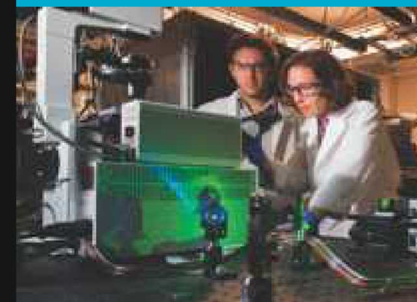
SAND2018-1586C

Frequency Response Function Matching for Test Fixture Design



2018 Topology Optimization Roundtable

Washington DC

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PRESENTED BY

Peter Coffin, Tyler Schoenherr and Brett Clark

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Outline

- Fixture Design Background and Motivation
- Design Problem Definition
- Proposed Levelset-CDFEM Approach
- Initial Problem and Levelset-CDFEM Results
- Conclusions

Fixture Design – Larger Context

Goal during design and production:

- Ensure that system and its components will survive

To qualify components:

- Estimate system and component mechanical environments
- Perform laboratory tests to prove margin

Possible errors with the above process:

- Predicted system environments
- Predicted component environments
- Unrepresentative component test

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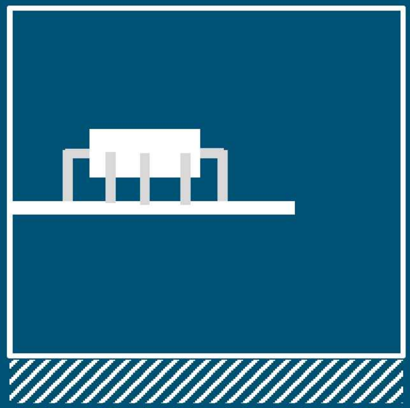
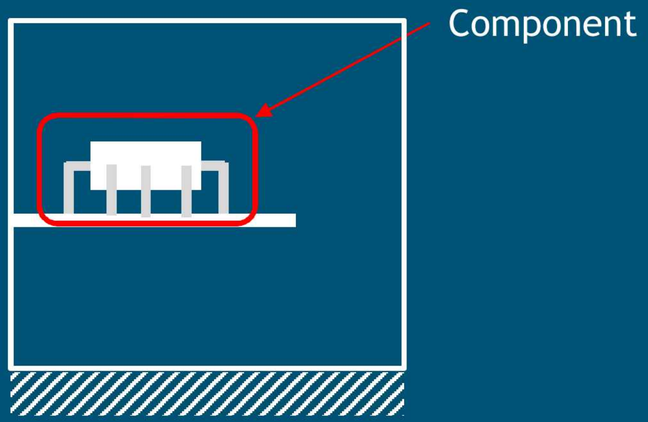
Bad Fixturing, an example



In System

Bad Fixturing, an example



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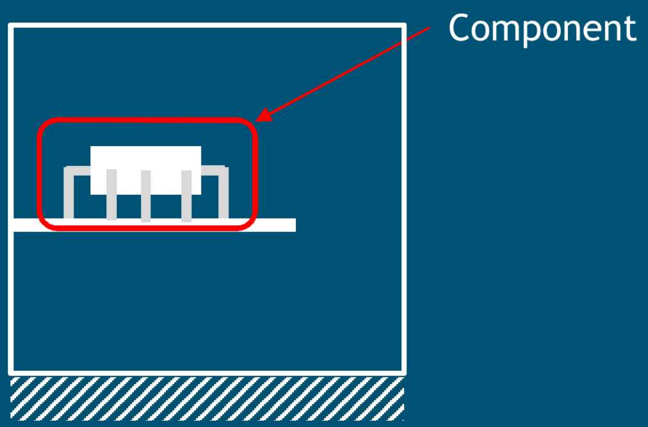

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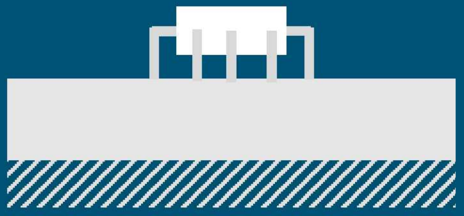
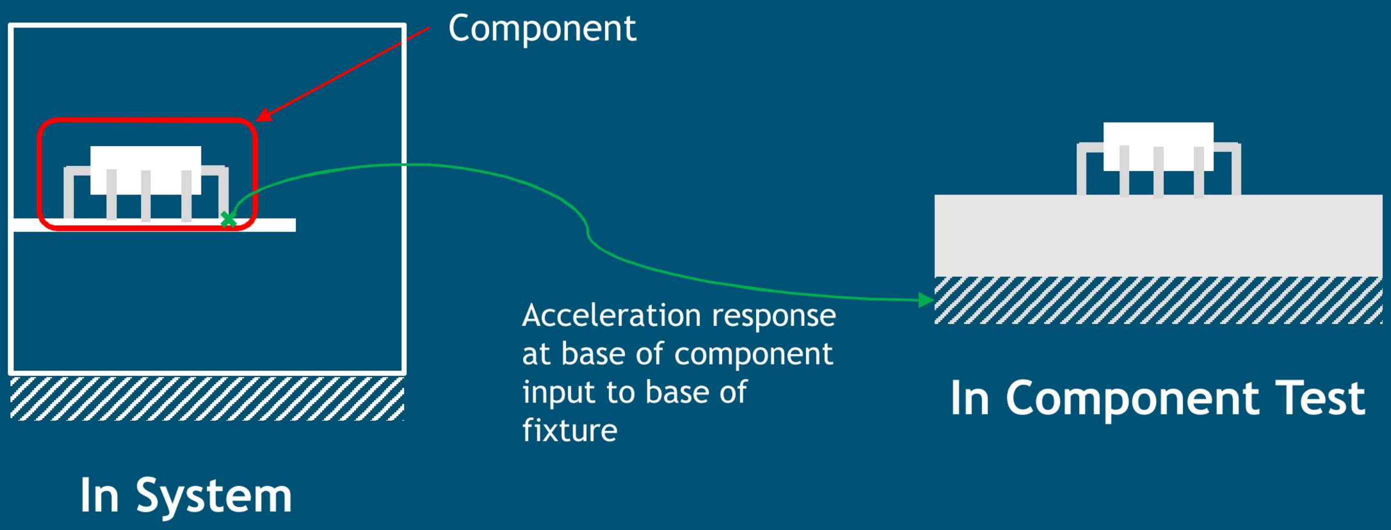
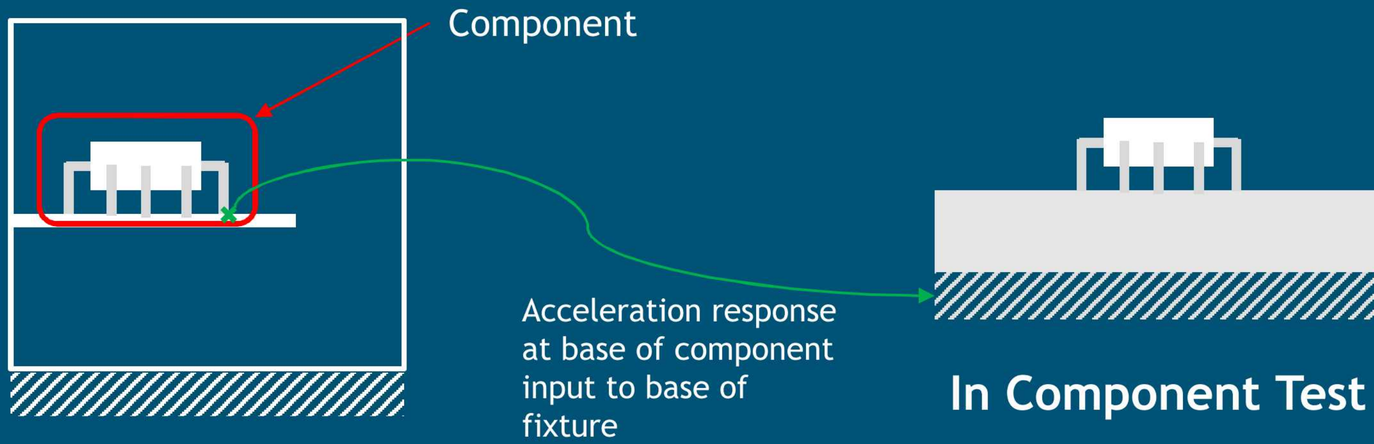


