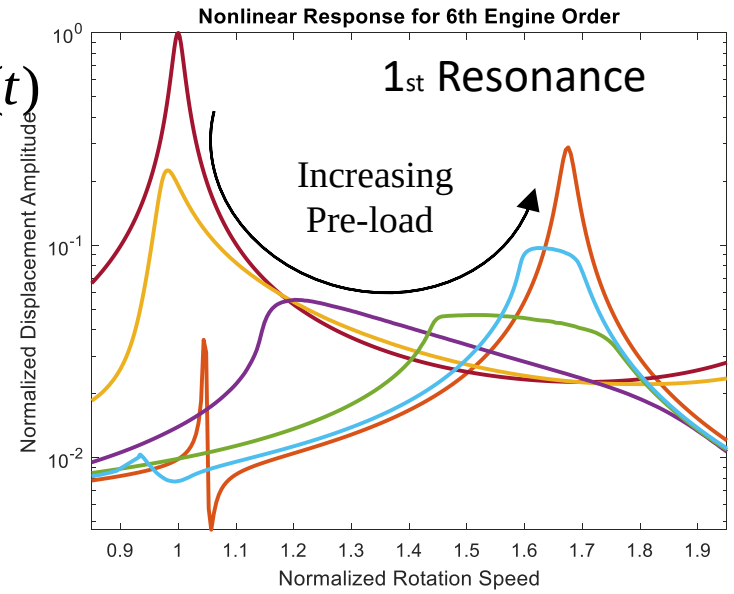
$$\mathbf{f}_{ex}(t)=\hat{\mathbf{f}}_{ex}^{0}+\mathrm{Im}\left(\sum_{h=1}^{H}\hat{\mathbf{f}}_{ex}^{h}e^{ih\omega t}\right)$$

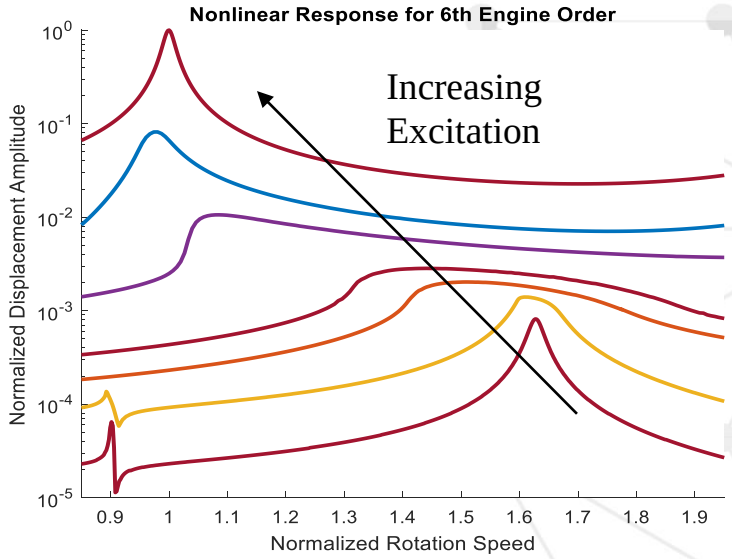
$$\mathbf{q}(t)=\hat{\mathbf{q}}^{0}+\mathrm{Im}\left(\sum_{h=1}^{H}\hat{\mathbf{q}}^{h}e^{ih\omega t}\right)$$

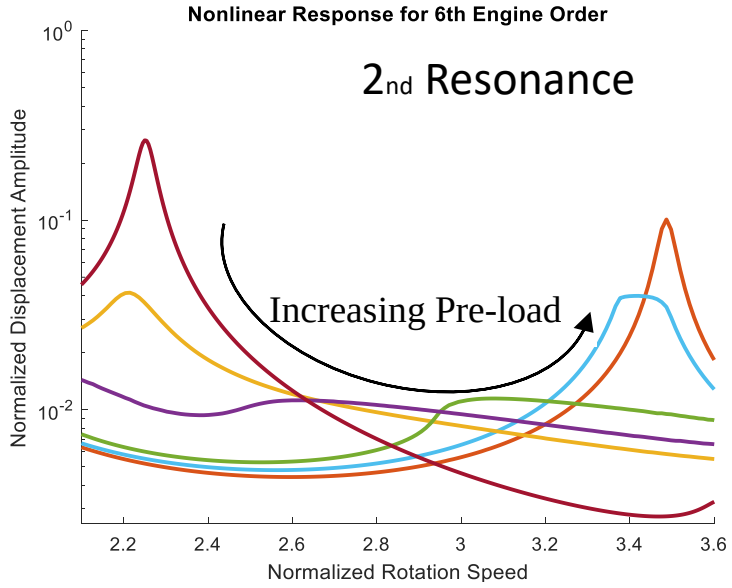
$$\mathbf{f}_{nl}(t)=\hat{\mathbf{f}}_{nl}^{0}+\mathrm{Im}\left(\sum_{h=1}^{H}\hat{\mathbf{f}}_{nl}^{h}e^{ih\omega t}\right)$$

