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Energy Dissipation of a System with Foam to Metal Interfaces

IMAC XXXIV

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Outline

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  - Effects of Snugness of Fit
- Numerical Results
  - Computational Model
  - Comparison Between Model and Experiments
- Conclusions

Motivations

- Electronic and electromechanical components are packaged in foam to prevent excessive vibration amplitudes during transportation and operation
- This packaging leads to foam/metal interfaces, which have long been recognized as significant contributors to energy dissipation
- The mechanisms for energy dissipation in these systems include friction, impacts and the large material damping common in most foams
- Need to be able to model and understand how systems containing foam to metal interfaces will respond to various vibration environments

Motivation

- it is important to understand the energy dissipation mechanisms and their effect on the dynamics
- Currently, modeling capabilities to capture the dissipative behavior of metal parts in foam are being developed
- Physical experiments are crucial to validate models and gain an understanding of the physical phenomena required for modeling

Objective

- Through a collaboration of experimental and modeling work conducted on a given test article investigate:
  - The physics through experimentation and computational modeling on a relatively simple geometry
  - The influence of several different parameters, including: amplitude of excitation, snugness of fit, load path, and sequence of testing
  - If a simplified model can capture the salient nonlinear behavior

Test Equipment – Single Axis

- Shaker System: Unholtz-Dickie T2000
  - Sequential excitation of X, Y, and Z axes
  - To test different axes an adapter cube is required

Specifications	
Test Frequency Range	10 – 3,000 Hz
Max Displacement	1.0 in
Force Rating - Random	107 kN-rms
Force Rating - Sine	111 kN-peak

- Controller Software: Spectral Dynamics JAGUAR Shaker Control and Analysis System
- Data Acquisition: National Instruments™ LabVIEW and NI PXIe-4496 Data Acquisition Modules

Specimen Details

- The specimen consists of:
  - a solid aluminum mass
  - foam cups
  - an aluminum can
- A preload is applied to the specimen:
  - through the steel disk on the top of the foam cups using a press
  - A threaded steel ring is tightened to secure the preload

Specimen Details

- Aluminum Can
  - has an inner diameter of 10cm, an outer diameter of 12.7cm and a depth of 15.2cm
  - welded to a square plate that has nine bolt holes
  - has a recess in the bottom to accommodate a uniaxial accelerometer to control the input acceleration
- Solid Mass
  - Three solid masses of different diameters are used
    - no gap specimen has a diameter of 7.62cm,
    - 1.5875mm gap specimen has a diameter of 7.46cm
    - 3.175mm gap specimen has a diameter of 7.30cm.
  - 10cm in length
  - 6061-T6 Aluminum
  - recessed area in the top that can accommodate a triaxial accelerometer.

Specimen Details

- Foam Specimens
  - made from 320 kilograms per cubic meter closed cell PMDI foam
  - in two parts, a top half which has an access hole for attaching an accelerometer and a bottom half which has a solid bottom
  - cup-like in nature with an outer diameter of 10cm and an inner diameter of 7.62cm
  - bottoms and sides of the cups are 12.7mm thick
  - Two different depths of cups are used in the experiment.
    - one has an interior depth of 5cm, yielding parallel load paths of through the solid mass and through the foam
    - The other were manufactured to have a smaller interior depth of 4.68cm so there would be a 6.35mm gap between the two pieces of foam, thus ensuring a load path through the solid mass even with variations due to machining tolerances.

Test Specifications

- Oriented so that it is being excited in the direction of the load path
- Energy dissipation comes from
  - the foam rubbing against the metal interface
  - the interface between the two sets of foam
- A constant acceleration sine sweep base excitation is run from 500 to 3000Hz at a rate of 3 octaves per minute
- Four different amplitudes, 1g, 2g, 5g and 10g, are used to determine the effects of excitation amplitude on the response of the test article

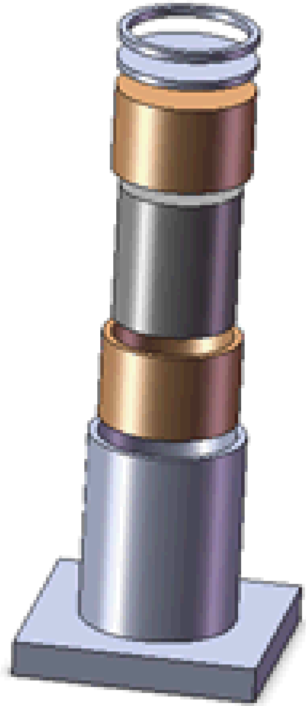
Test Specifications

- A test series was run for all possible combinations
- Between series of tests on each configuration, the setup was disassembled and then reassembled
- The sequence of tests was repeated to determine if vibrating the specimen changed the dynamic characteristic
- The final test assembly 3 was run to see if the order in which the amplitudes were applied affected the dynamics

