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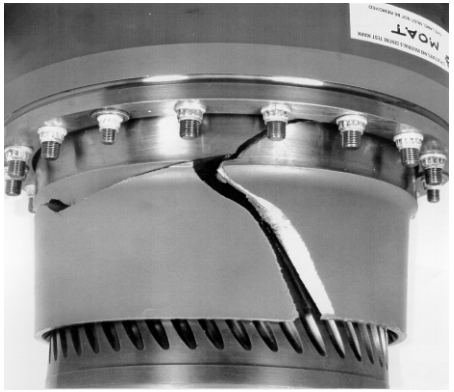
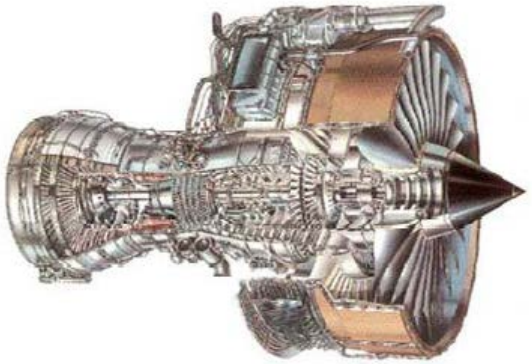
Sandia National Laboratories

N=O=MAD Research Institute





Dynamics of Bolt Loosening

Students: Chris Johnson, Max Miller, Noah Sonne

Mentors: Rob Kuether, John Mersch, Jeff Smith, Jonel Ortiz, Keegan Moore, Gustavo Castelluccio

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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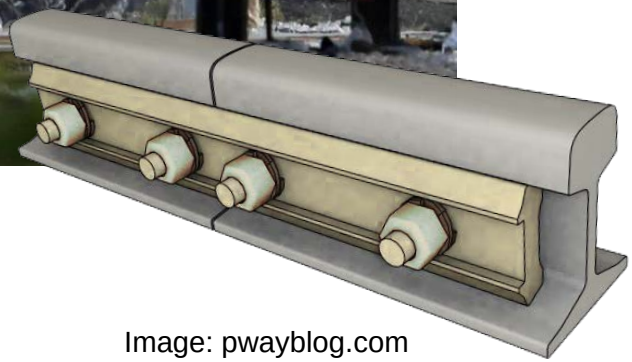
Motivation

2013 Paris SNCF train derailment

Image: CNN



- 7 deaths, dozens of injuries
- Suspected cause: loose fishplate bolts

Image: pwayblog.com

Max’s Story

Project Overview

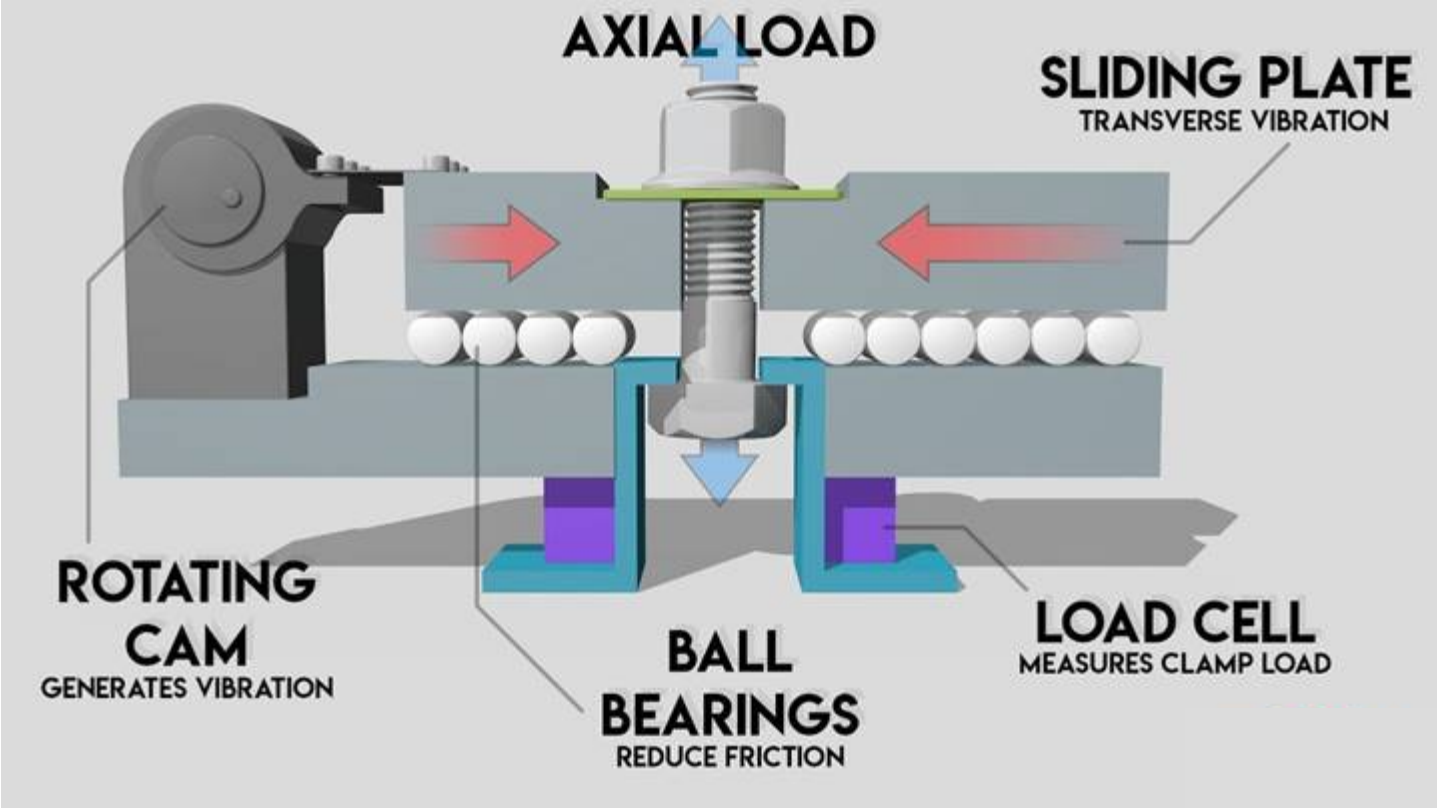
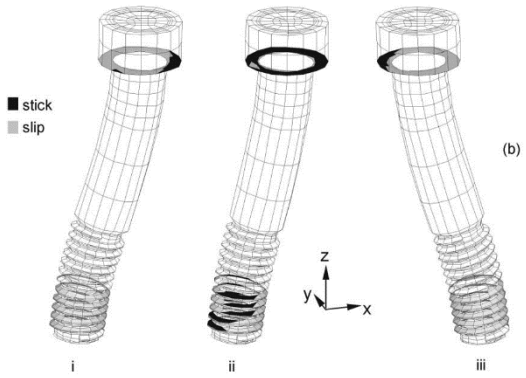


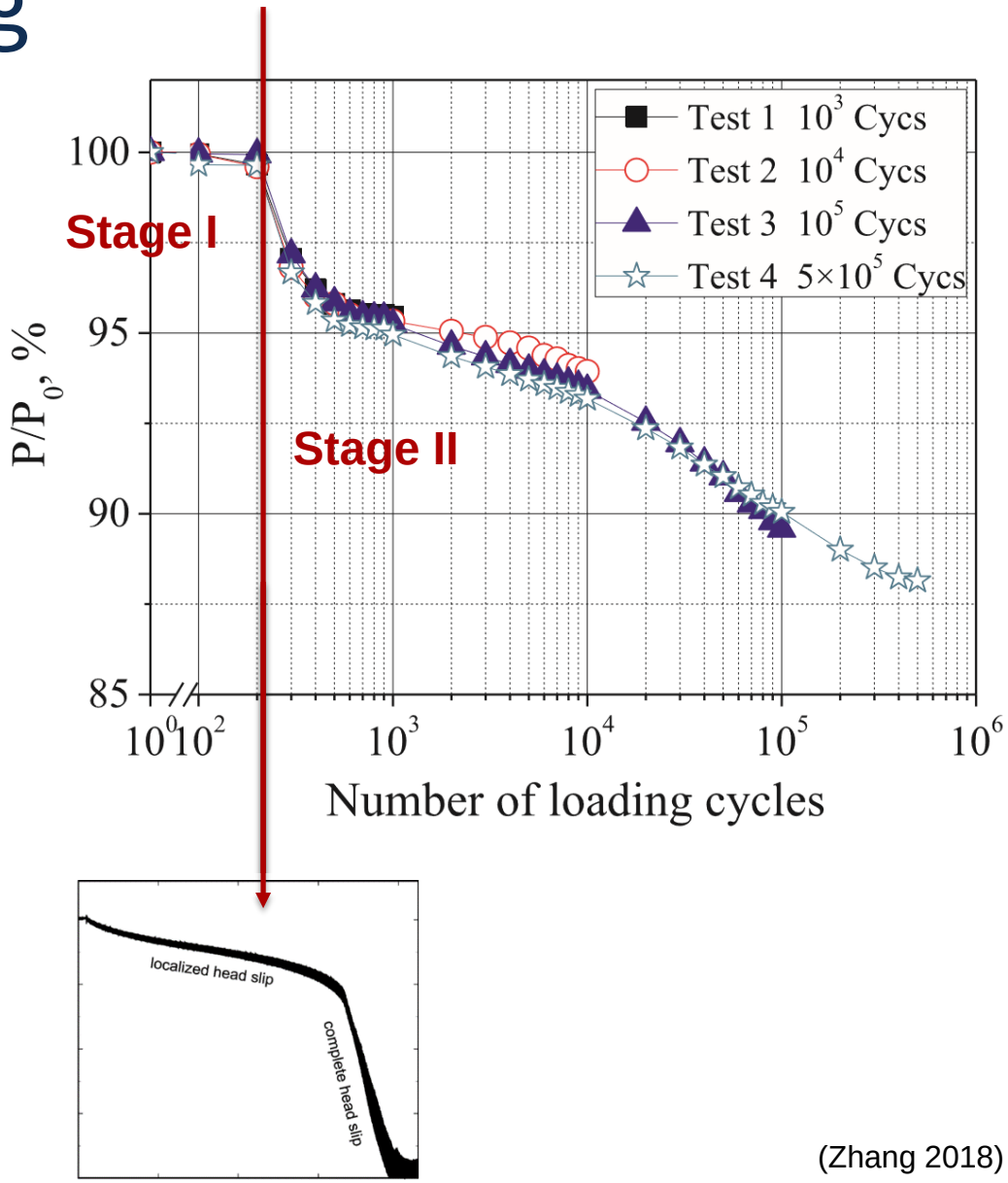
Image: https://www.youtube.com/watch?v=Jq38Oe6lMEg

Bolt Loosening

- Stage I
  - Plastic Deformation
  - Fretting Wear
- Stage II
  - Rotation in the nut and bolt



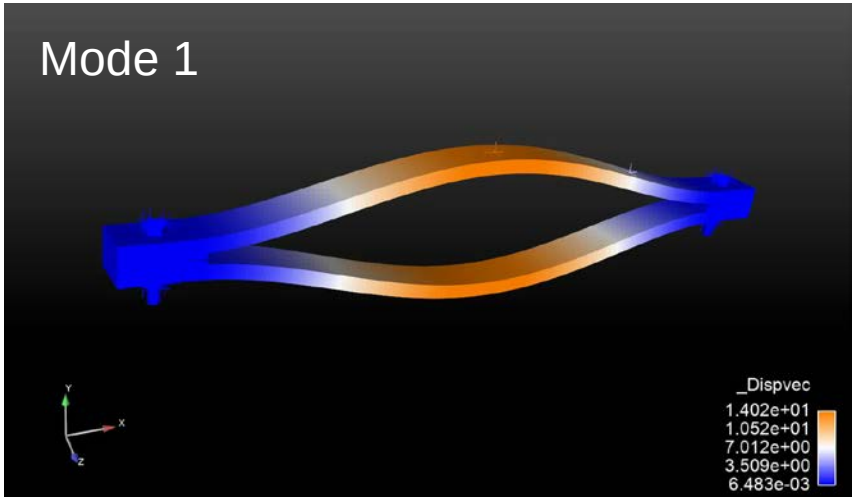
(Pai, Hess 2002)