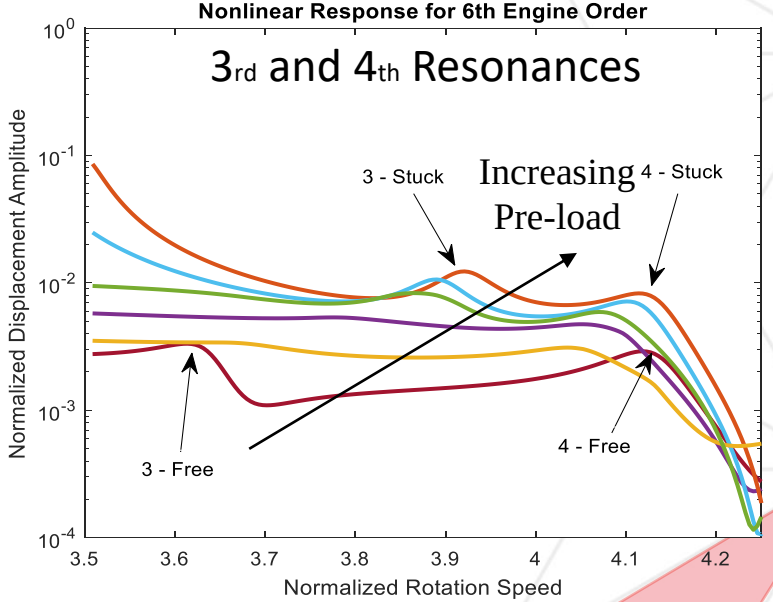
$$\mathbf{K}^{0}\hat{\mathbf{q}}^{0}+\hat{\mathbf{f}}_{nl}^{0}-\hat{\mathbf{f}}_{ex}^{0}=\mathbf{0}$$

$$\left(\mathbf{K}^{h}-\left(h\omega\right)^{2}\mathbf{M}^{h}+ih\omega\mathbf{C}^{h}\right)\hat{\mathbf{q}}^{h}+\hat{\mathbf{f}}_{nl}^{h}-\hat{\mathbf{f}}_{ex}^{h}=\mathbf{0}$$