In Component Test

Bad Fixturing, an example



Bad Fixturing, an example



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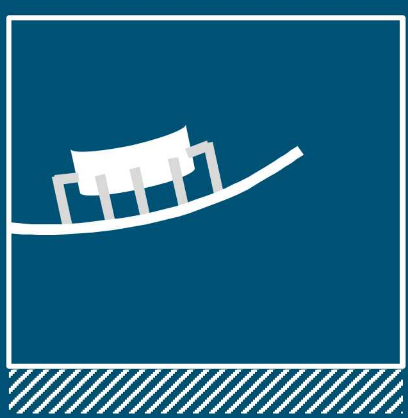
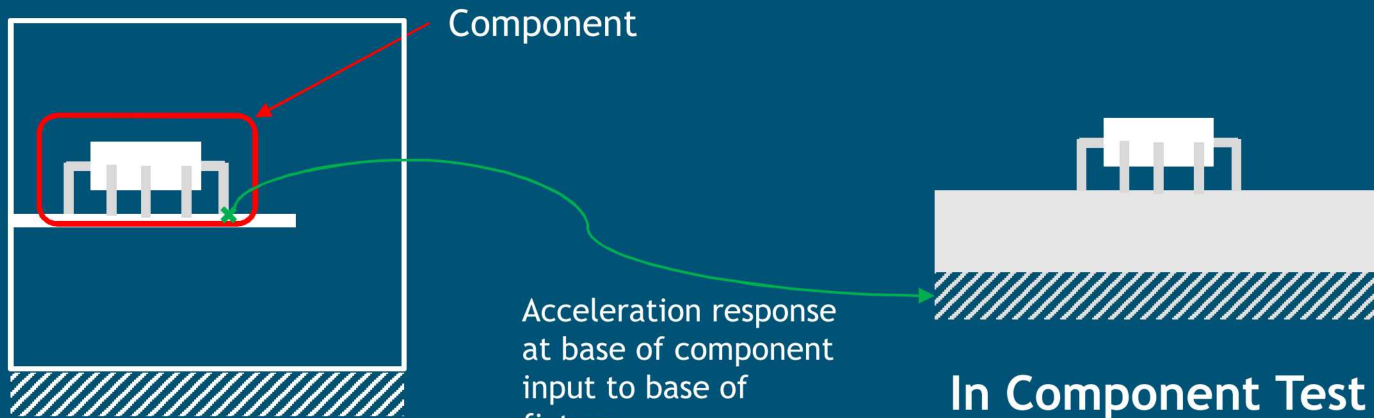
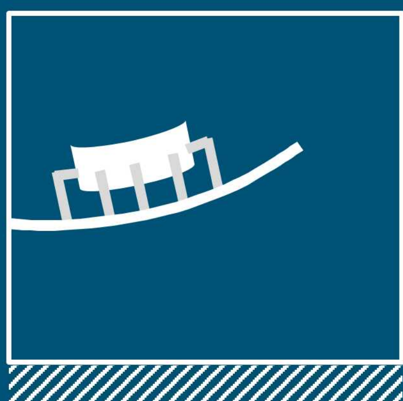


System response at plate first frequency

Bad Fixturing, an example



In System



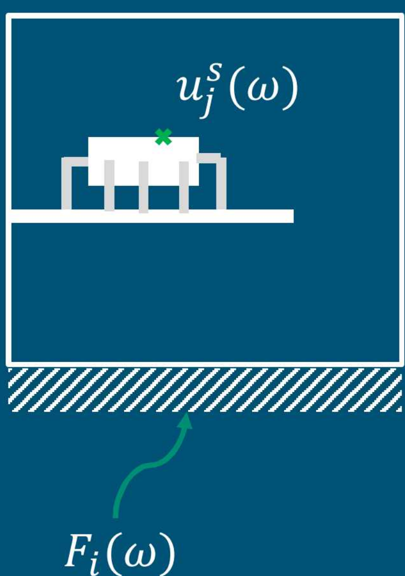
System response at plate first frequency

Cannot replicate this deformation (and possible failure mode) with above component test!