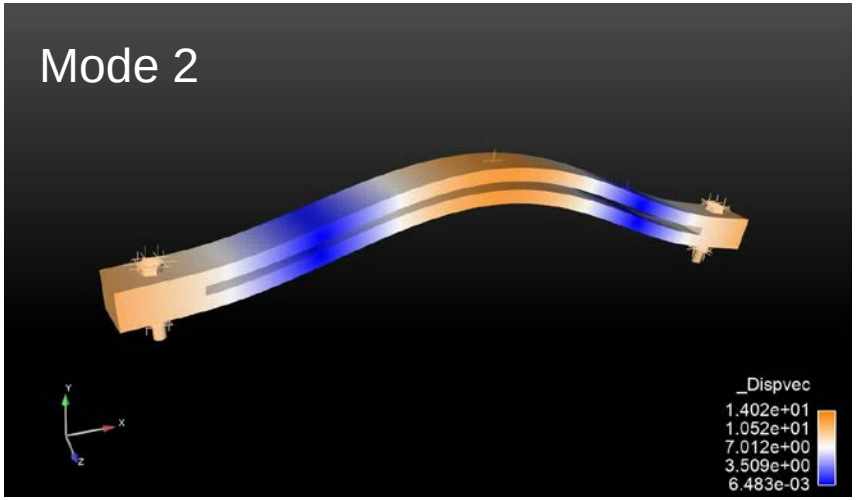


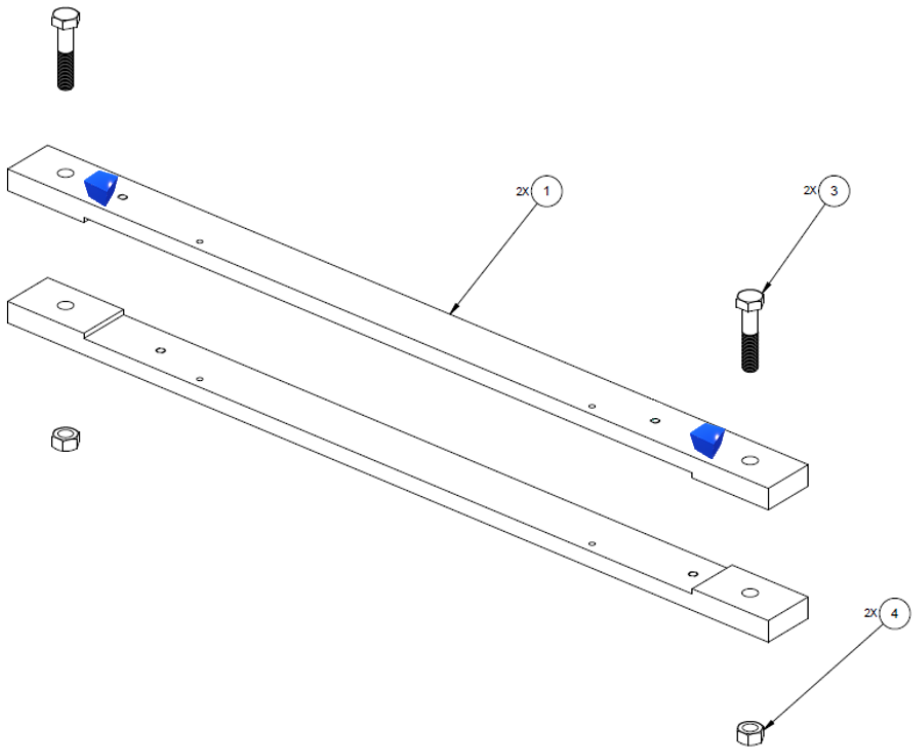
(Zhang 2018)

Project Overview

Observe bolt loosening due to loss of preload through modal excitation.