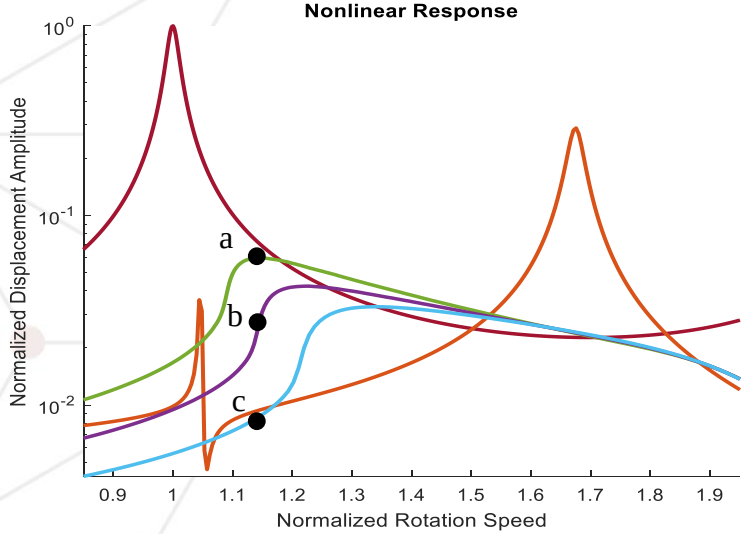


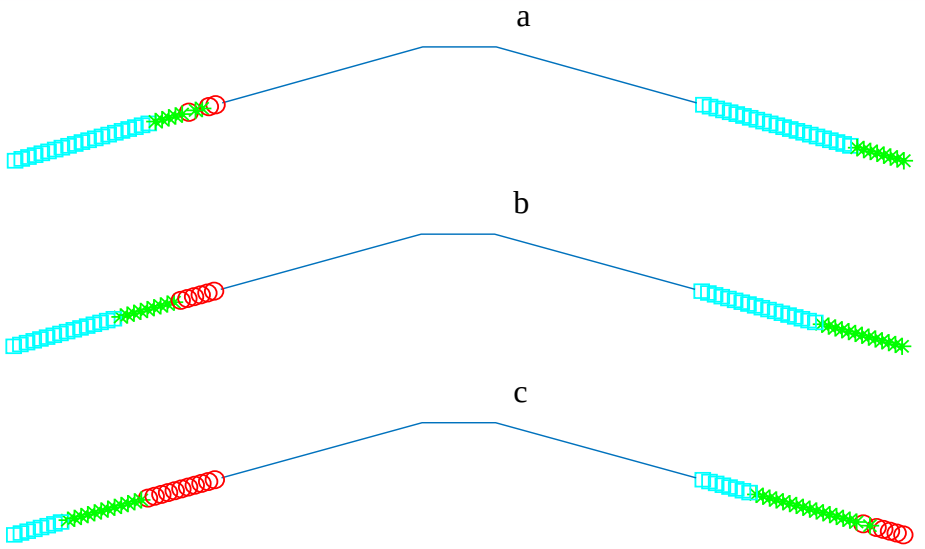




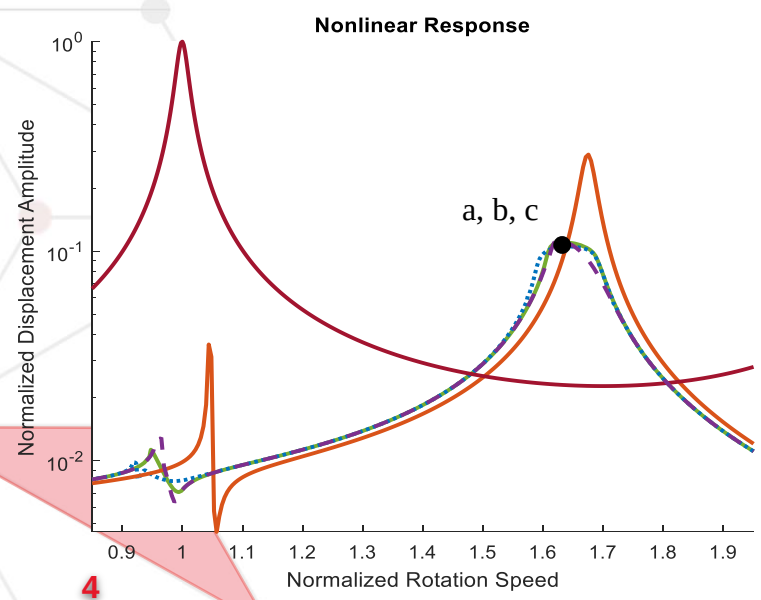
E. Ferhatoglu, S. Zucca, D. Botto, J. Auciello, L. Arcangeli, Nonlinear vibration analysis of turbine bladed disks with mid-span dampers, Proceedings of ASME Turbo Expo 2020: Turbomachinery Technical Conference and Exposition. Virtual, Online, September 21-25, 2020.