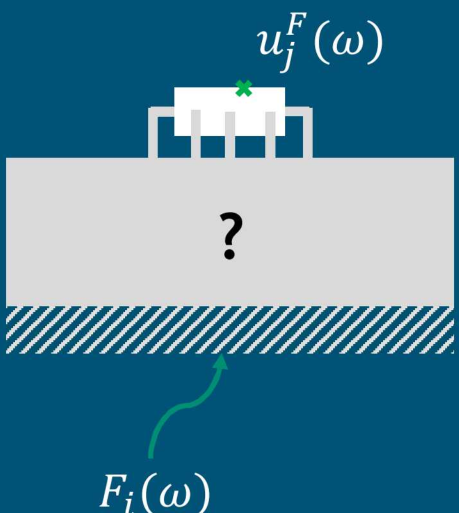
Proposed Approach

Design test fixture that results in component dynamics similar to those of component in system

Restated: Design test fixture such that the Frequency Response Functions relating input (shaker) excitation to component response are as similar to those of the full system as possible.



Objective
Minimize difference between $u_j^S(\omega)$ and $u_j^F(\omega)$



Proposed Approach

Ma, Zheng-Dong, Noboru Kikuchi, and Hsien-Chie Cheng. "Topological design for vibrating structures." *Computer methods in applied mechanics and engineering* 121.1-4 (1995): 259-280.

Ma, Z-D., Noboru Kikuchi, and I. Hagiwara. "Structural topology and shape optimization for a frequency response problem." *Computational mechanics* 13.3 (1993): 157-174.

Shu, Lei, et al. "Level set based structural topology optimization for minimizing frequency response." *Journal of Sound and Vibration* 330.24 (2011): 5820-5834.

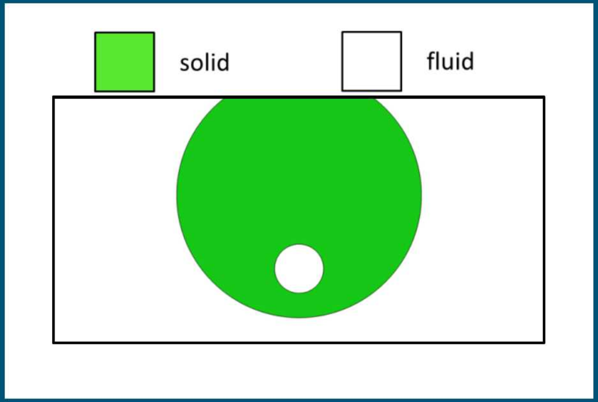
Jensen, Jakob S. "Topology optimization of dynamics problems with Padé approximants." *International journal for numerical methods in engineering* 72.13 (2007): 1605-1630.

Rong, J. H., et al. "Topology optimization of structures under dynamic response constraints." *Journal of Sound and Vibration* 234.2 (2000): 177-189.

Challenges and approach

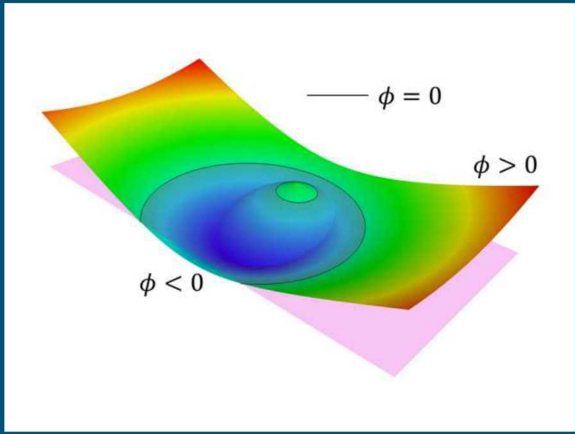
Initial research using both commercial and Plato density method software:

- Significant amounts of intermediate material
- Small material densities led to ill conditioning of linear system
- Non-convex