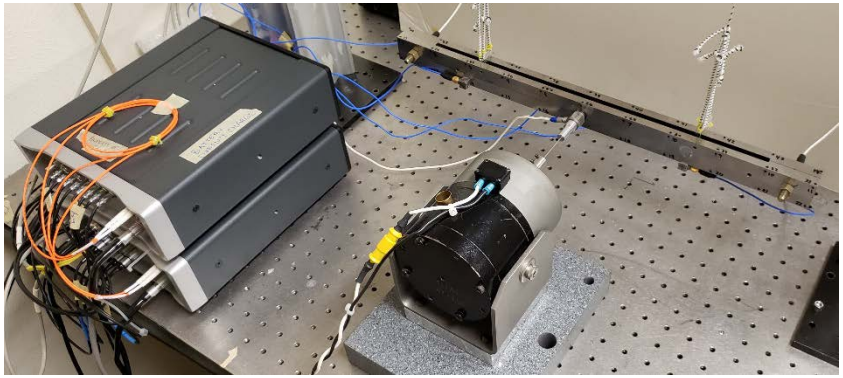


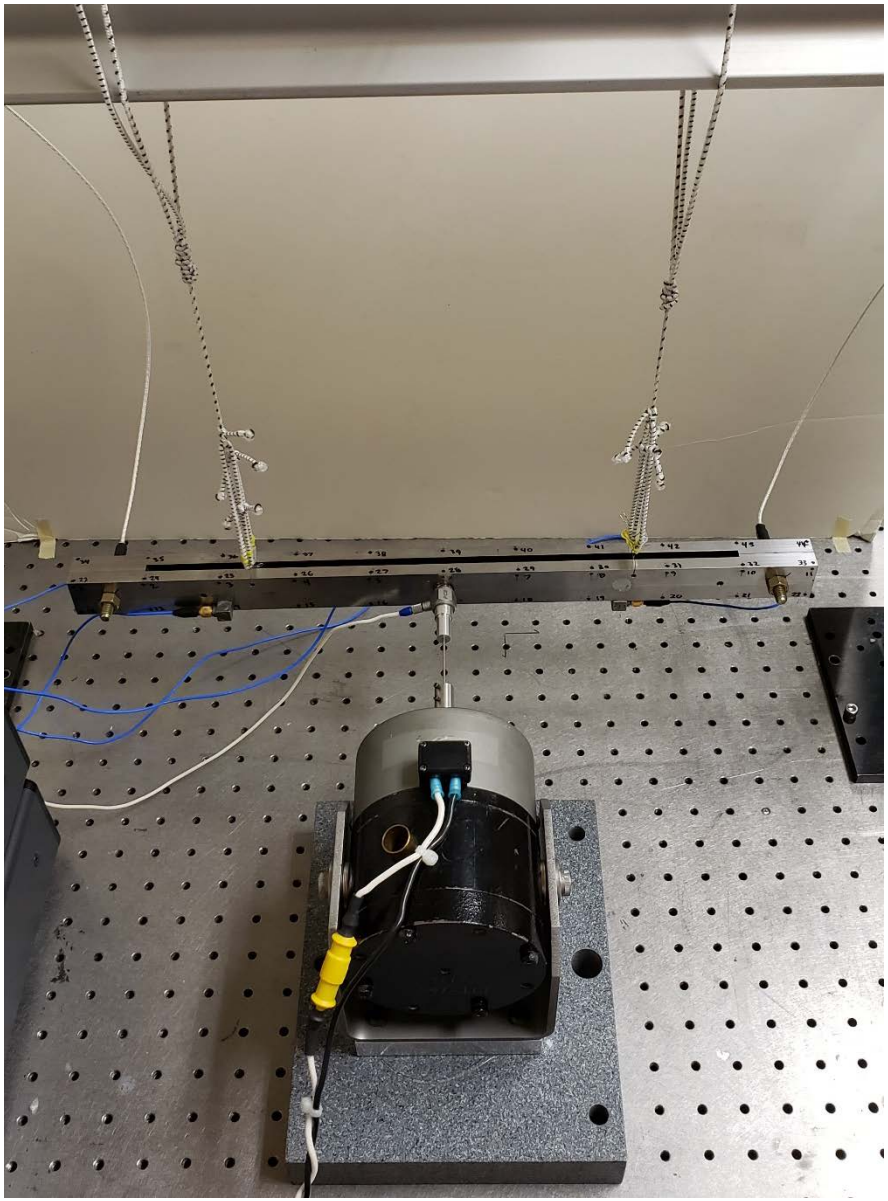




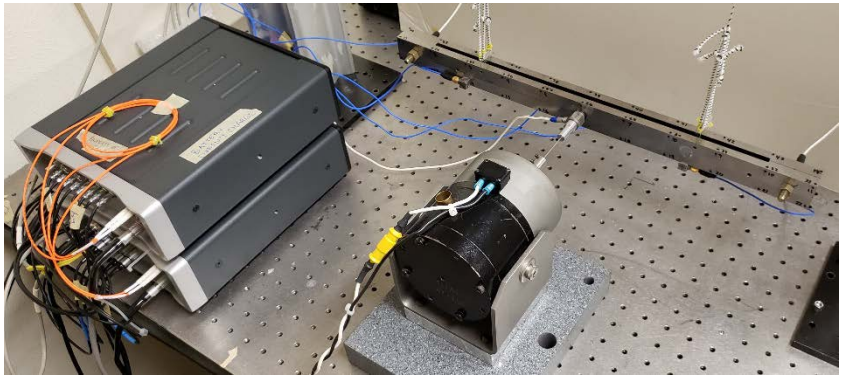
Project Goal

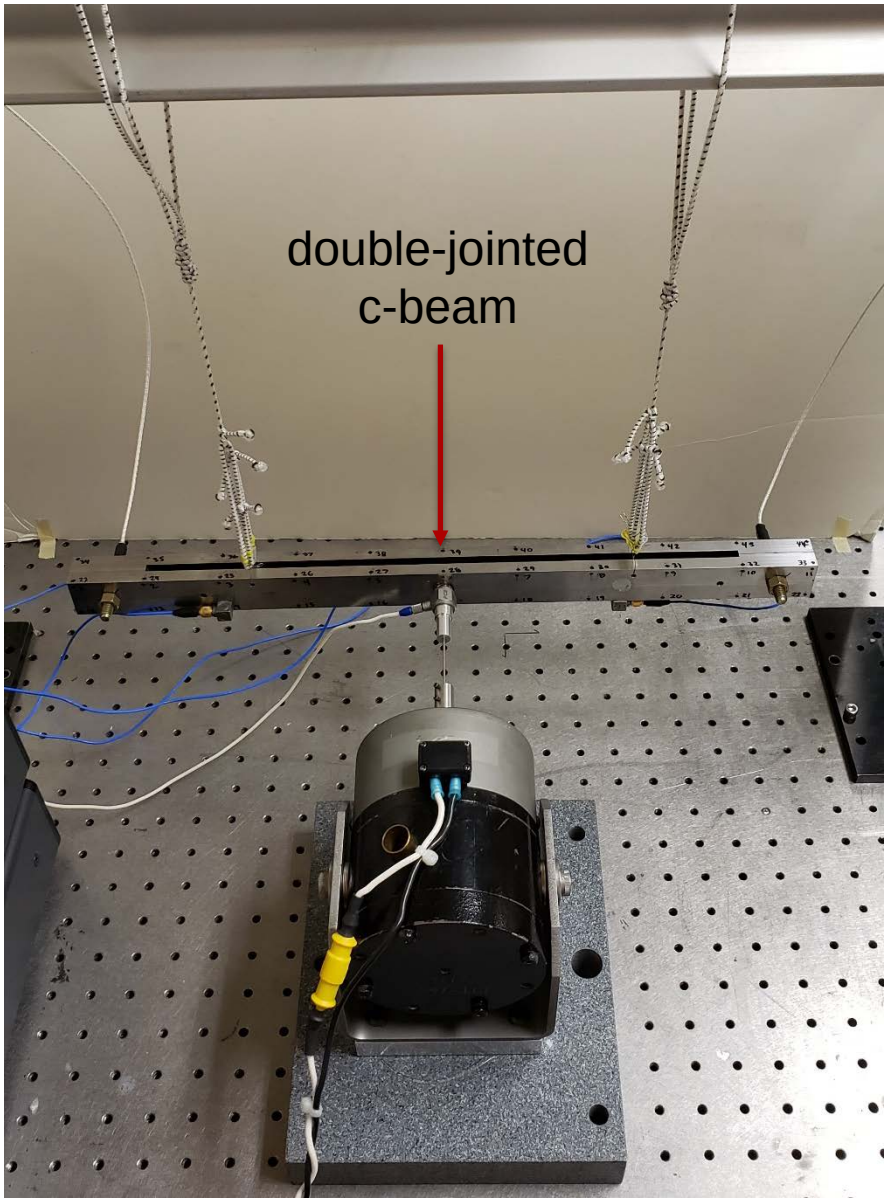
Experimental Setup





Experimental Setup





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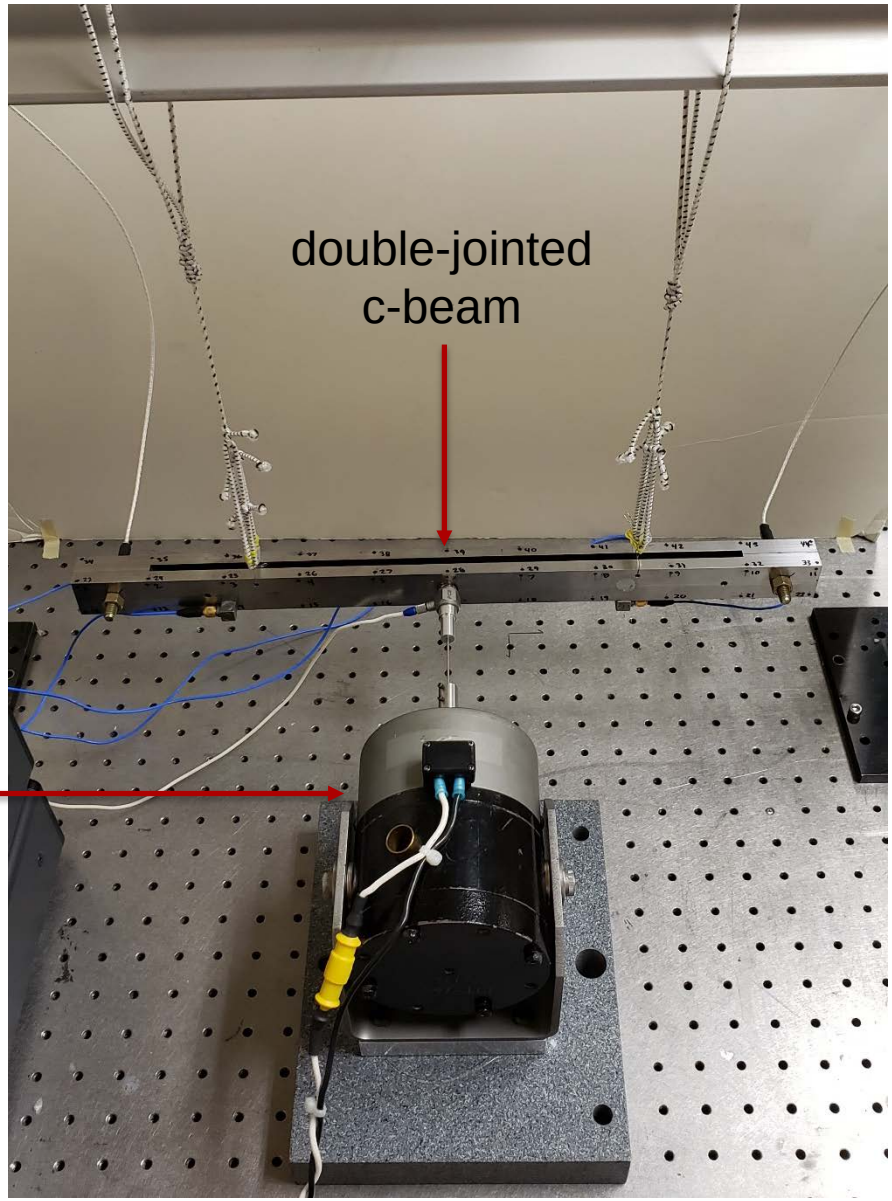
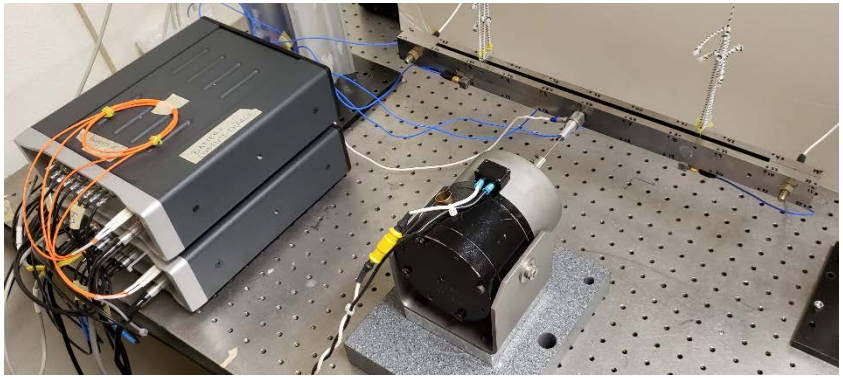
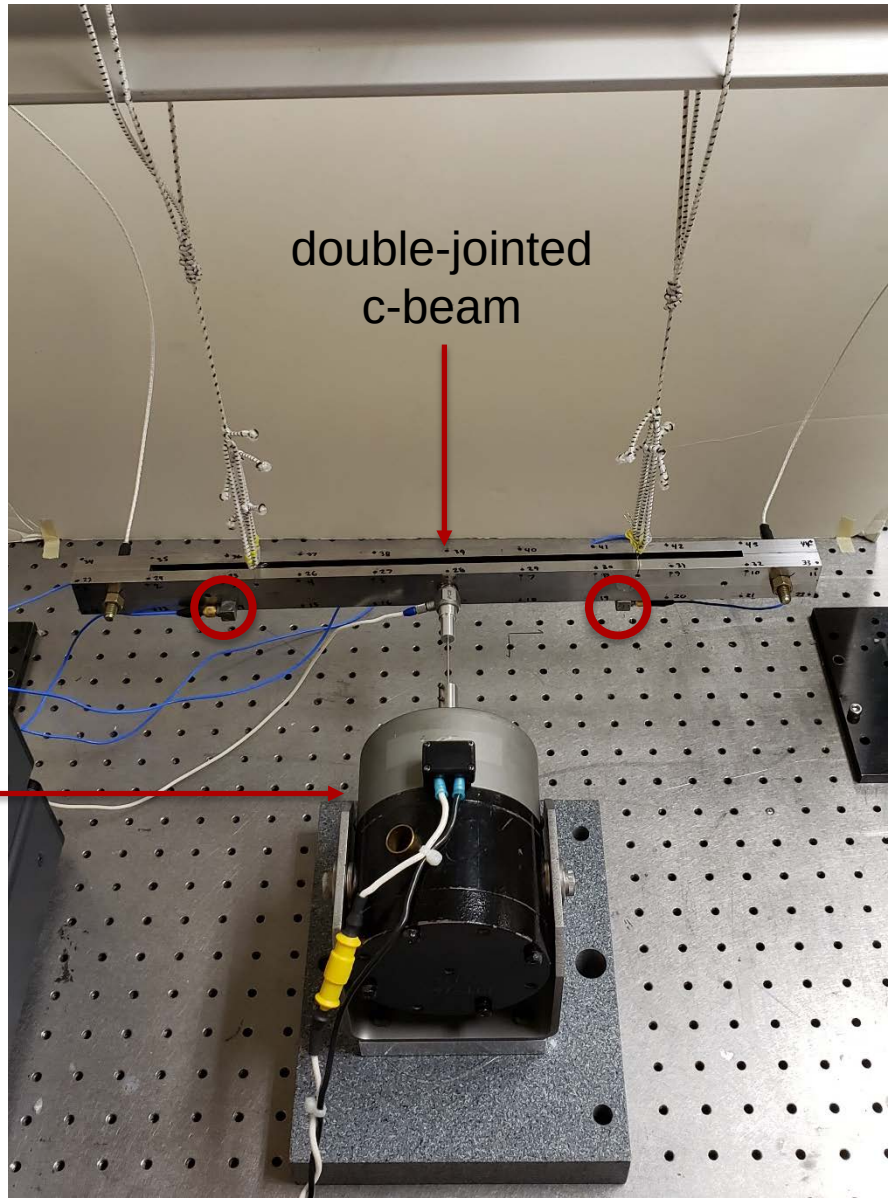
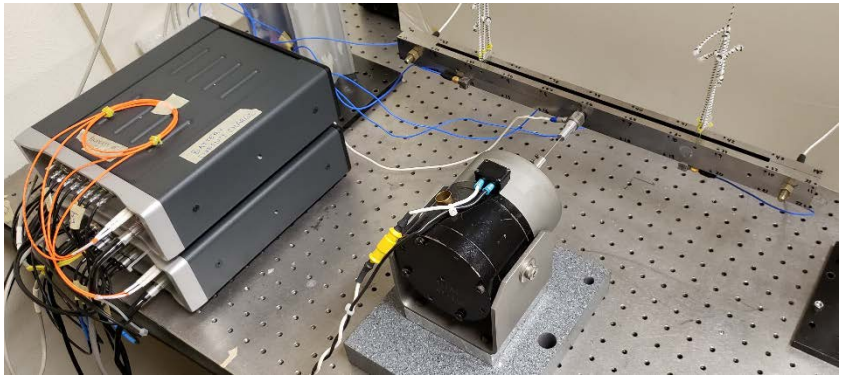




Experimental Setup





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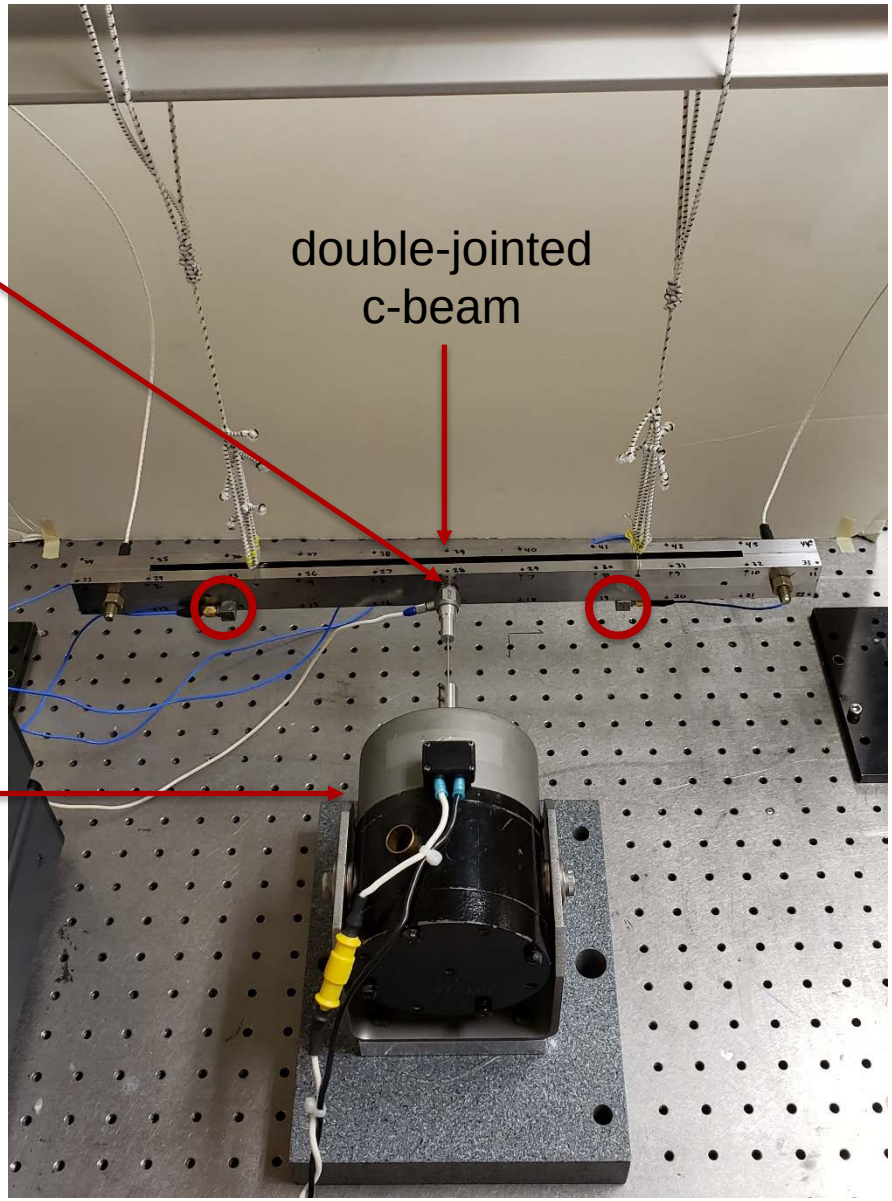
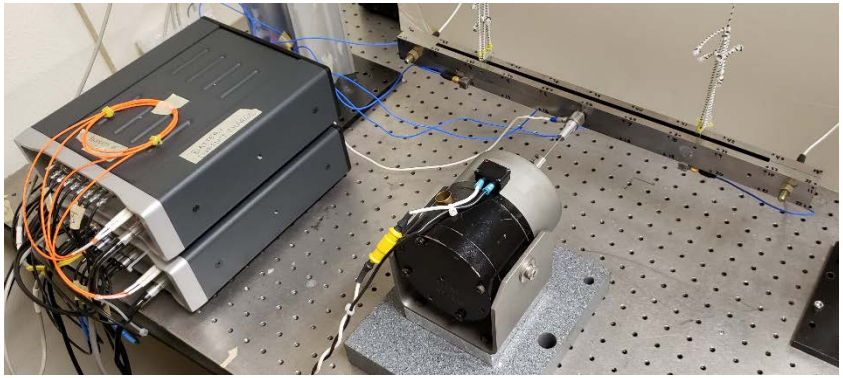
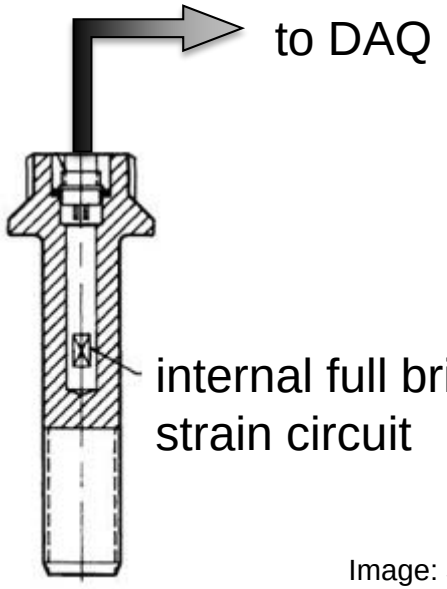




Experimental Setup



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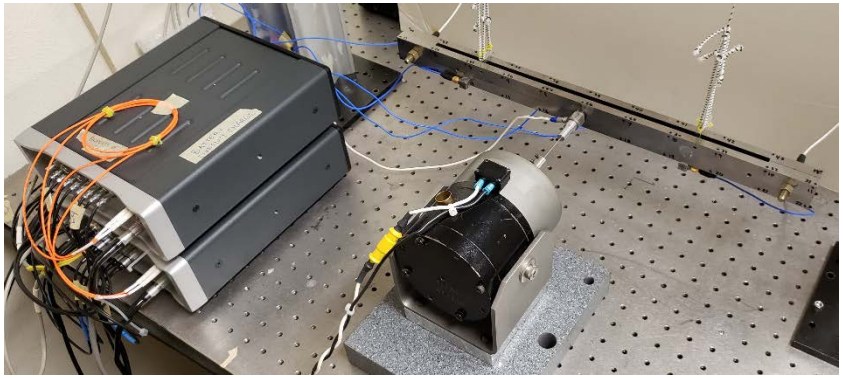