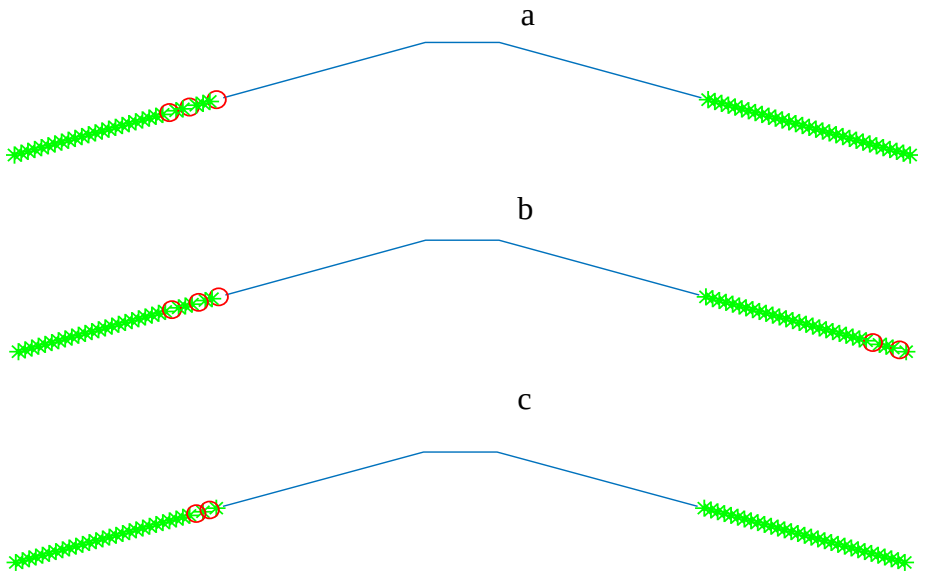
Variability of Nonlinear Response



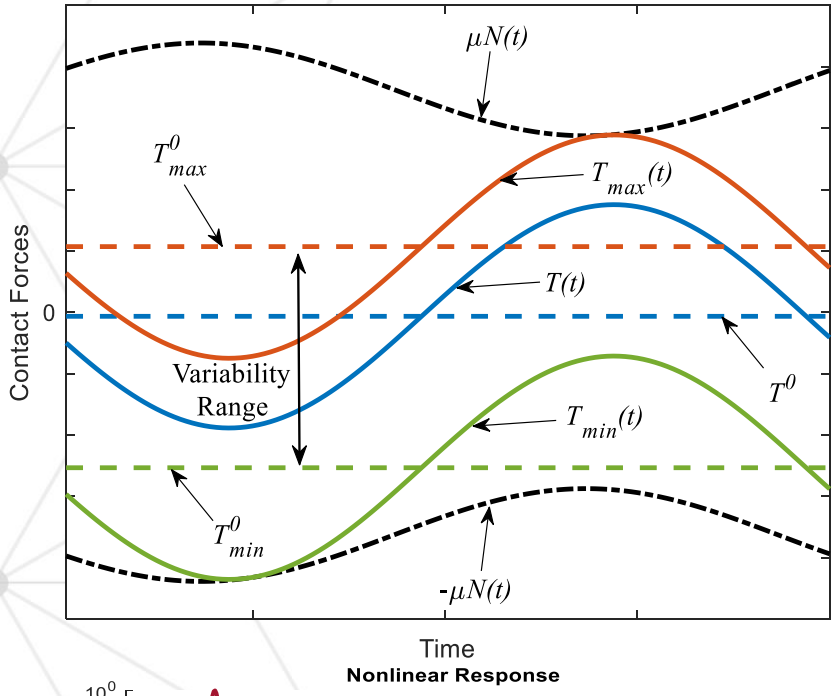


RED CIRCLE – FULL STICK
GREEN STAR – STICK-SLIP
CYAN SQUARE – STICK-SLIP-SEPARATION

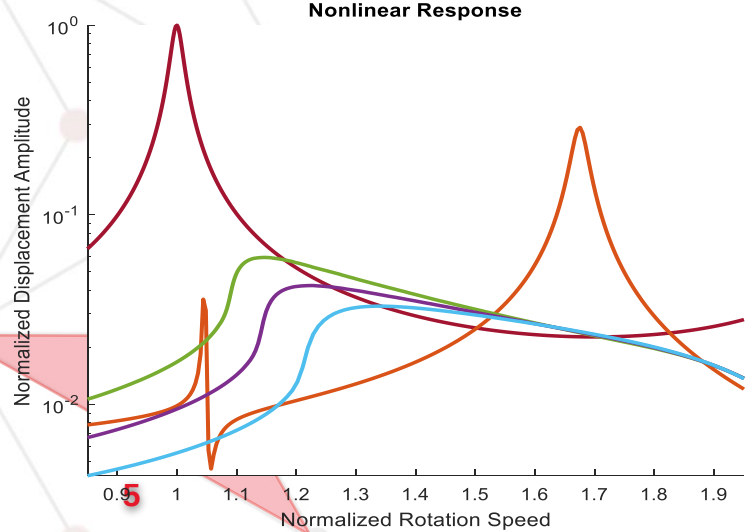




Non-Unique Contact Forces



Nonlinear Response



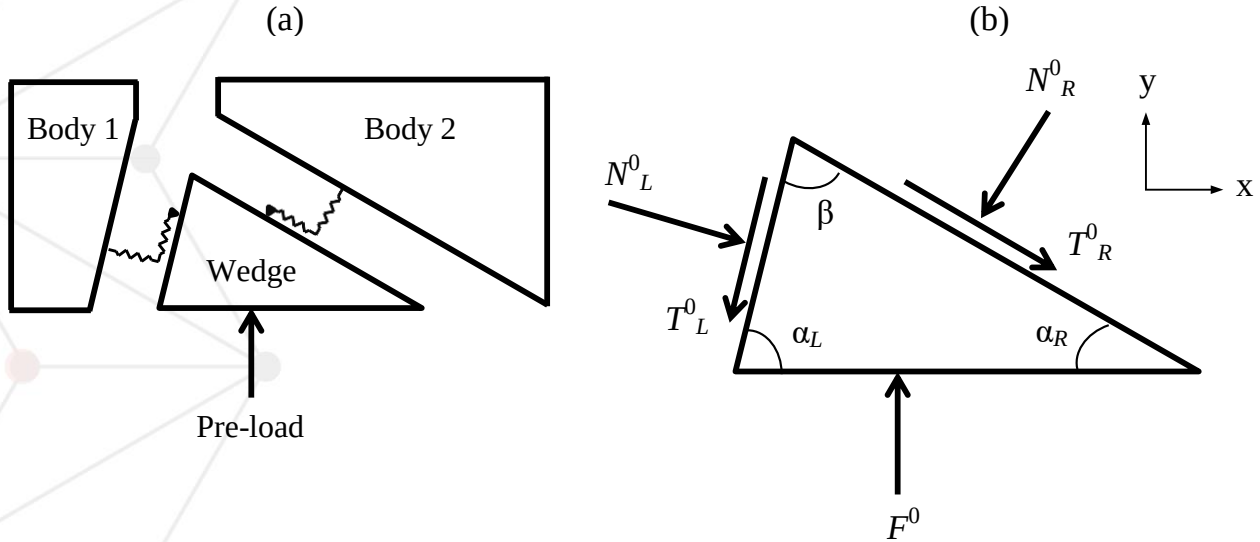
- For a fully stuck element, there is an infinite number of tangential forces.
- If there is at least one slipping additional element in the system
- Due to coupling in the set of nonlinear equations, normal load of slipping elements that dissipates energy, N_0, may change.