Our proposed approach: Levelset-CDFEM

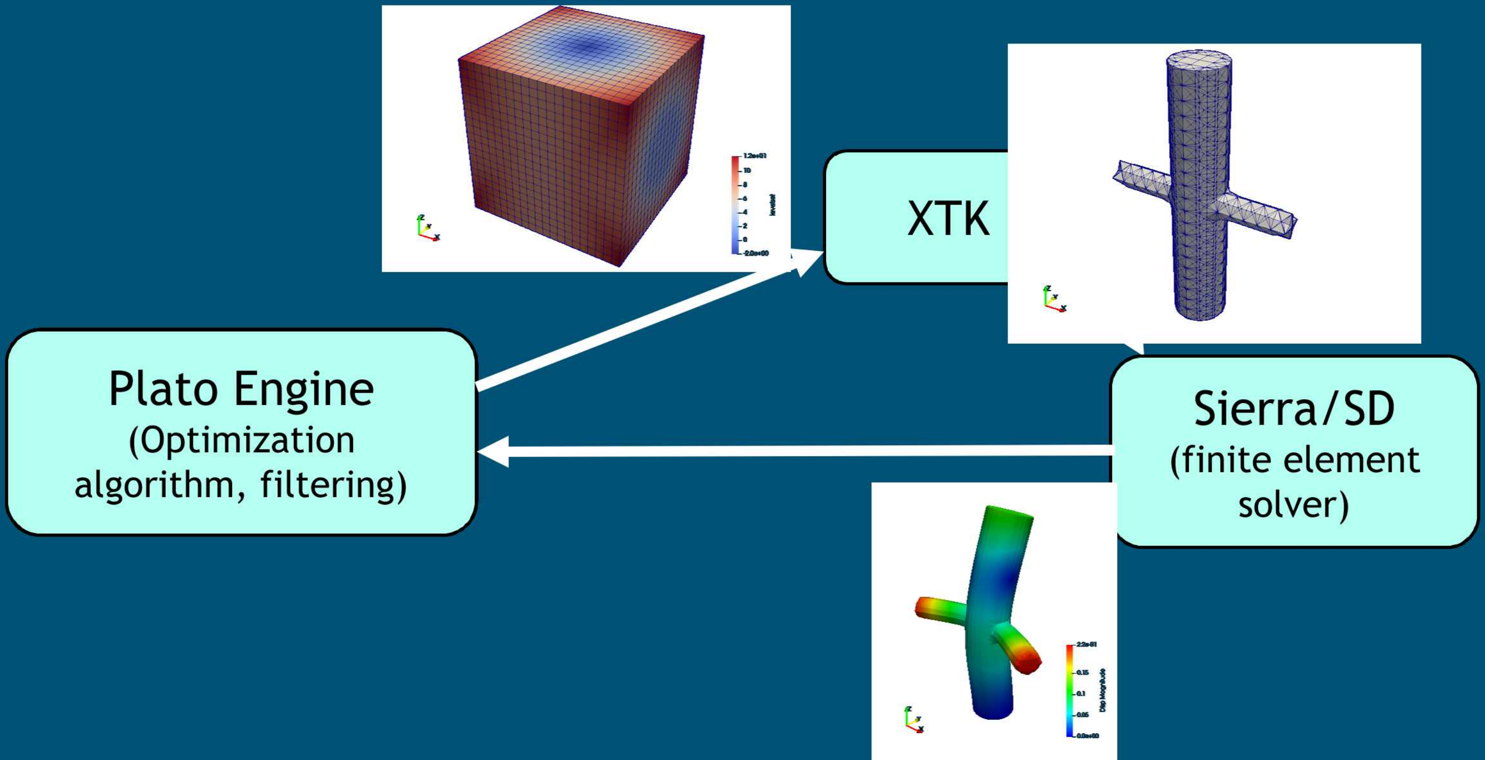
- Good:
  - No intermediate material
  - No ill conditioning from void material
  - Start from meaningful geometry (shape optimization)
- Bad:
  - Implementation complexity
  - Computational cost



Levelset-CDFEM Approach

How will we implement this?

- Nodal finite element discretization of levelset field
- XFEM ToolKit (XTK) library from CU Boulder (Keenan Doble and Prof Kurt Maute)
  - Produce conformal tetrahedral mesh (CDFEM)
  - Future: incorporate multipoint constraints to construct XFEM system
- Sierra/Structural Dynamics (SD) as finite element solver
- XTK and Sierra/SD wrapped in topology optimization framework provided by new Plato Engine architecture



The Design Problem

Minimize: $\sum_{k=1}^{N_\omega} \left[\frac{\kappa}{2}\left(\{\boldsymbol{u}^k\} - \{\boldsymbol{u}_S^k\}\right)^{\boldsymbol{T}}[\boldsymbol{Q}]\left(\{\boldsymbol{u}^k\} - \{\boldsymbol{u}_S^k\}\right)\right]$

$s, \boldsymbol{u}$

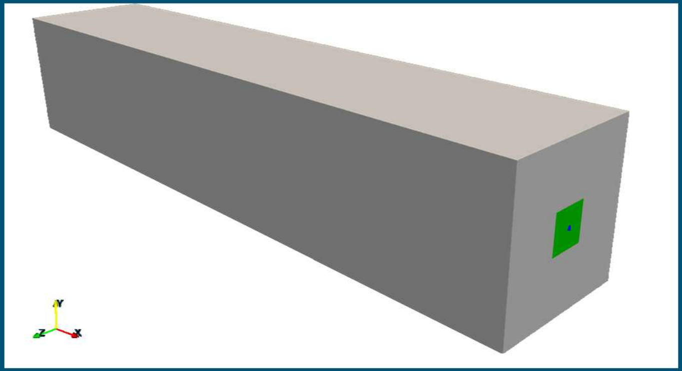
Subject to: $[K(\boldsymbol{s})]\{\boldsymbol{u}^k\} + i\omega_k[C(\boldsymbol{s})]\{\boldsymbol{u}^k\} - \omega_k^2[M(\boldsymbol{s})]\{\boldsymbol{u}^k\} - \{\boldsymbol{f}_k\} = \{\boldsymbol{0}\}$

Consider a beam:

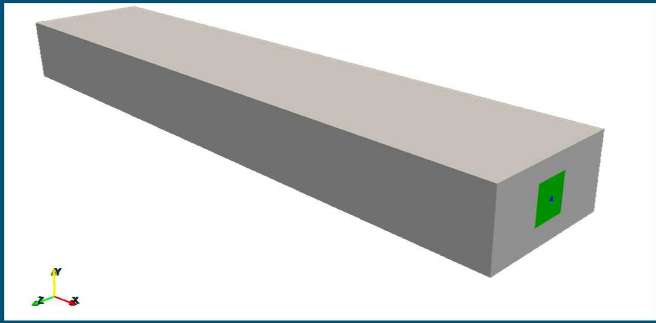
- Traction in x, y and z applied on green patch
- Measured response at blue point
- Fixed left end

κ	Scaling coefficient
$\boldsymbol{u}^k$	displacement degrees of freedom for frequency k
$\boldsymbol{u}_S$	System (match) displacement degrees of freedom
N_ω	Number of evaluation frequencies
$\boldsymbol{Q}$	degree of freedom boolean/weighting matrix
$K(\boldsymbol{s})$	Finite element stiffness matrix
ω_k	K-th frequency
$C(\boldsymbol{s})$	Finite element damping matrix
$M(\boldsymbol{s})$	Finite element mass matrix
$\boldsymbol{f}_k$	Nodal external force at frequency k