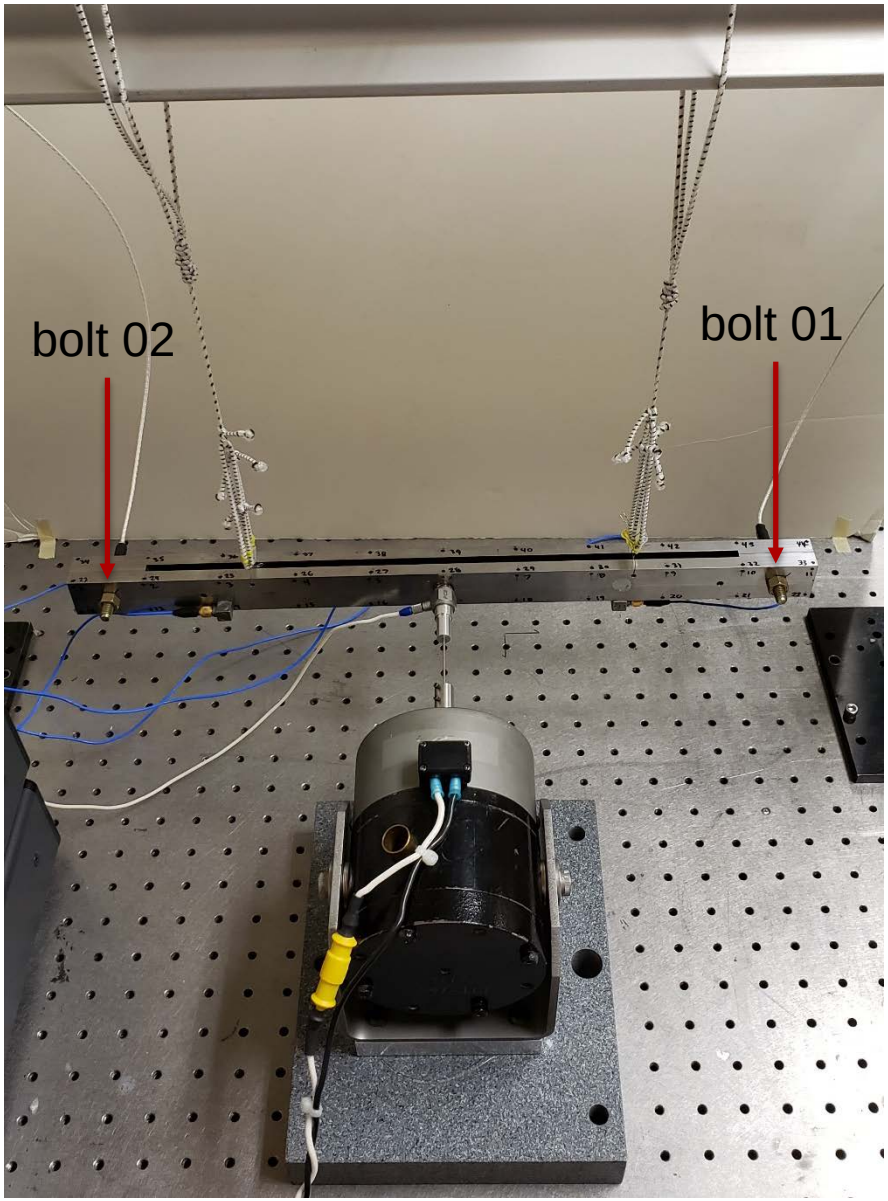

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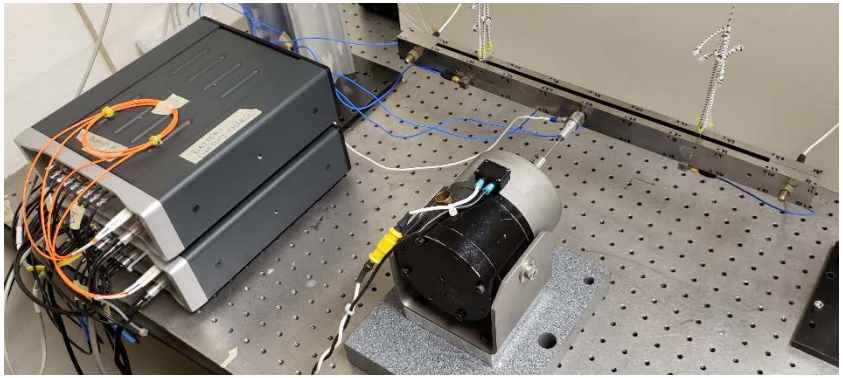
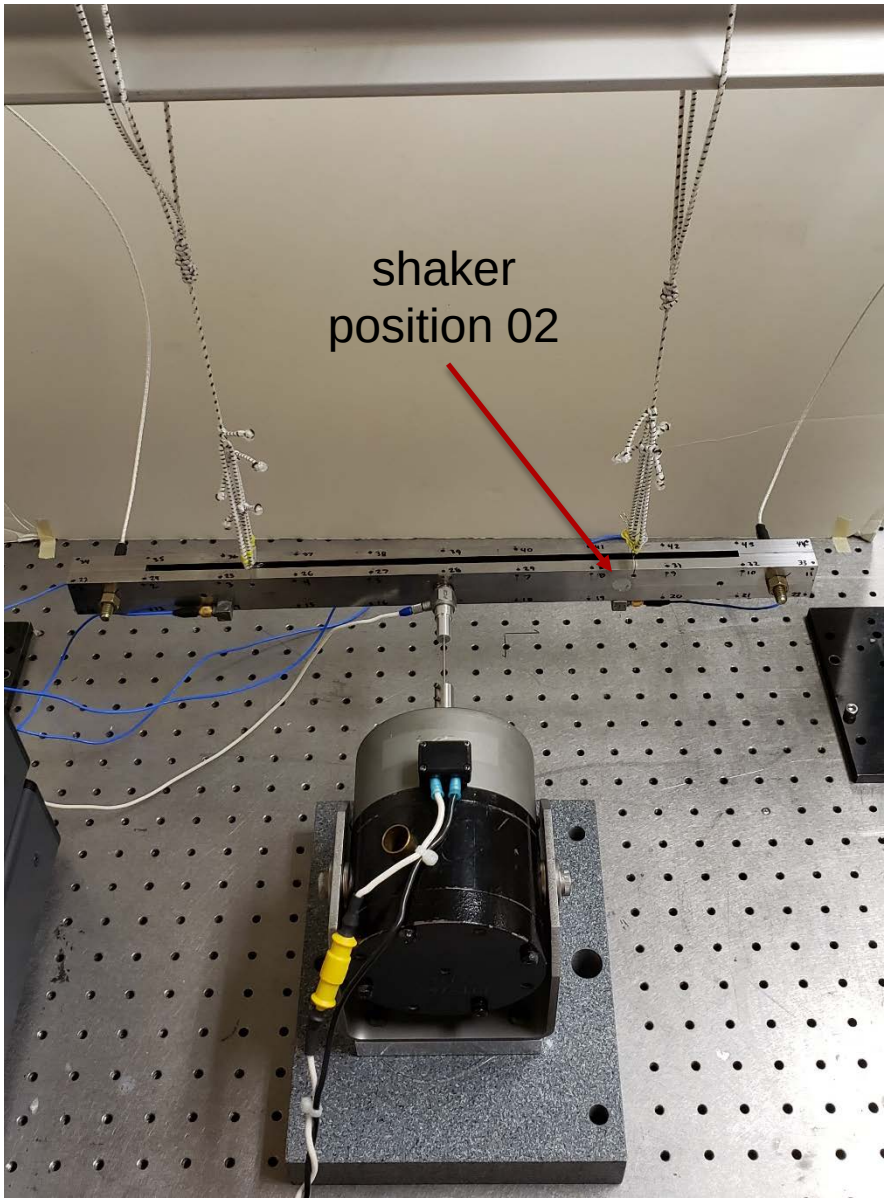
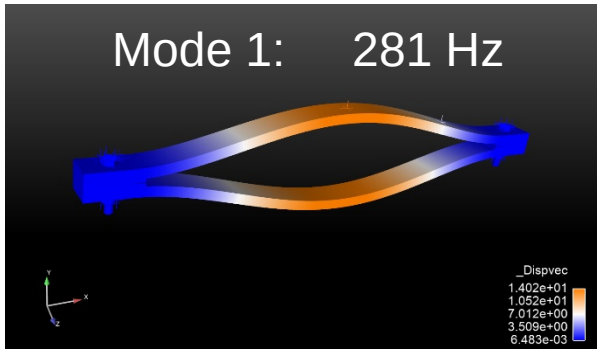
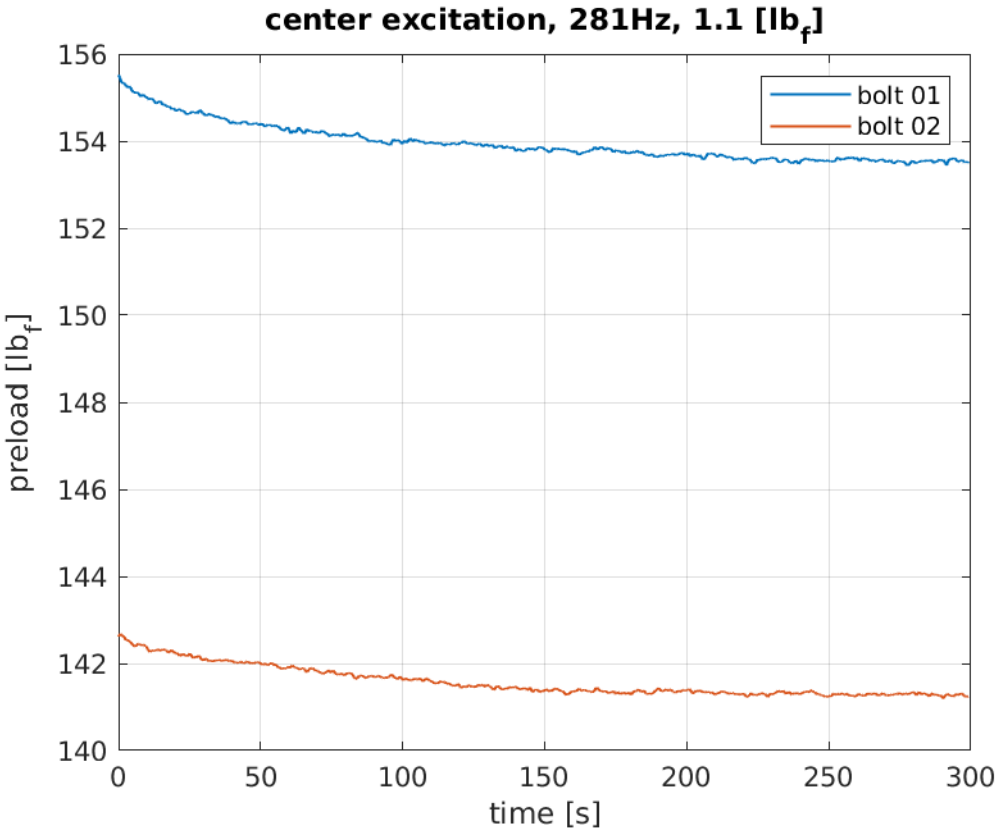