$$\mathbf{K}^0\hat{\mathbf{q}}^0 + \hat{\mathbf{f}}^0_{nl} - \hat{\mathbf{f}}^0_{ex} = \mathbf{0}$$

$$\left(\mathbf{K}^h - (h\omega)^2\mathbf{M}^h + ih\omega\mathbf{C}^h\right)\hat{\mathbf{q}}^h + \hat{\mathbf{f}}^h_{nl} - \hat{\mathbf{f}}^h_{ex} = \mathbf{0} \quad (h = 1, \cdots, H)$$

- Multiple solutions may exist.
- The existence of multiple solutions requires predicting the response boundaries in terms of engineering point of view.

Boundaries for Wedge Dampers



$$T^0_R\cos(\alpha_R)-N^0_R\sin(\alpha_R)-T^0_L\cos(\alpha_L)+N^0_L\sin(\alpha_L)=0$$

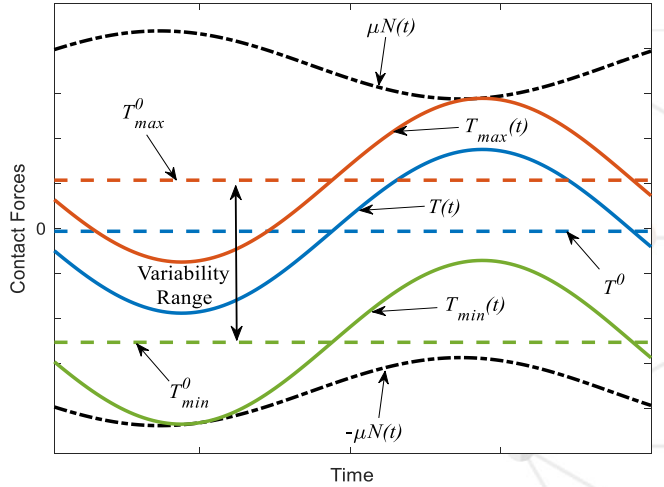
$$T^0_R\sin(\alpha_R)+N^0_R\cos(\alpha_R)+T^0_L\sin(\alpha_L)+N^0_L\cos(\alpha_L)=F^0$$

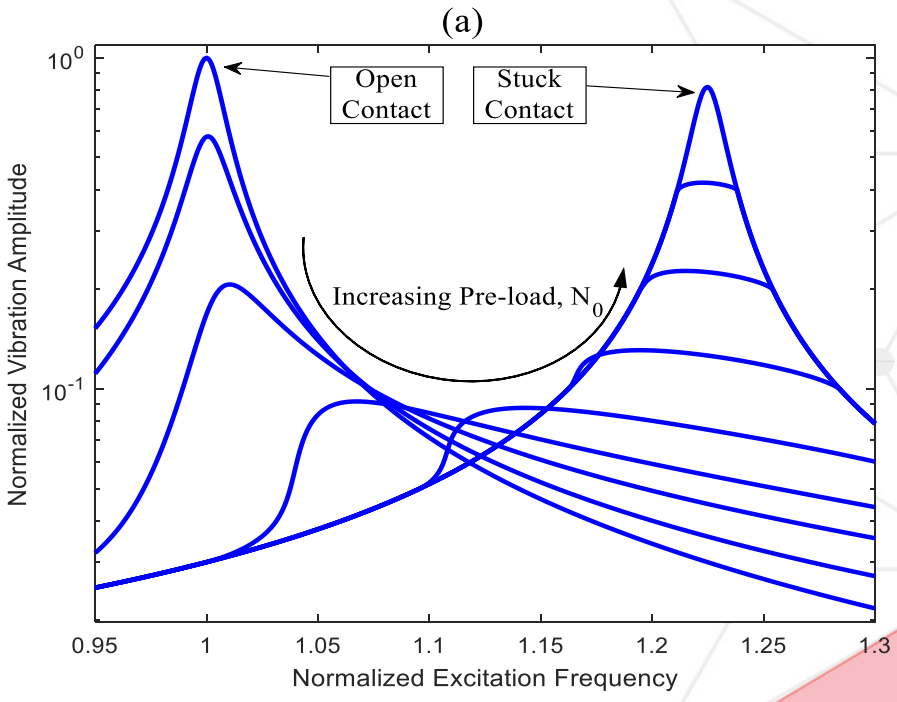
$$N^0_R=F^0\cos(\alpha_R)-N^0_L\cos(\alpha_L+\alpha_R)-T^0_L\underbrace{\sin(\alpha_L+\alpha_R)}$$

