Multibody Simulations with Reduced Order Flexible Bodies Obtained by FEA

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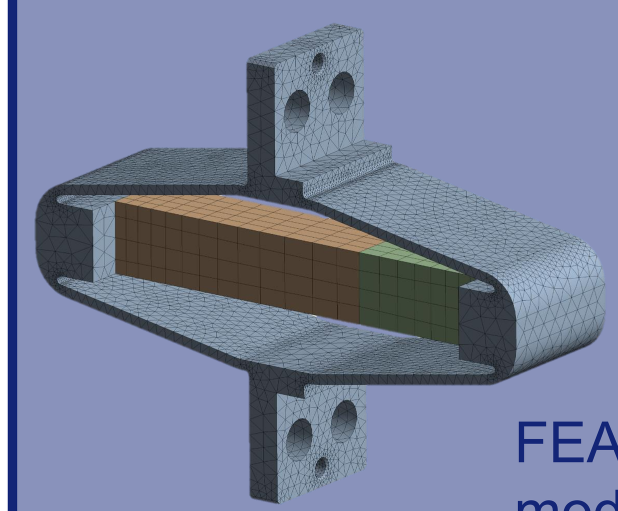
We chose multi-body design model approach for the development of the new actively stabilized ID31 end-station. Significance of such models depend strongly on its input and consideration of the right stiffness of the system's components and subsystems. For that matter, we considered sub-components in the multi-body model as *reduced order flexible bodies* representing the component's modal behavior with reduced mass and stiffness matrix obtained from finite element analysis (FEA) models. We validated the technique with a test bench that confirmed the good modelling capabilities using reduced order flexible body models obtained from FEA for an amplified piezoelectric actuator.

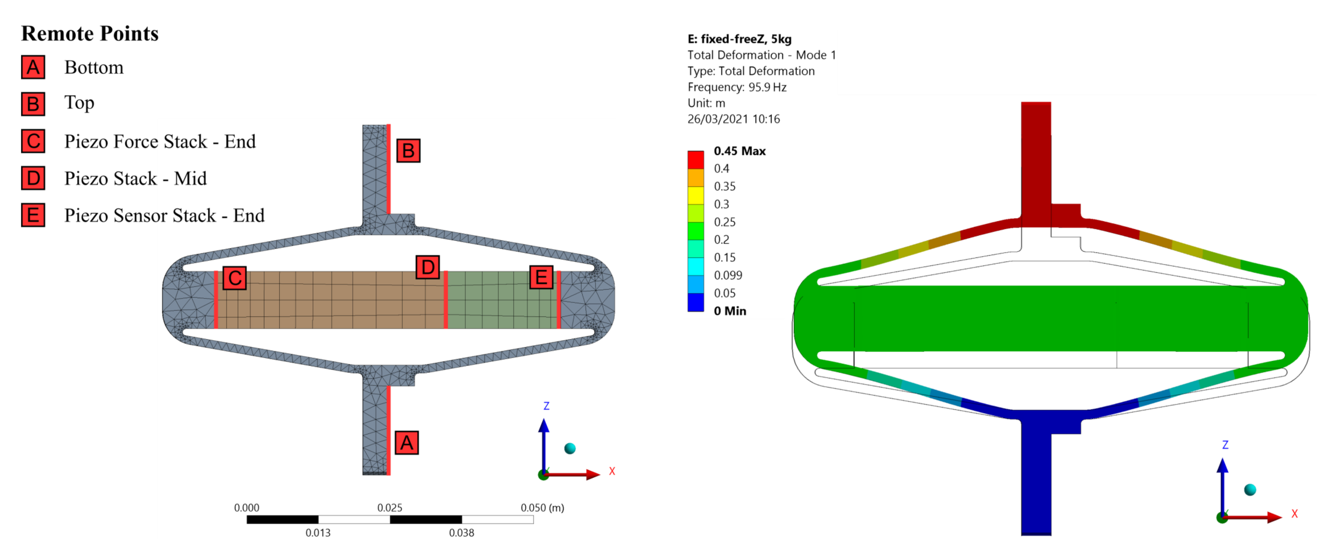
Introduction

- Control design of new nano-endstation with "model based design" & multibody model
- Limitation of multibody models to simple rigid bodies can be overcome with use of *reduced order flexible bodies*
  - Description of bodies flexible behavior with reduced stiffness $\widehat{\boldsymbol{K}}$ and mass matrix $\widehat{\boldsymbol{M}}$
  - Reduced matrices can be obtained from FEA models
- **Application** on amplified piezo as subcomponent of future nano-hexapod