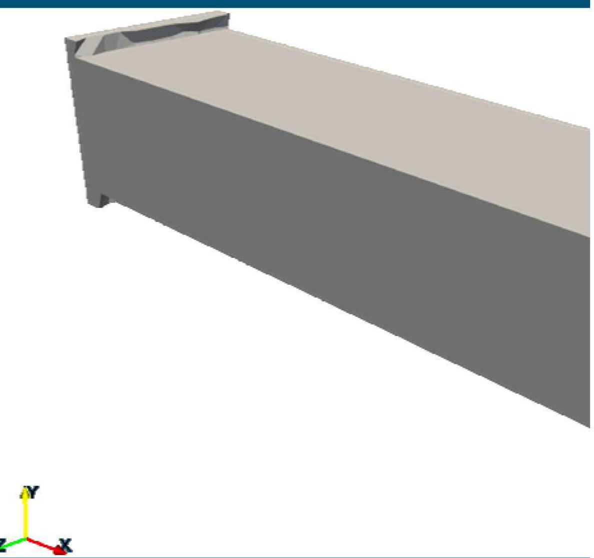
Design domain:
4 cm x 4 cm x 20 cm

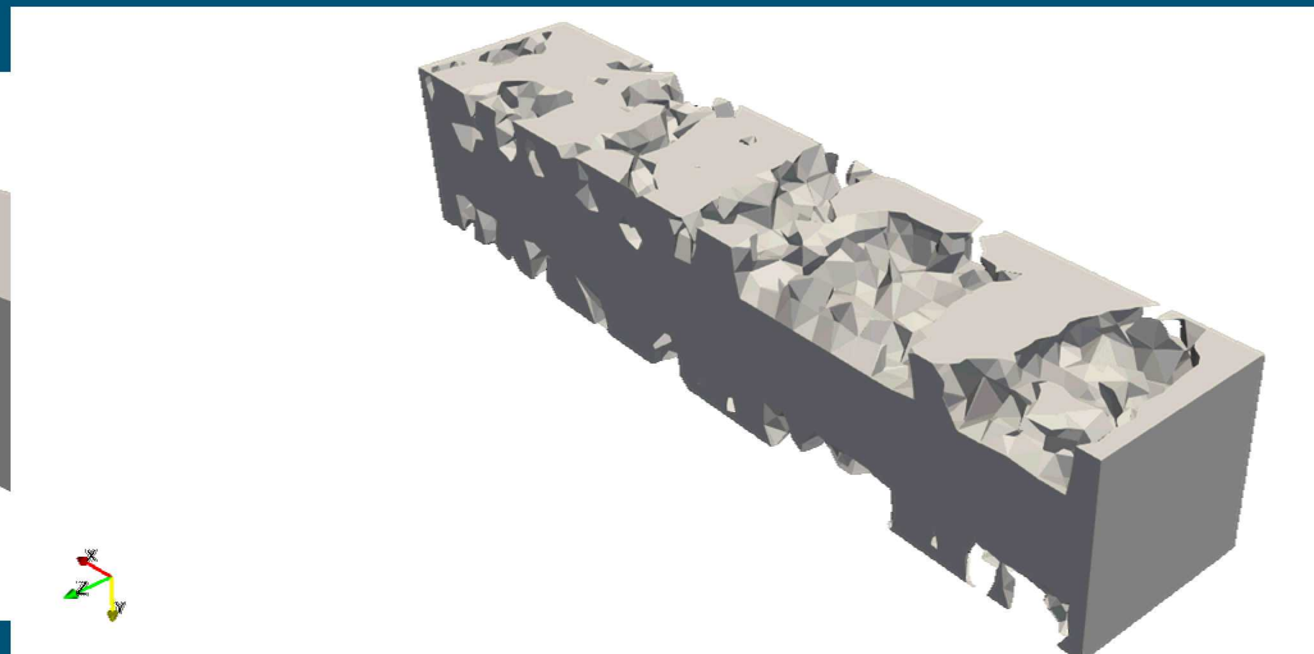


Measure $\boldsymbol{u}_S$ from reference beam:
2cm x 4cm x 20cm



Initial Results Geometry

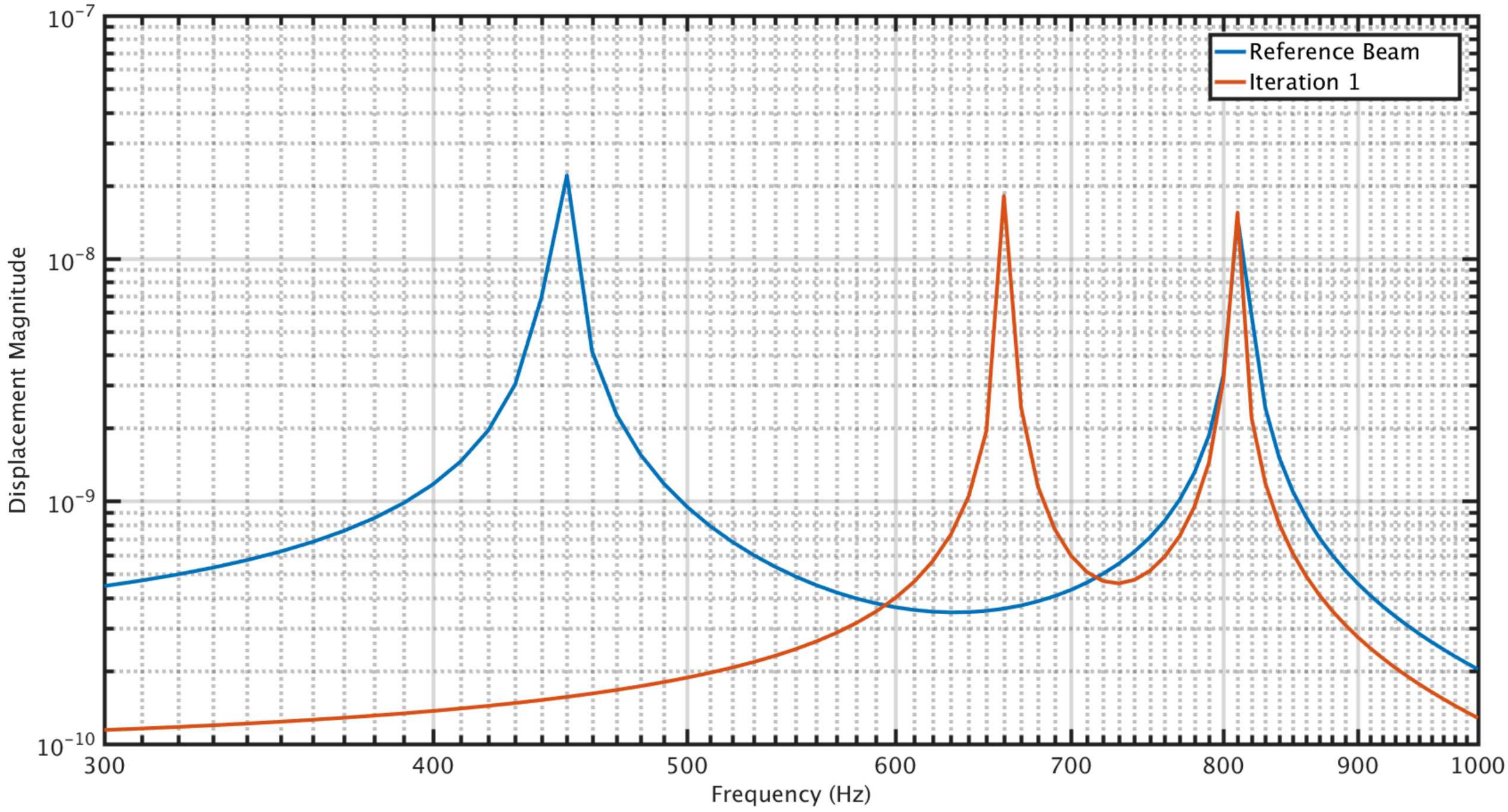




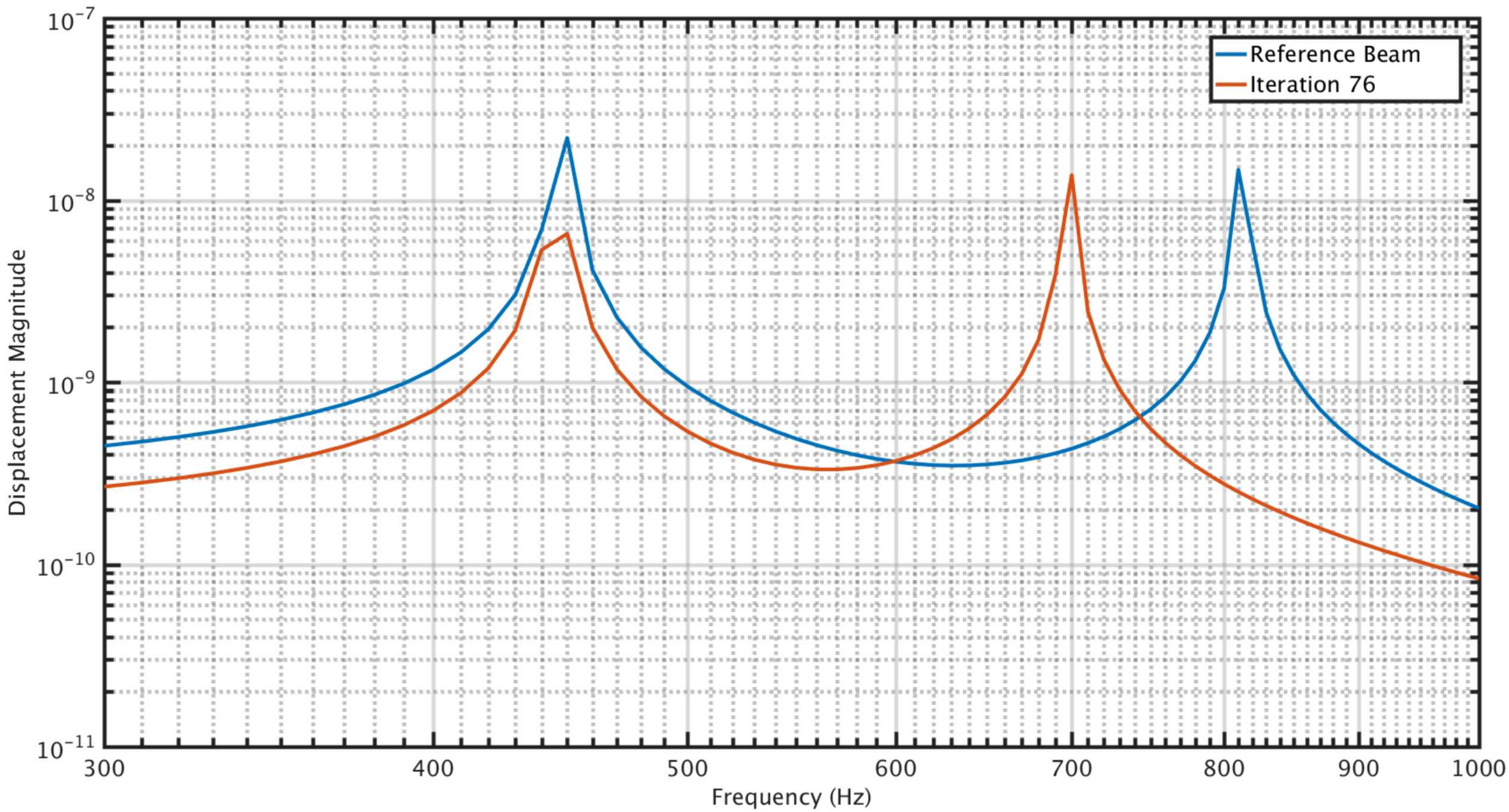
Initial Design

Final Design