always positive

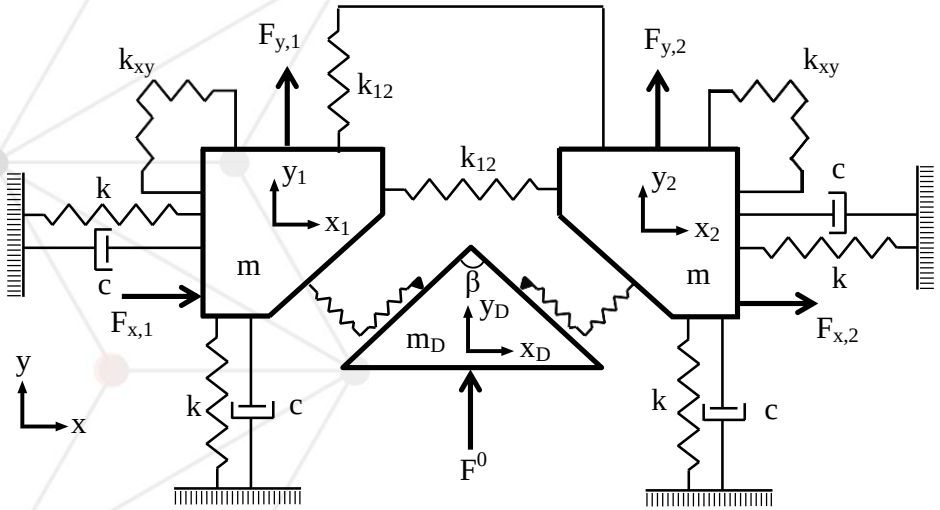
Max T^0_L ⟶ Min N^0_R

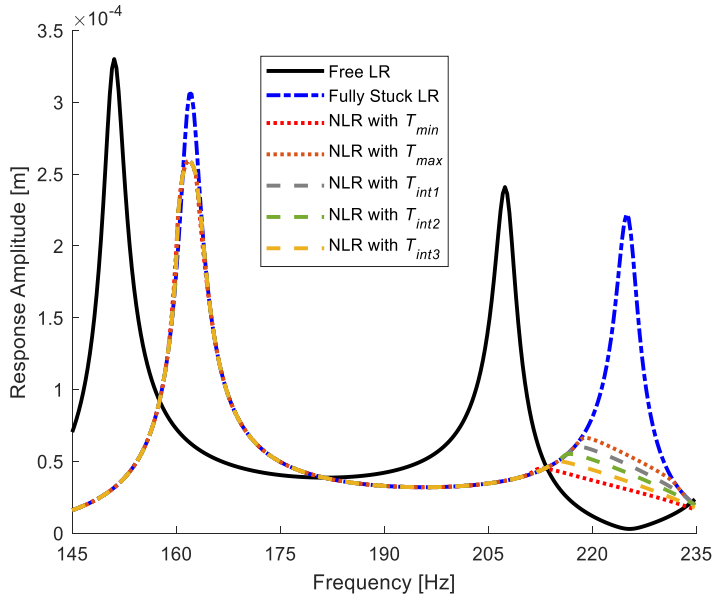
Min T^0_L ⟶ Max N^0_R

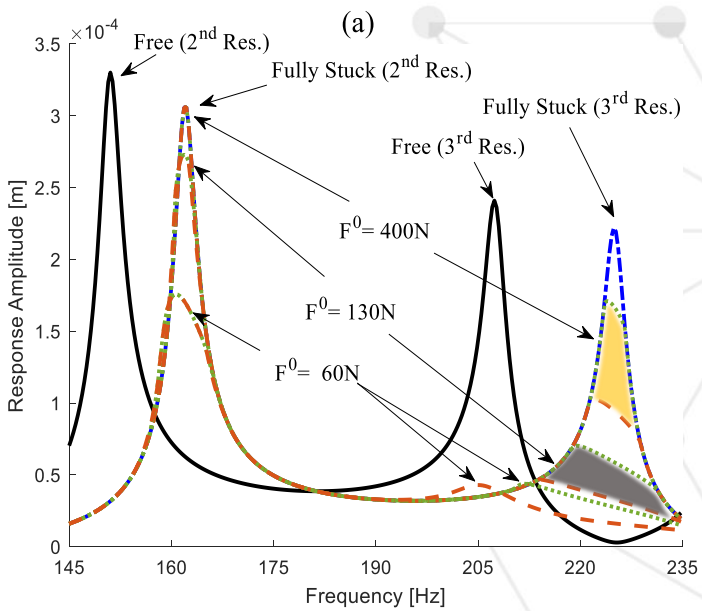


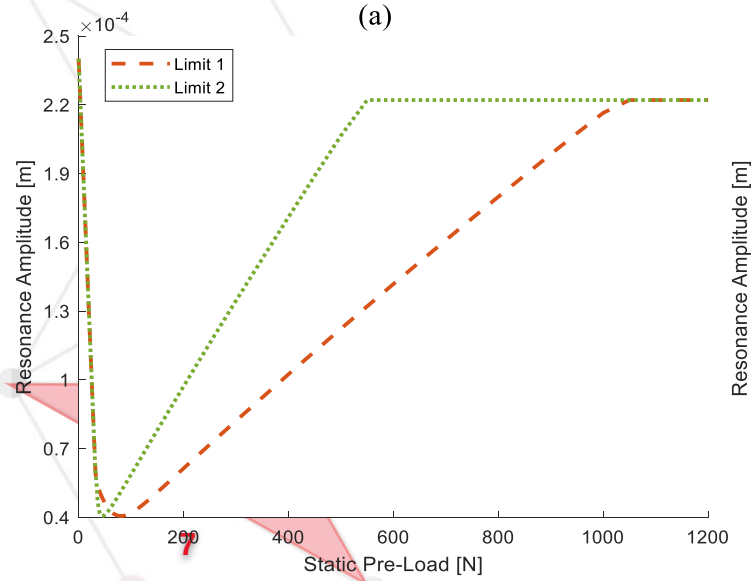


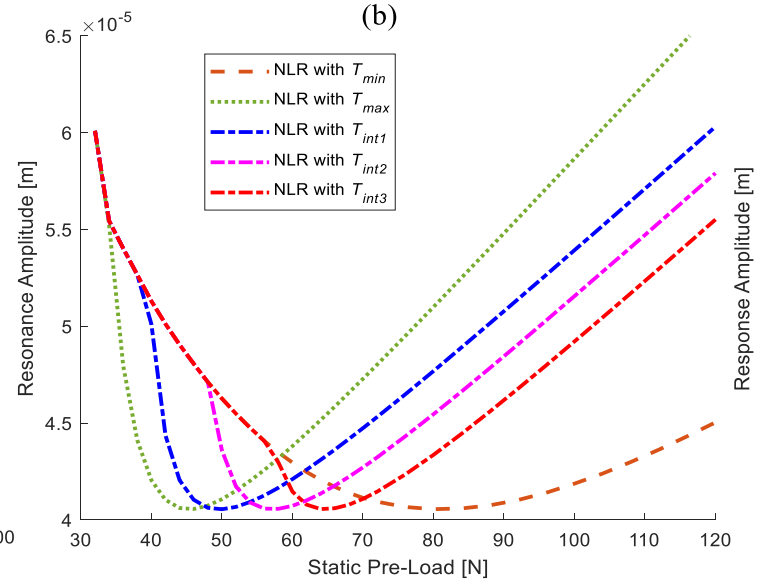
Boundaries for Wedge Dampers

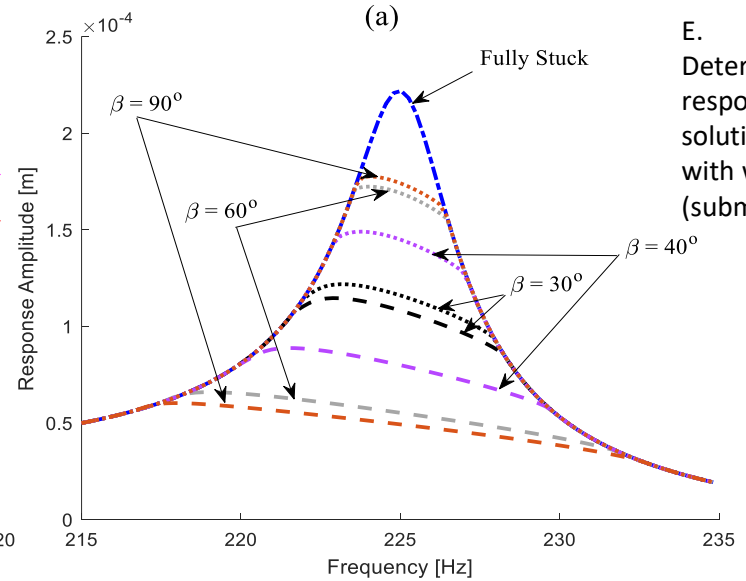