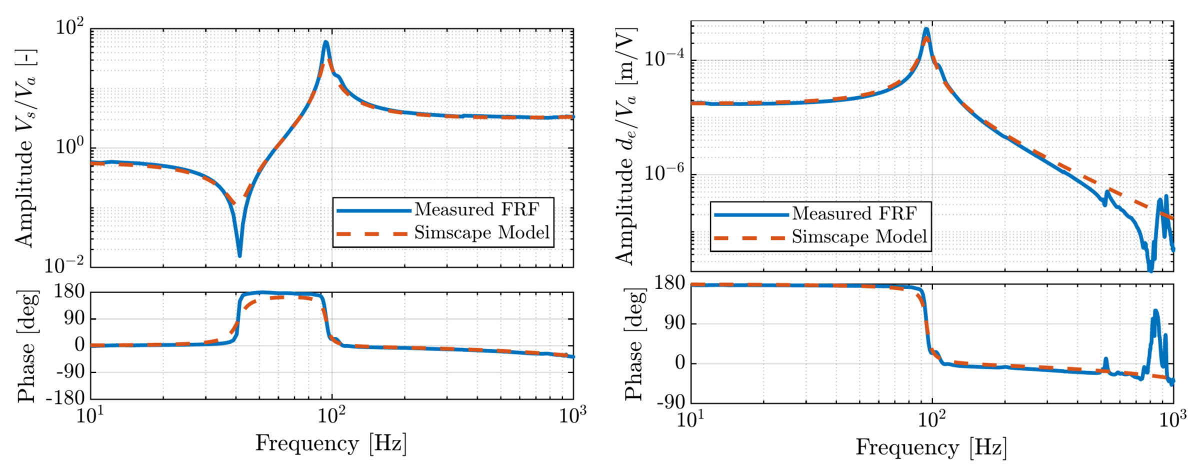


FEA model of amplified piezo used for modal reduction

Results



FEA Reduction model and first mode ($f_1 \approx 95\ Hz$)



Comparison: experiment / *Simscape* model (using reduced order FEA model)

Methodology

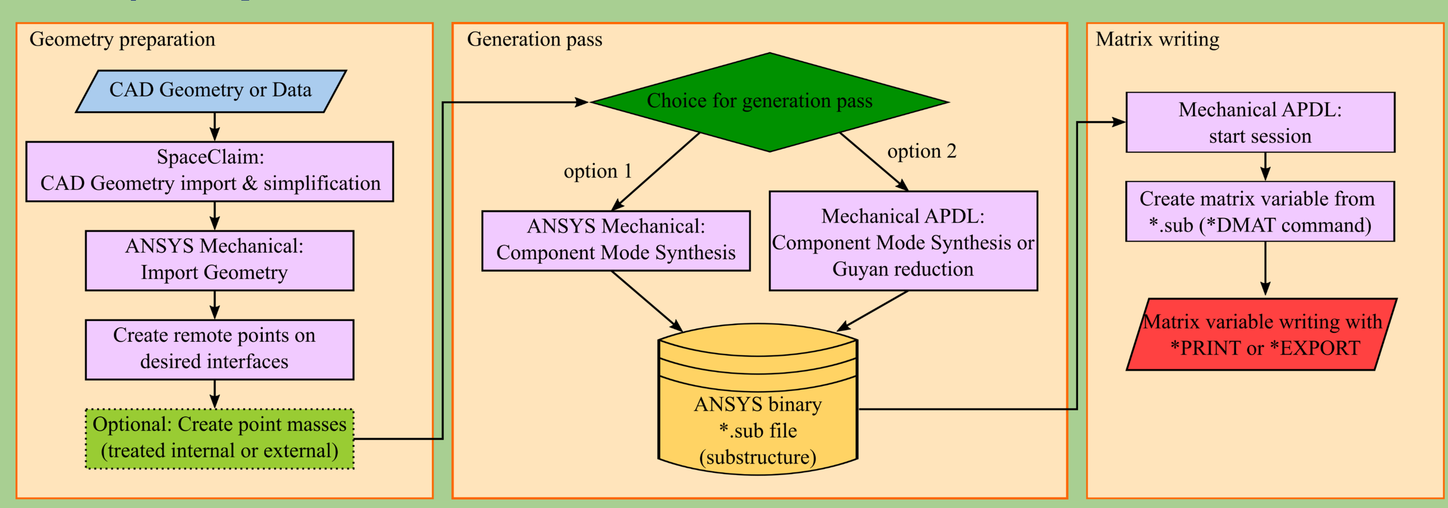
- Use of *ANSYS* FEA for modal reduction of global system matrices from undampened dynamic equation