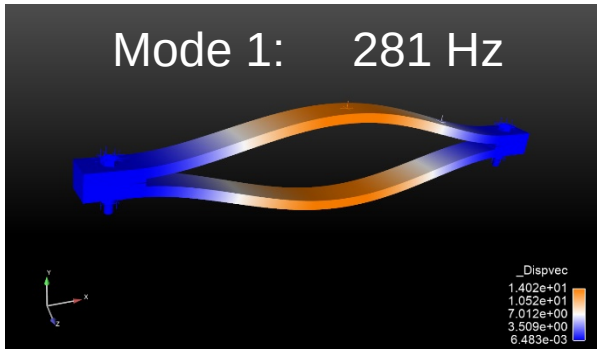


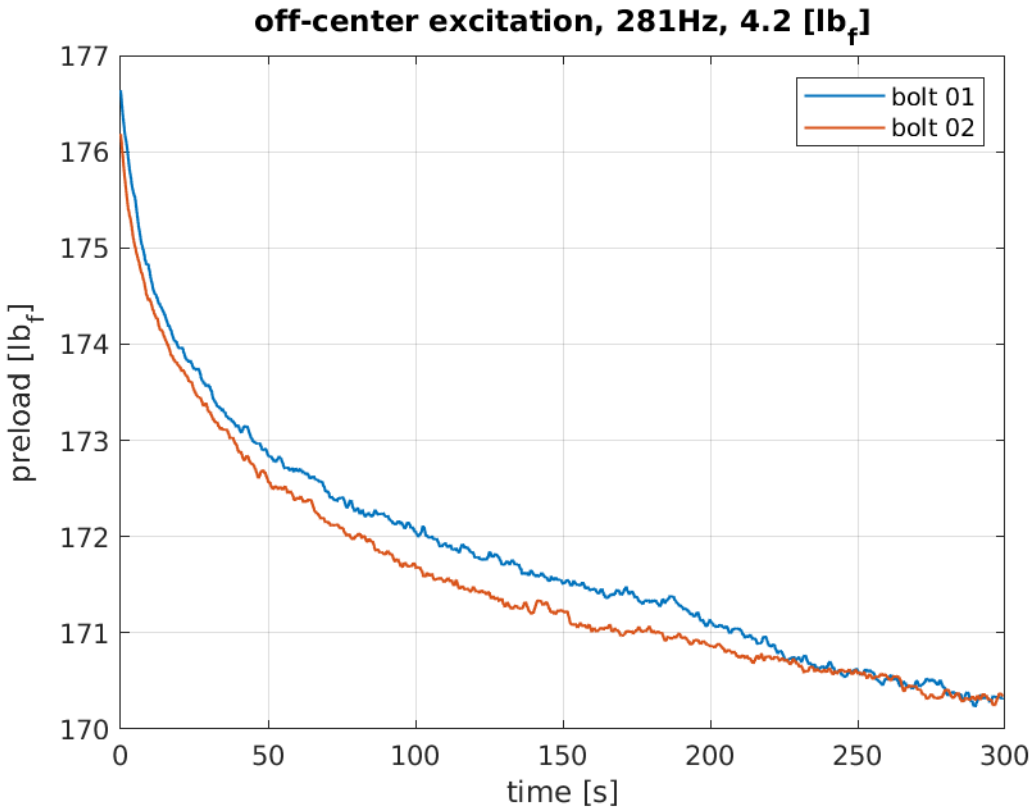
Experimental Results





Experimental Results





Experimental Results

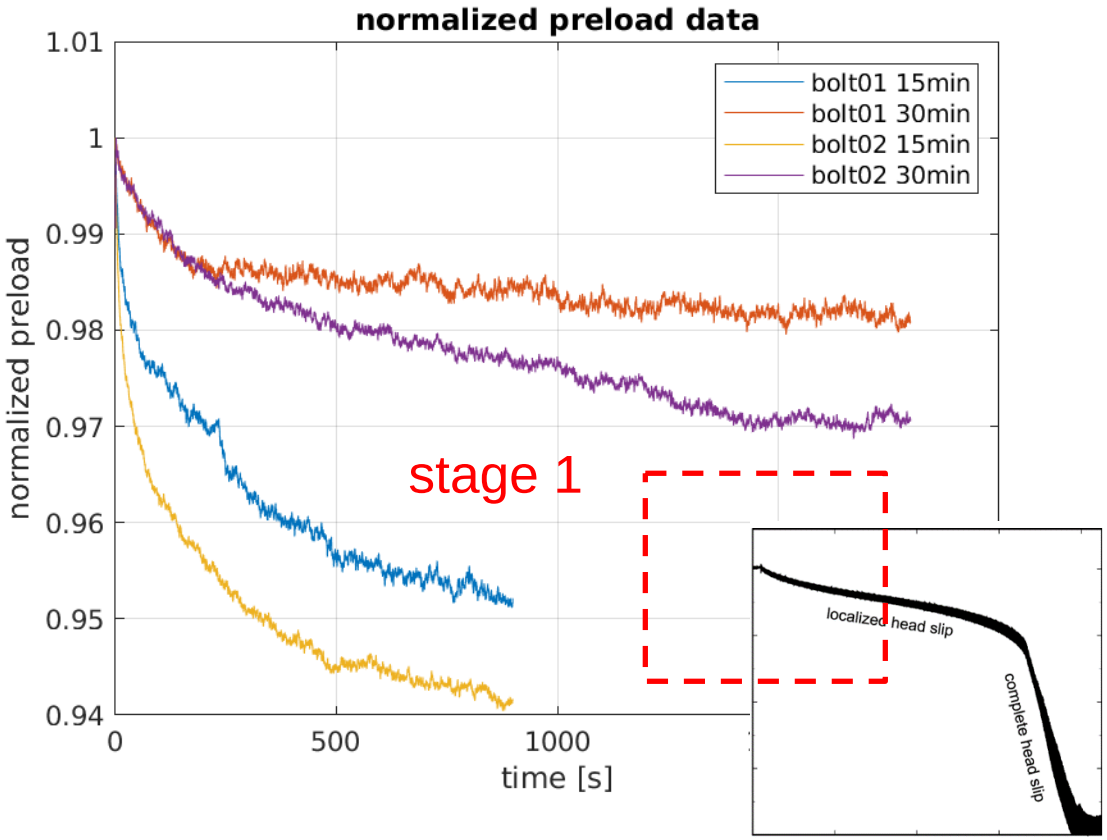


Image: https://www.youtube.com/watch?v=Jq38Oe6lMEg

Discussion, Resonance Dwell

$$\underline{F} = \mathrm{j}\omega m\underline{v} + c\underline{v} + \frac{k\underline{v}}{j\omega}$$

$$\underline{Z}_{mech} = \frac{\underline{F}}{\underline{v}} = j\omega m + c + \frac{k}{j\omega}$$