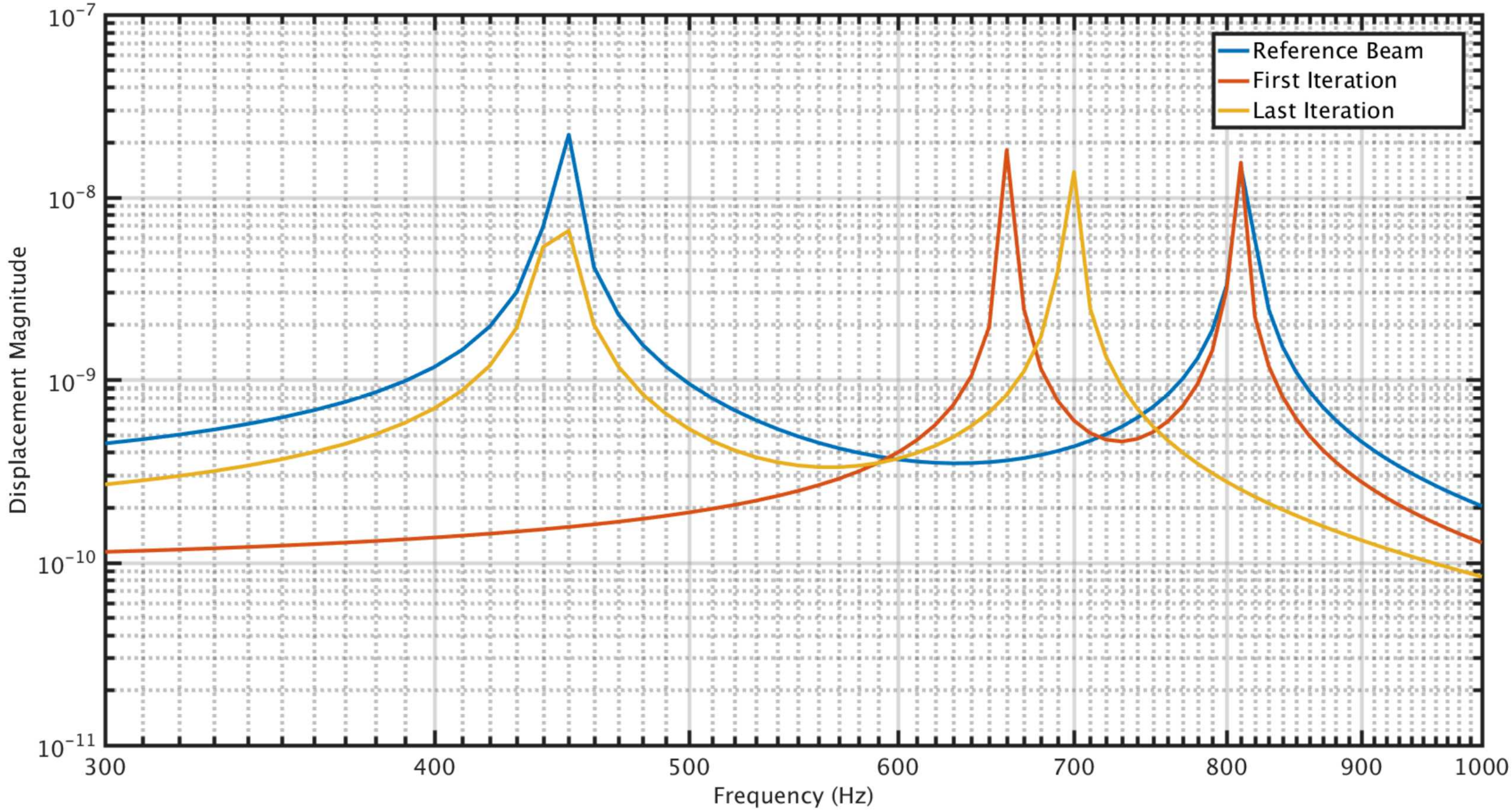
Initial Design Response



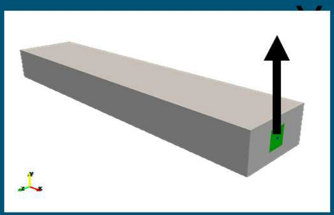
Final Design Response

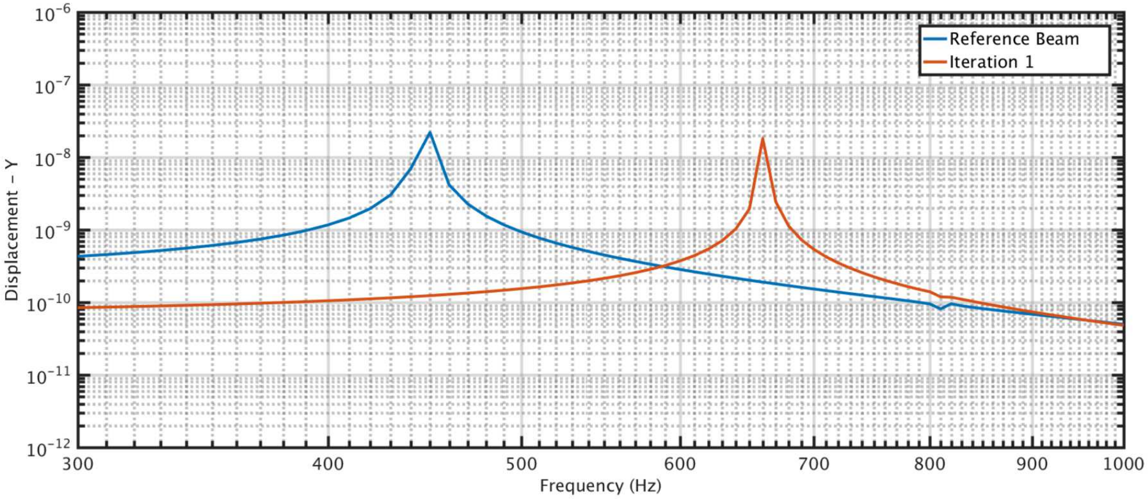


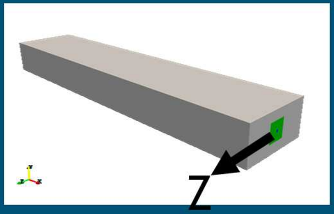
Initial and Final Response

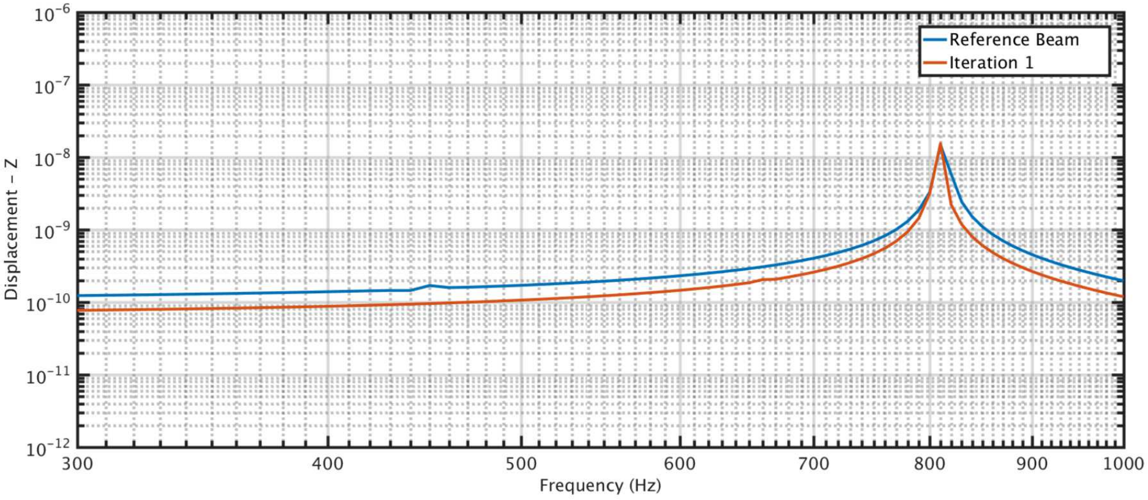


Initial Design Response by Coordinate