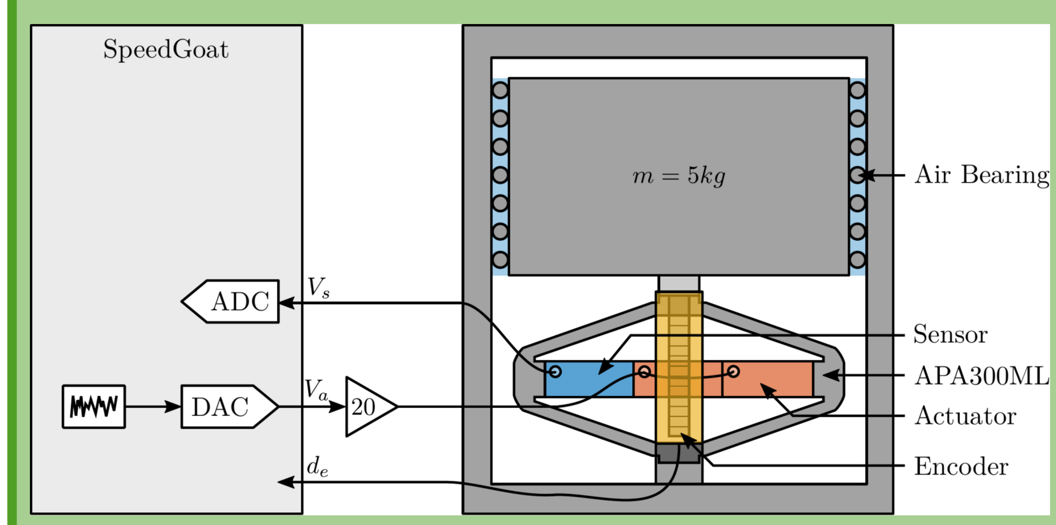
$$\boldsymbol{M}\ddot{\boldsymbol{u}} + \boldsymbol{K}\boldsymbol{u} = \boldsymbol{F}$$

$\boldsymbol{M}_{n\times n}, \boldsymbol{K}_{n\times n}$ mass and stiffness matrix for n degrees of freedom

- Used reduction method: Component Mode Sythesis (CMS) – fixed interface method (Craig-Bampton method) [1,2]
  - Selection of a small number of m master DoFs and $s = m - n$ slave DoFs
  - FEA solves constrained Eigenvalue problem for all master nodes blocked (numerically slowest part): $\omega M_{ss}\phi_s = K_{ss}\phi_s$
  - Output: reduced matrices $\widehat{\boldsymbol{K}} = \boldsymbol{T}^T\boldsymbol{K}\boldsymbol{T}$, $\widehat{\boldsymbol{M}} = \boldsymbol{T}^T\boldsymbol{M}\boldsymbol{T}$ via transformation with matrix $\boldsymbol{T}$ containing Eigenshapes and global stiffness elements
  - Size of $\widehat{\boldsymbol{K}}$ and $\widehat{\boldsymbol{M}}$ **is** $(\boldsymbol{m}+\boldsymbol{p}) \times (\boldsymbol{m}+\boldsymbol{p})$ with p **"**retained**"** additional user-chosen Eigenmodes

Developed **procedure** for modal reduction via *ANSYS* FEA model





- **Test** of reduced order model of amplified piezo in testbench
  - White noise actuator input
  - Outputs: force sensor stack and top displacement

Conclusions

- Modal reduction permits consideration of flexible bodies in multibody simulations
- Procedure was validated on test bench for end-station design project

[1] R. R. Craig and M. C. C. Bampton, *"Coupling of substructures for dynamic analyses,"* AIAA Journal, vol. 6, no. 7, pp. 1313–1319, Jul. 1968, doi: 10.2514/3.4741.

[2] Ansys® Academic Research Mechanical APDL, Release 2020R2, *Help System, Theory reference, 15.6. Substructuring Analysis*, 2020, ANSYS Inc.

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