$\omega = \omega_r$

$$\overline{P}_{in} = F_{rms}v_{rms} = c(v_{rms})^2$$

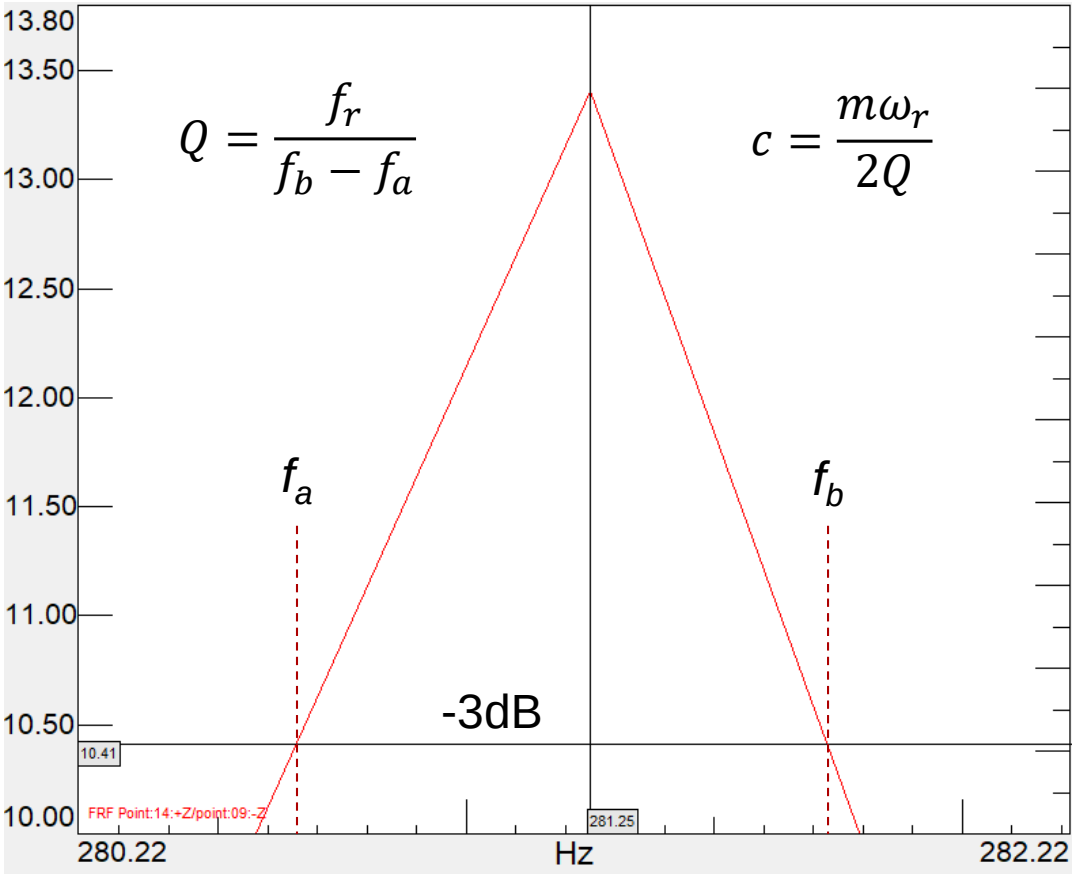
$\omega = \omega_r$

Measured / calculated

$$F_{rms}v_{rms} = 0.37\ W$$

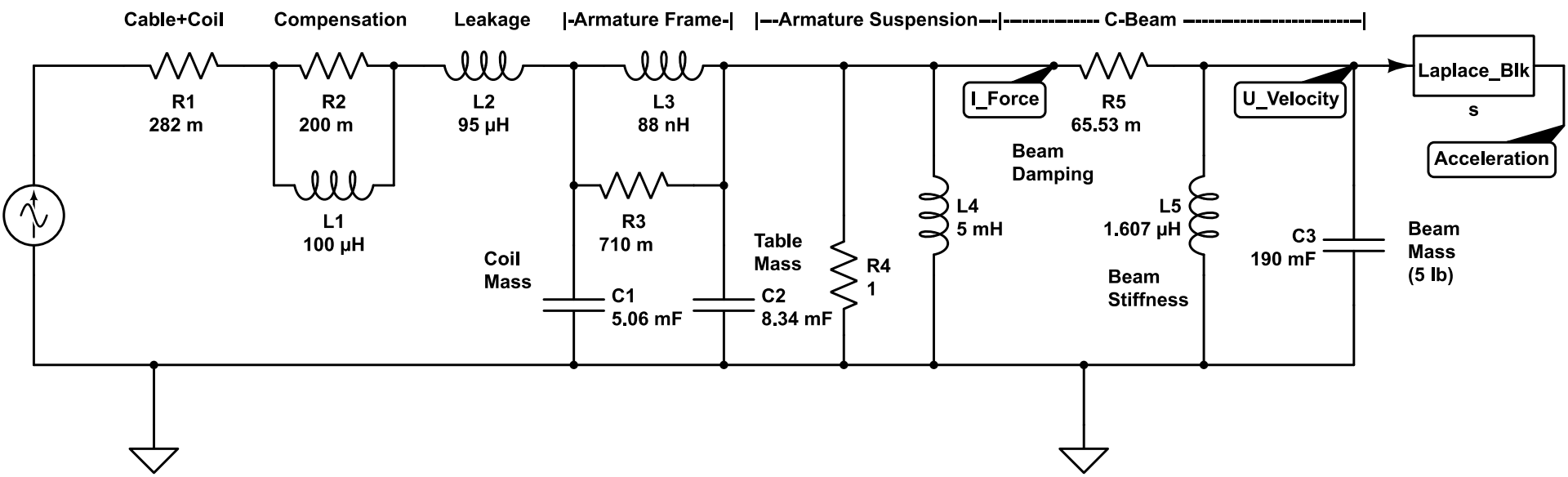
$$c(v_{rms})^2 = 0.36\ W$$

Real Active Power



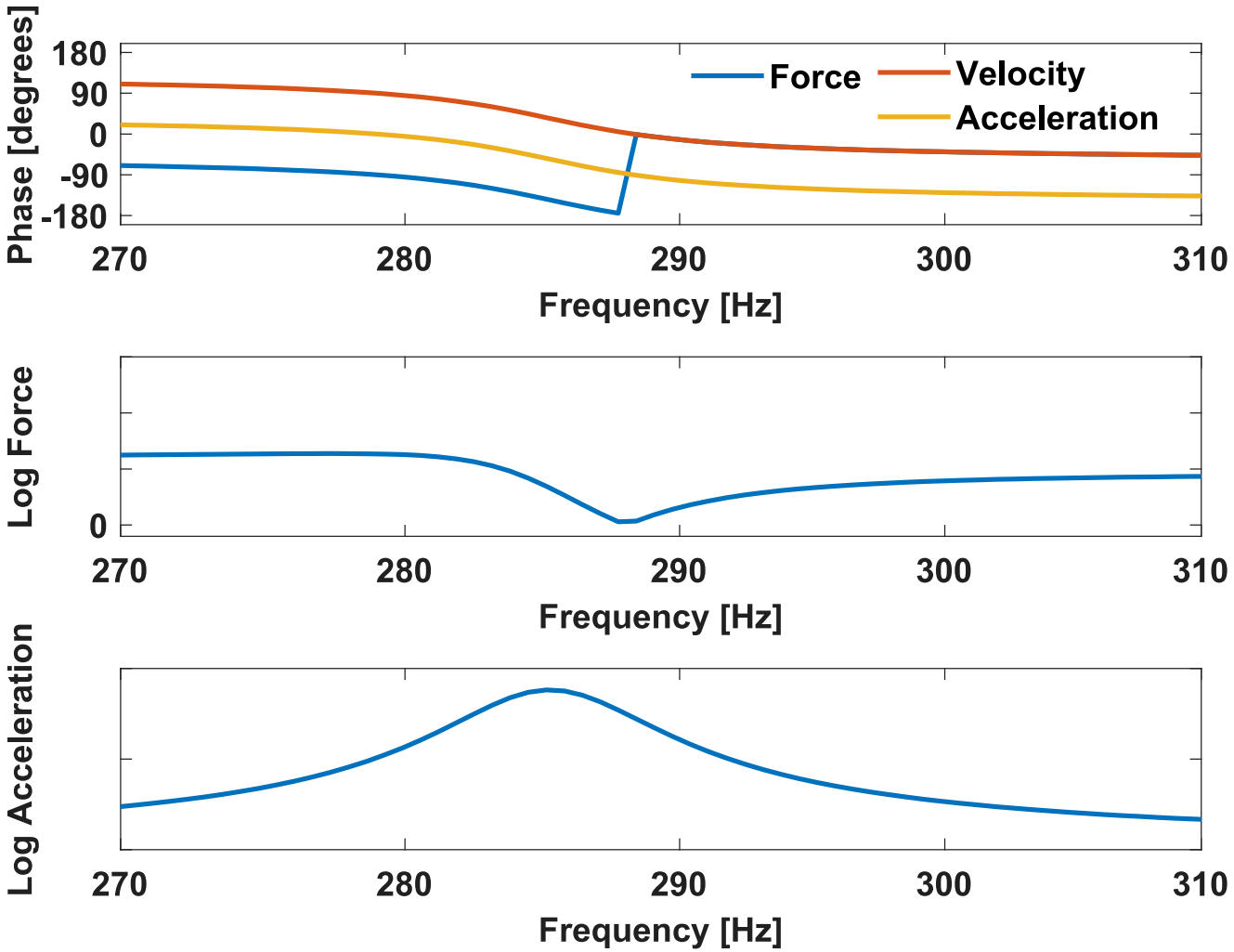
f_r = 281 Hz , 170 lbf Preload

Discussion, Simulated System

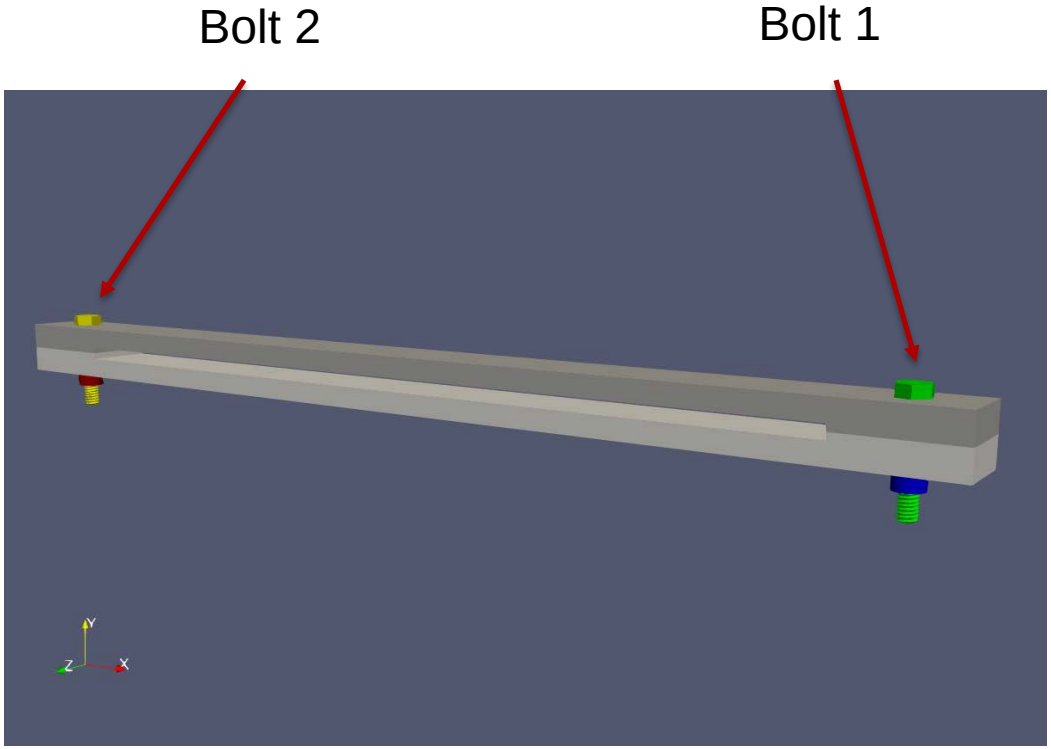


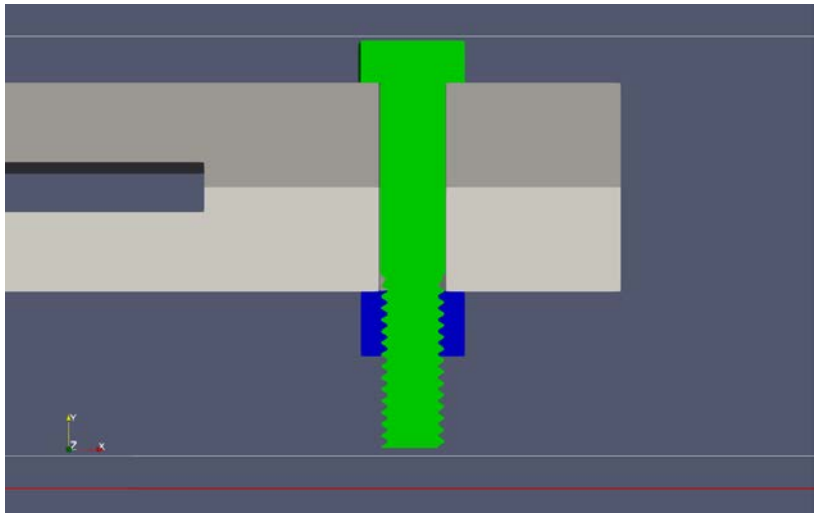
*Adapted from Lab Works Inc. schematic

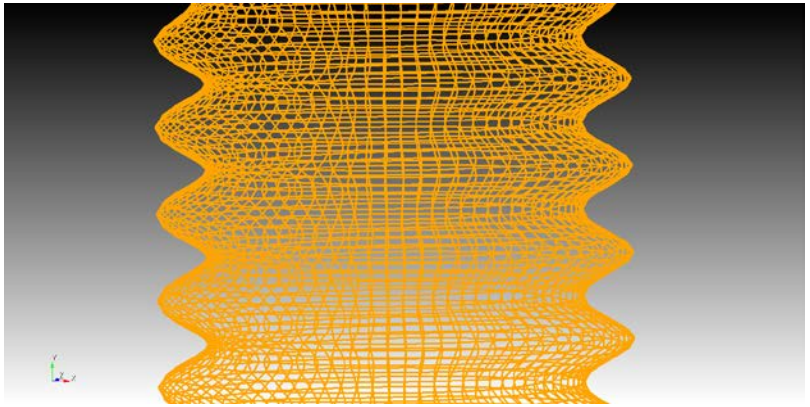
Discussion, Simulated System



FEA Setup – Model







Total # Elements:
~800,000 hex elements

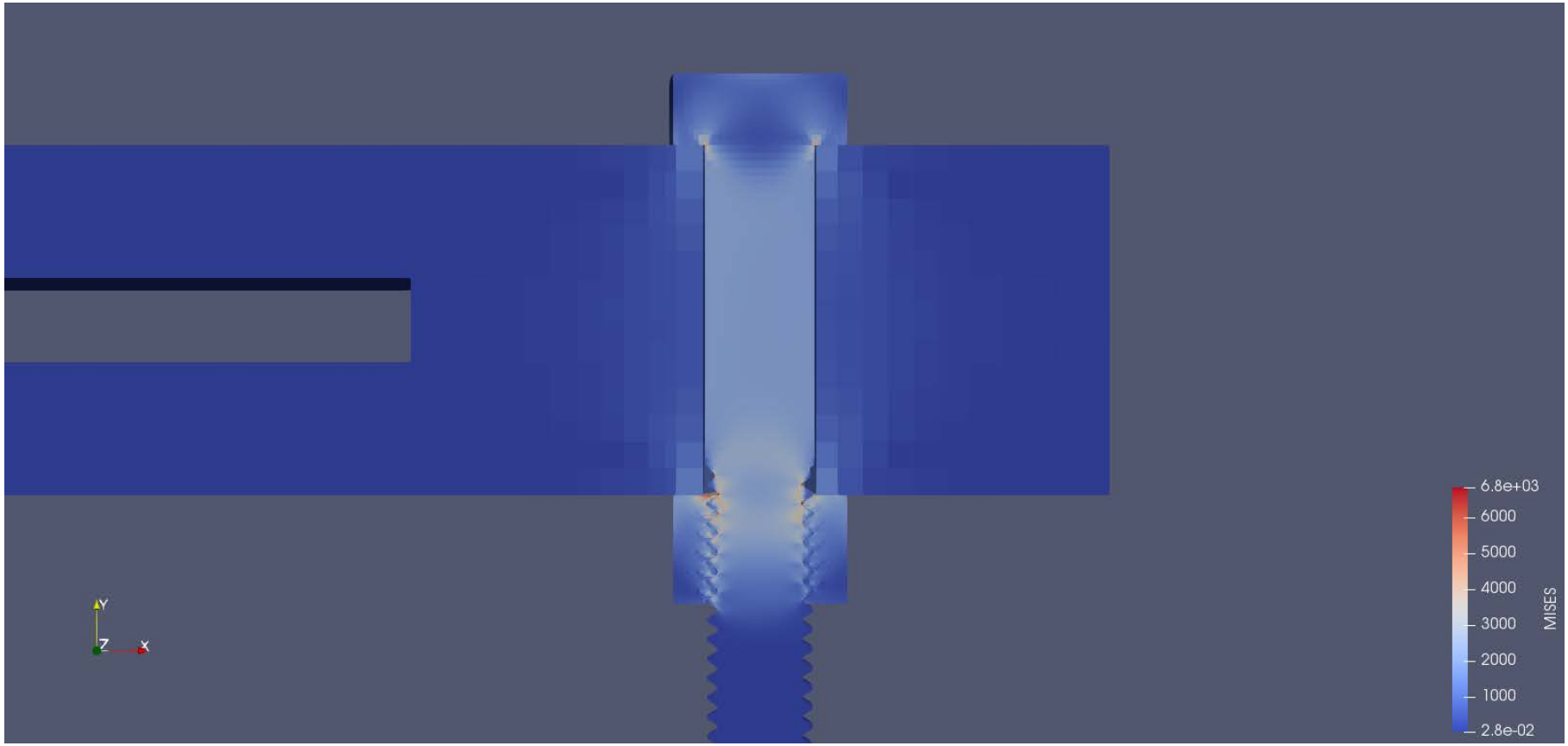
FEA Setup – Key Features

- Preload: 30 – 2400 lb
- Shaker Force: 25 lb
- Mode Frequencies:
  - Mode 1: 241-288 Hz
  - Mode 2: 321-350 Hz
- Material Model: Elastic-plastic
- Stick-slip friction model
  - $\mu_s = 0.6$
  - $\mu_k = 0.2$

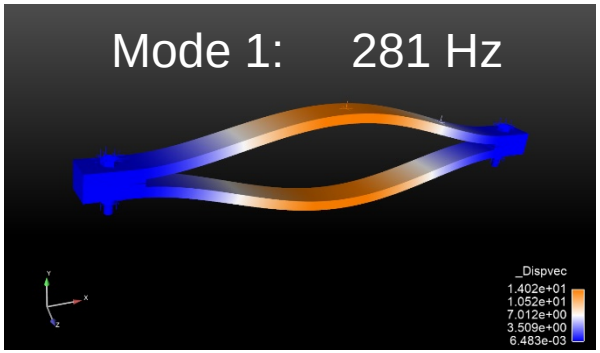
- SIERRA Step 1: Preload via nut rotation
- SIERRA Step 2: Sine force input at mode frequency