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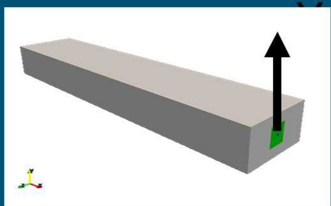

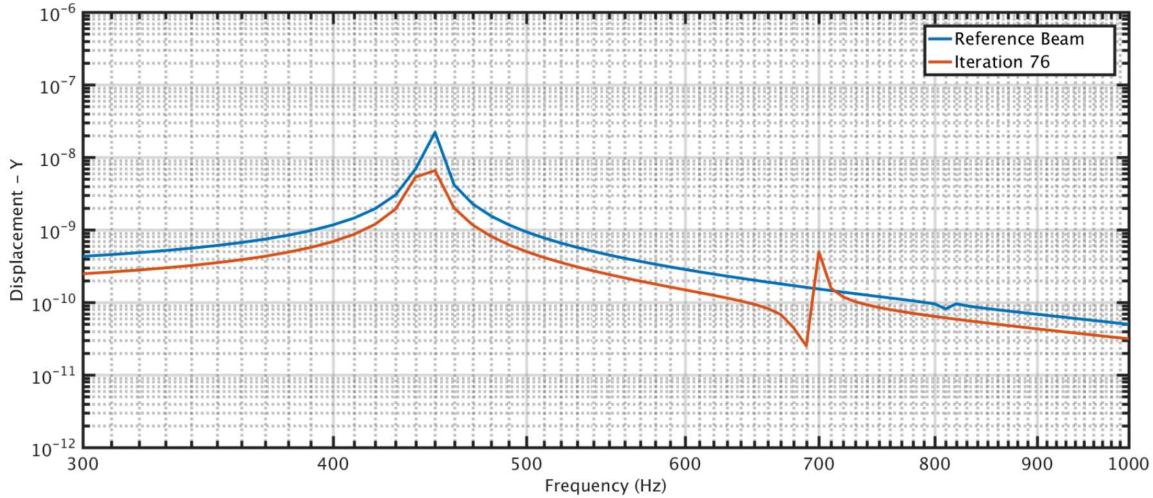

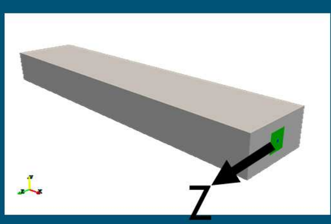

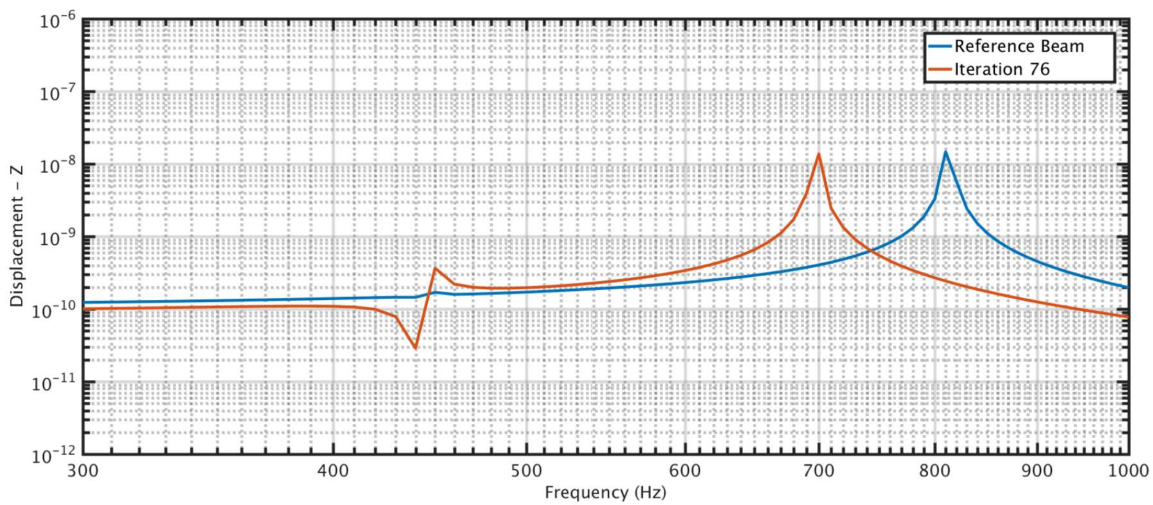

Conclusions

Problem as posed: density method may have fundamental difficulties

Little available literature on dynamics matching

Levelset-CDFEM Pros:

- Verification problem consistency
- No ill conditioning due to void material
- Easy to start with simple geometry optimization problems and expand

Levelset-CDFEM Cons:

- Non-trivial implementation and verification cost
- Speed penalty for reinitializing solvers
- Filters don't provide geometry control