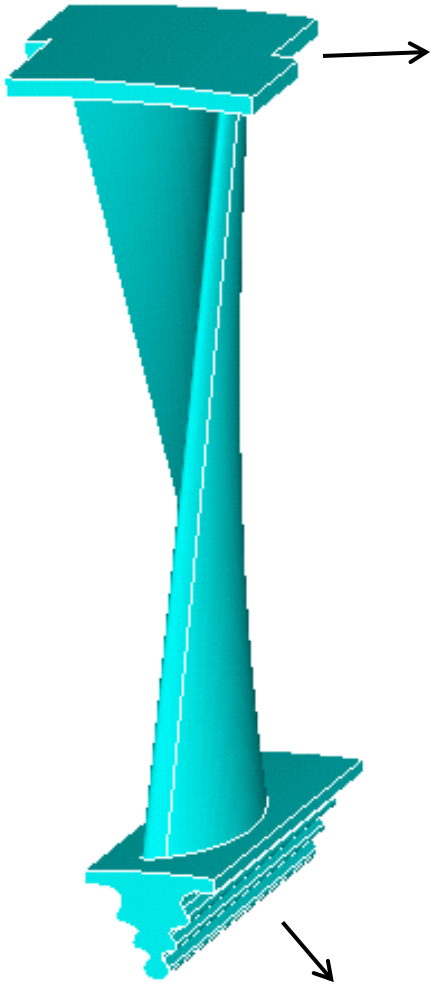


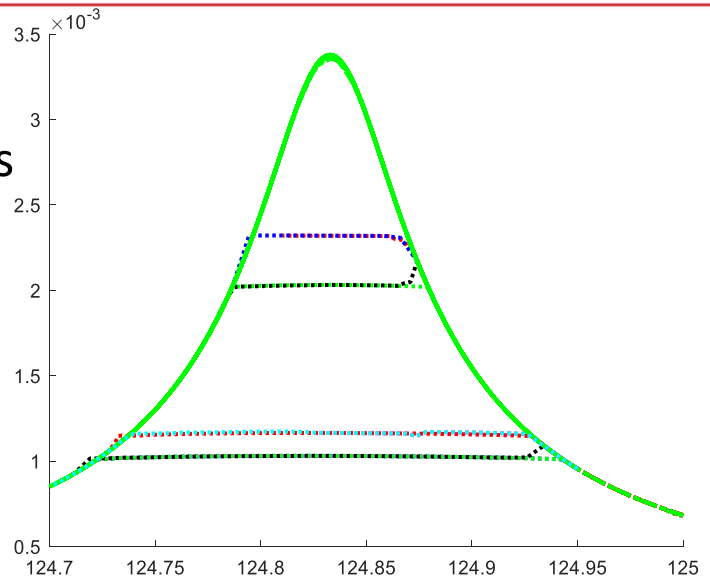


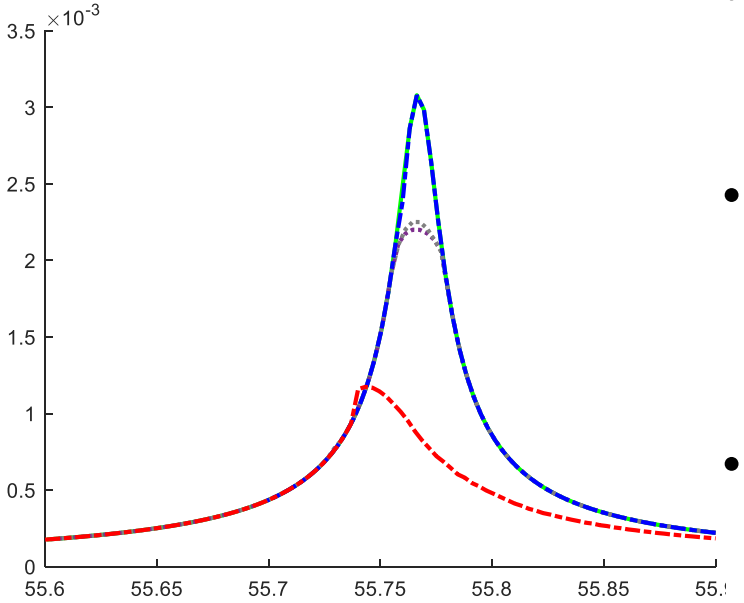


E. Ferhatoglu, S. Zucca, Determination of periodic response limits among multiple solutions for mechanical systems with wedge dampers, J Sound Vib. (submitted)

Generalized Approach for Limits







Future work

- Generalized approach for all applications
- More detailed investigation with several analyses on the realistic turbine blade
- Showing the performance of the new method
- Design of a test setup and comparison of the experimental results with the computational ones
- Finalizing the numerical solver code of the joint project with Baker Hughes company