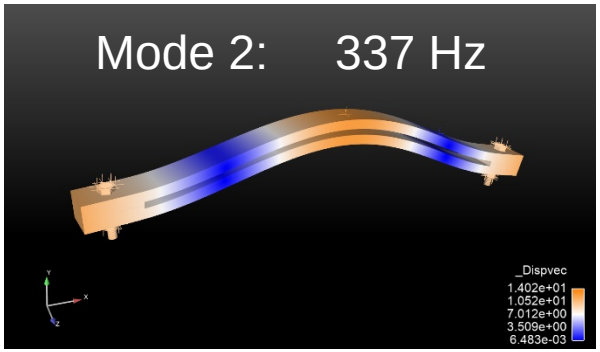
SIERRA Step 1 – Fastener Stress

150 lb Preload

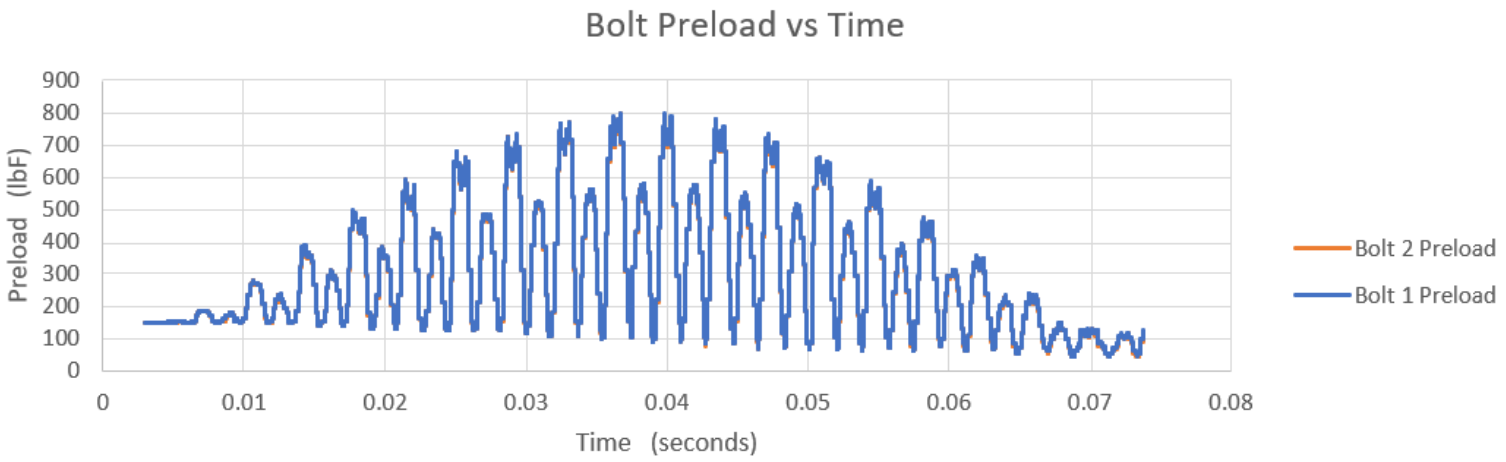


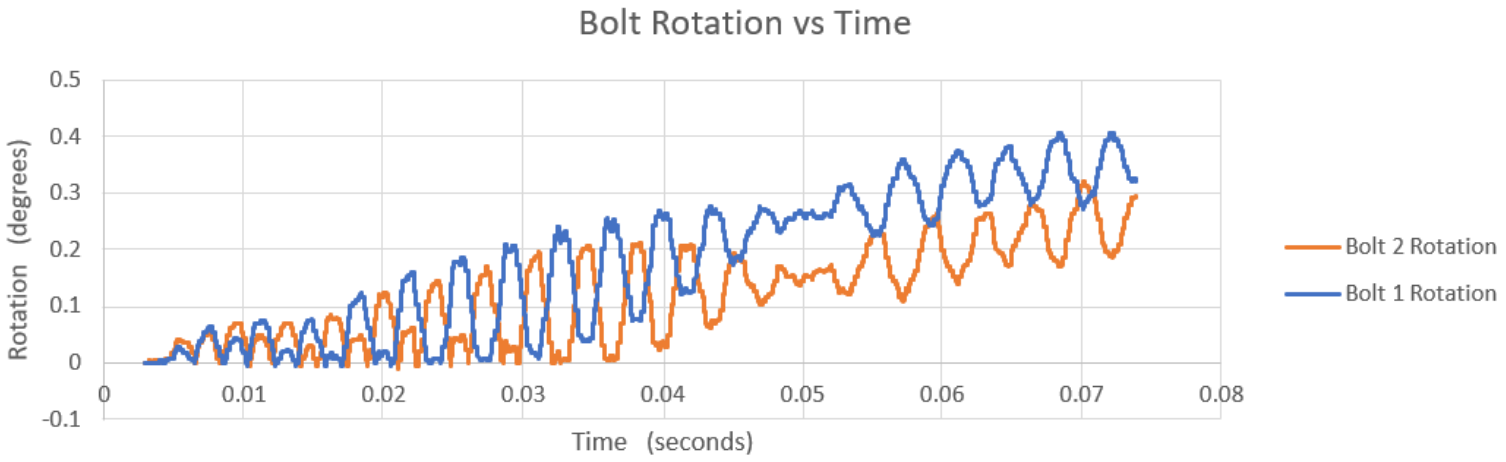
SIERRA Step 2 – 150lb Preload



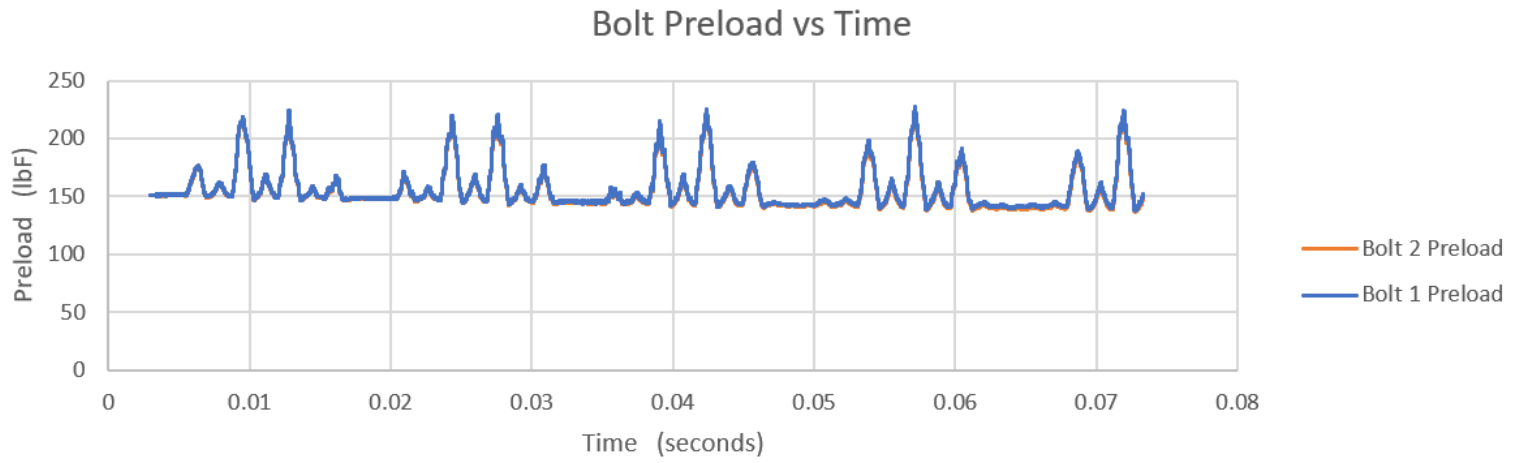


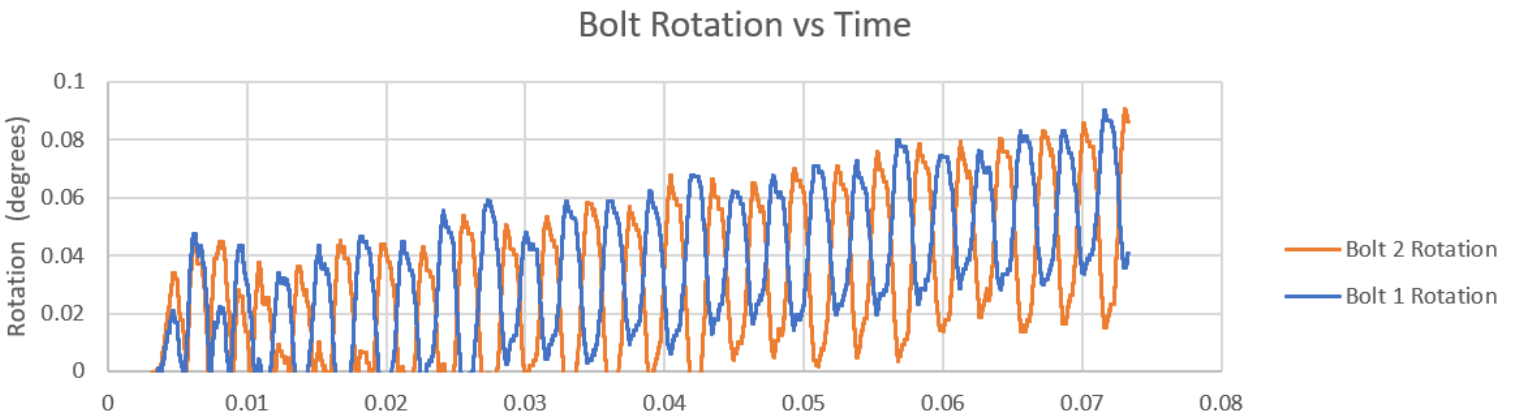
SIERRA Step 2 – 150lb Preload





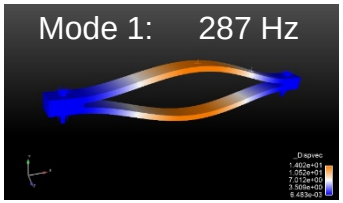
SIERRA Step 2 – 150lb Preload

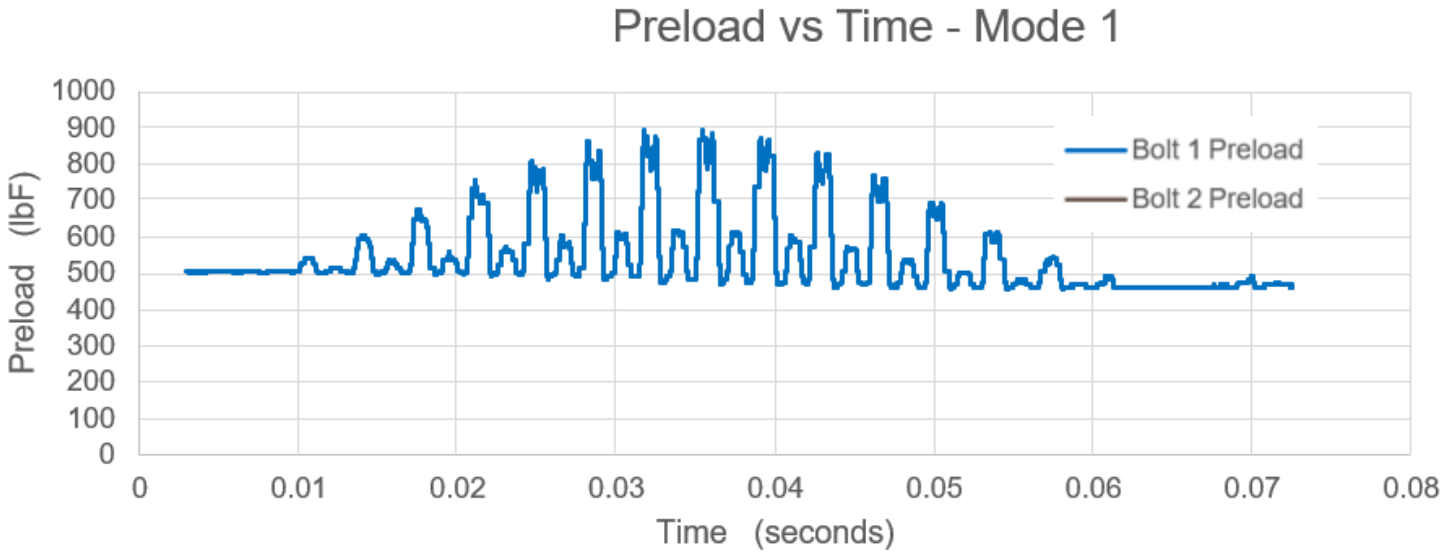


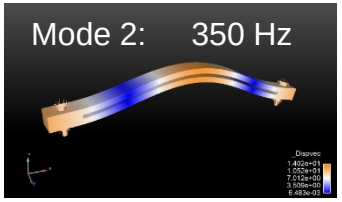


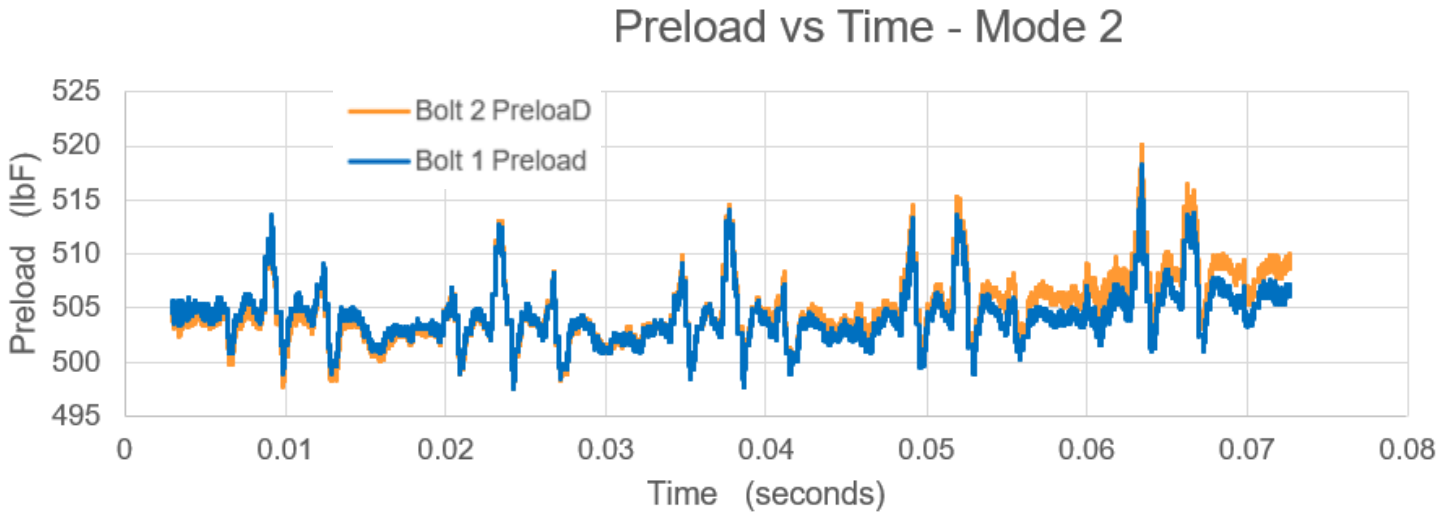
Contact Stress – 150lb Preload

SIERRA Step 2 – 500lb Preload

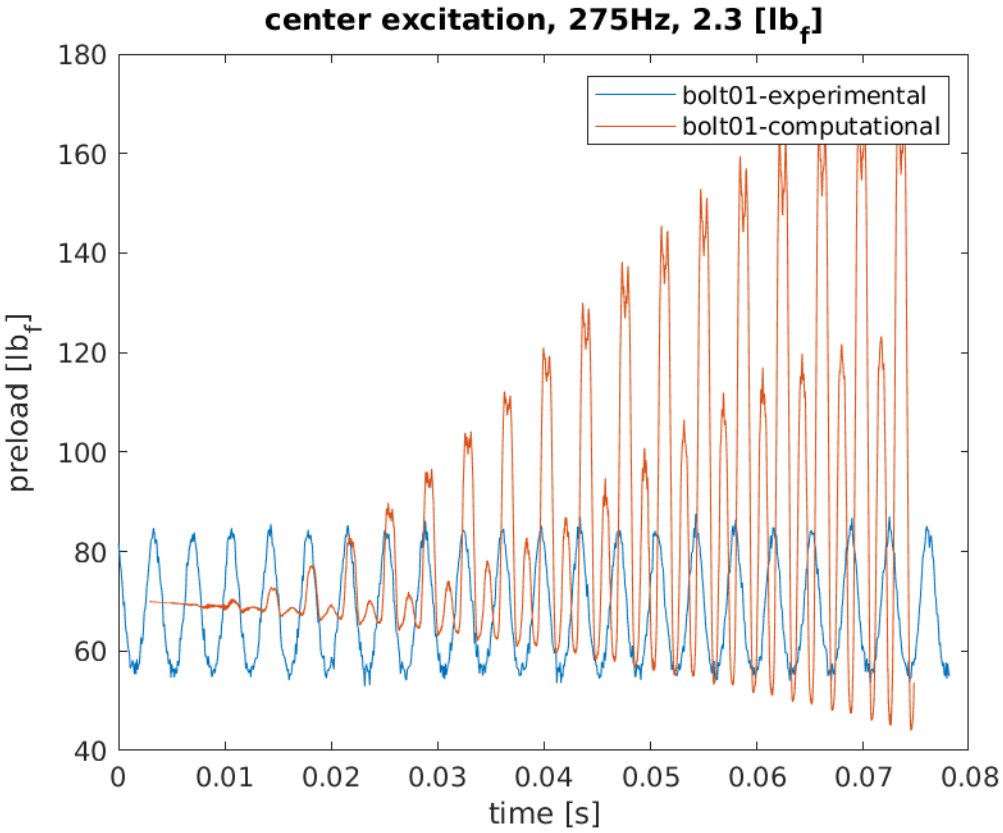








Experiment vs Computational



Conclusions

- Observed self-loosening through harmonic excitation
  - Stage I experimentally
  - Stage II computationally
- Mismatch in experimental/computational behavior
  - Experimental limitations
  - Computational model

Future Work

- Things to try:
  - more realistic preloads (50-80% σ_y)
  - simplified structure
- Comparison with reduced order models
- Other metrics of loosening

Acknowledgements

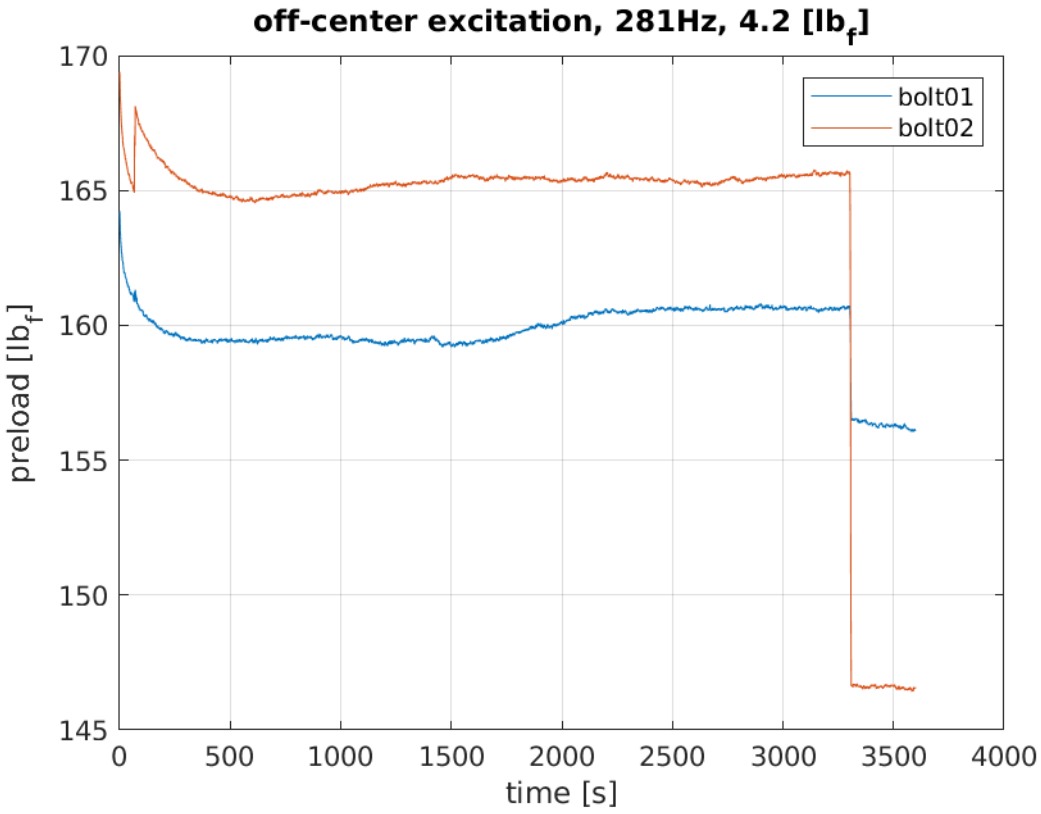
- This research was conducted at the 2019 Nonlinear Mechanics and Dynamics Research Institute supported by Sandia National Laboratories and hosted by the University of New Mexico.

- Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

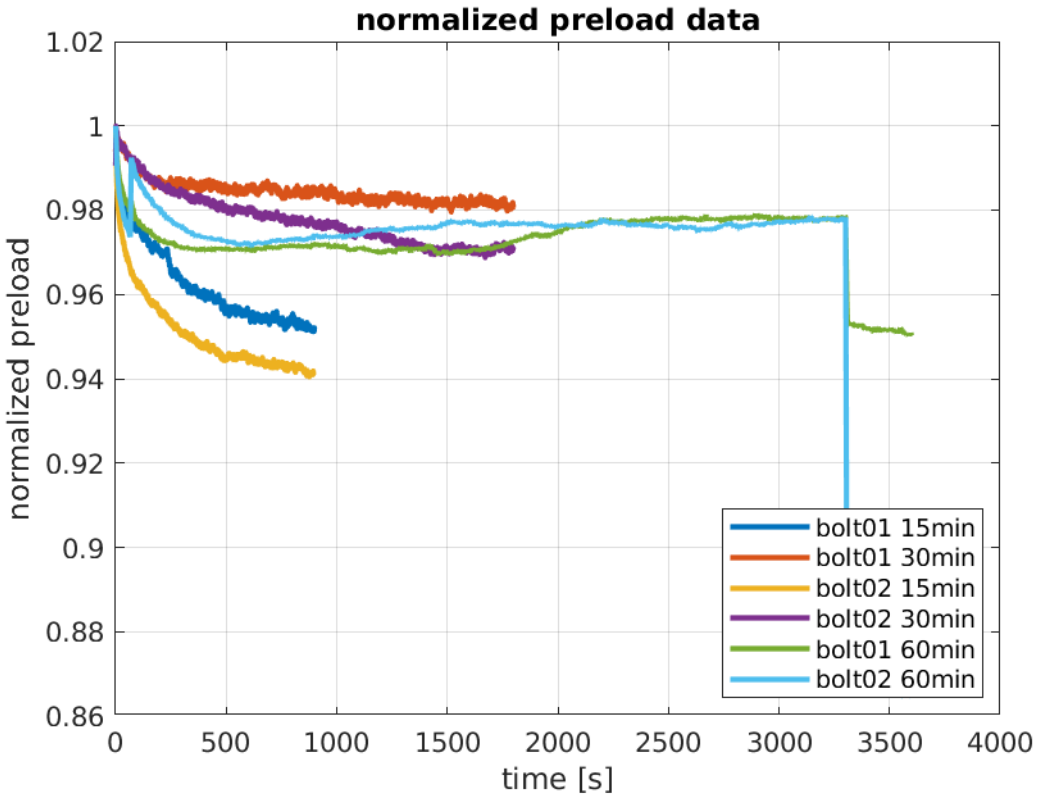
Thank you!

Questions?

Experimental Results



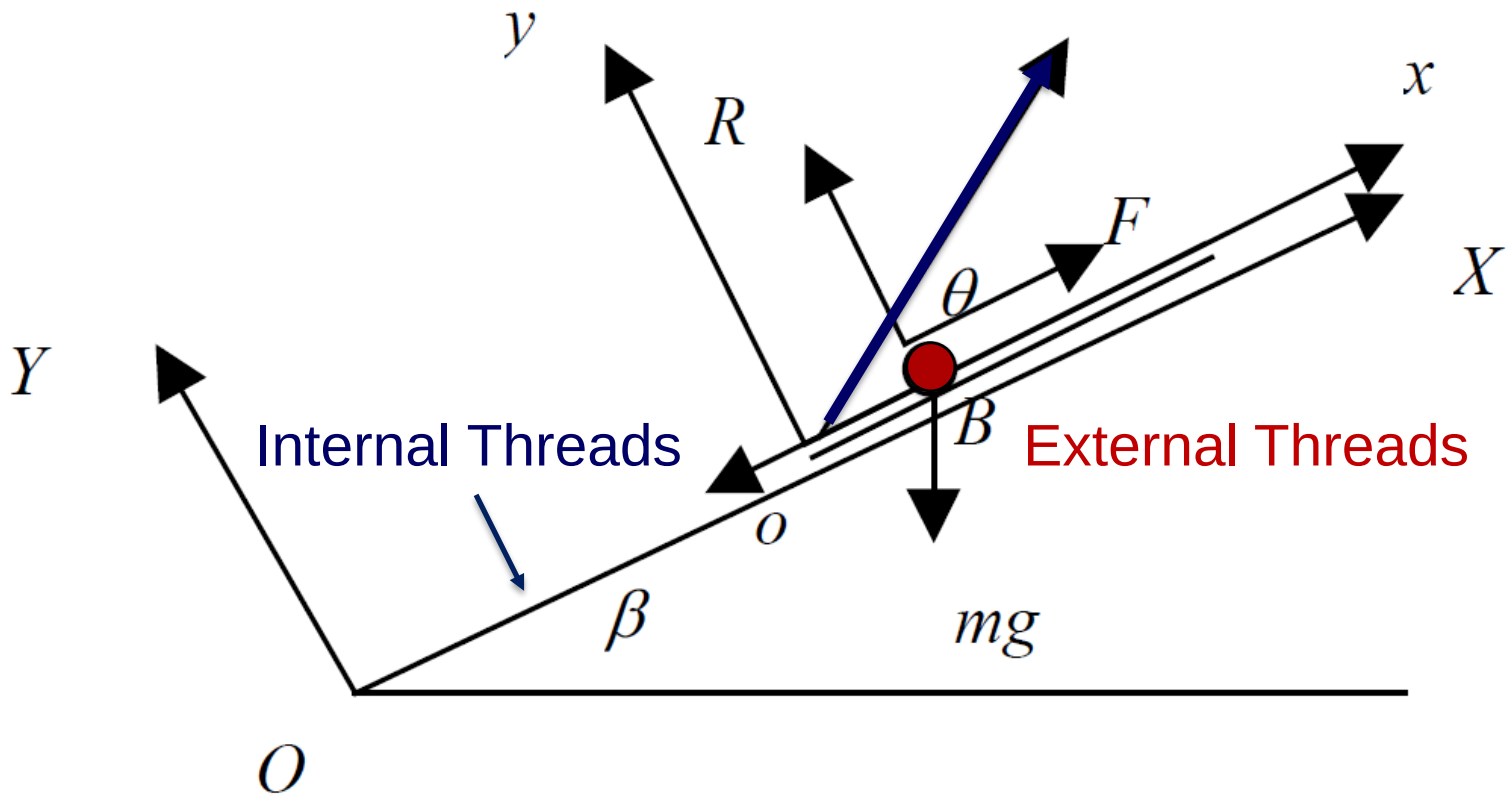
Experimental Results



Project Overview

vibratory conveyor

forces on joint
(preload, shear, axial, etc…)



(Fernando 2005)