Assembly Number	Sweep Series Amplitudes
1	1g, 2g, 5g, 10g, 1g, 2g, 5g, 10g
2	1g, 2g, 5g, 10g, 1g, 2g, 5g, 10g
3	10g, 2g, 5g, 1g, 10g, 5g, 2g, 1g

Data Collection

- A triaxial accelerometer measures data at the top of the solid mass
- A uniaxial accelerometer attached to the baseplate is used to control the input to the structure



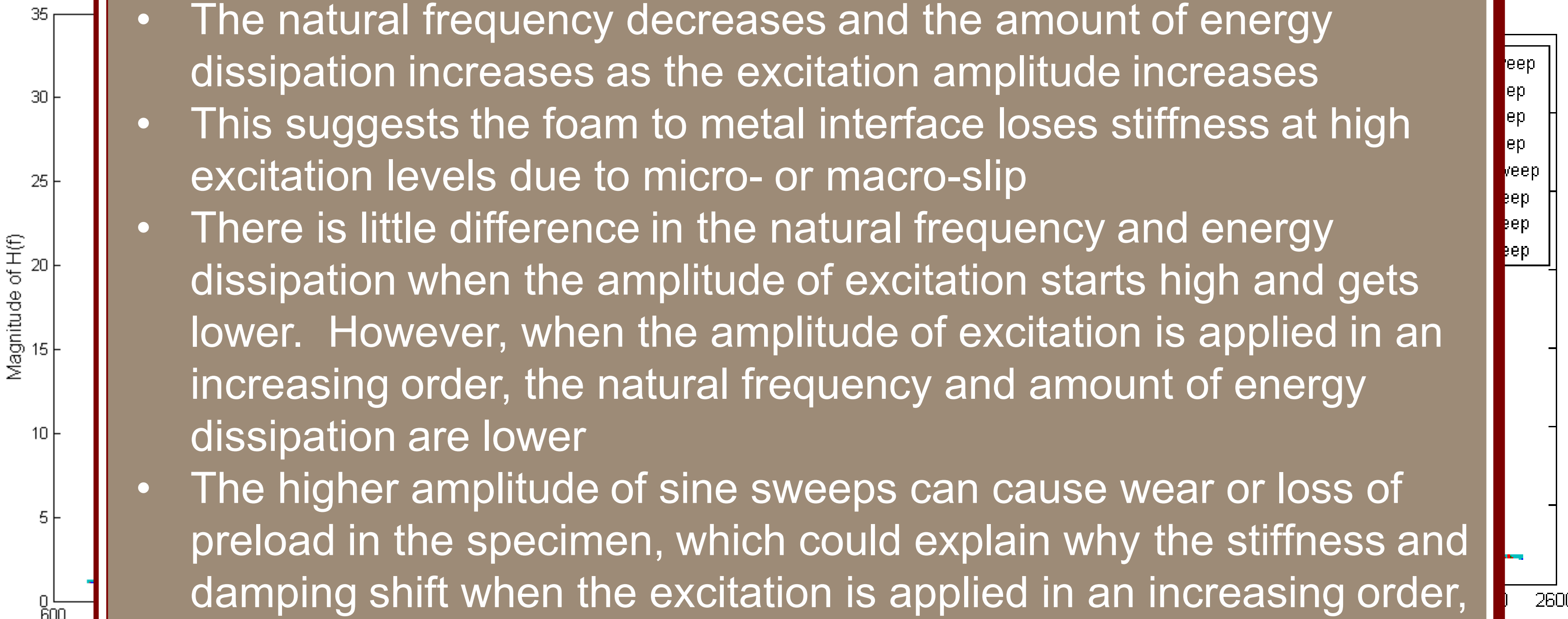
Data Analysis

- The data are used to calculate transfer functions between the responses of the three different axes at the top of the solid mass and the input accelerations
- The maximum amplitude of the transfer function gives Q, the amplification factor of the input at the natural frequency.
- The energy dissipation of can be calculated using :

$$\frac{\pi * Q * A_b^2}{f_n^2} \quad \text{(Eq. 1)}$$

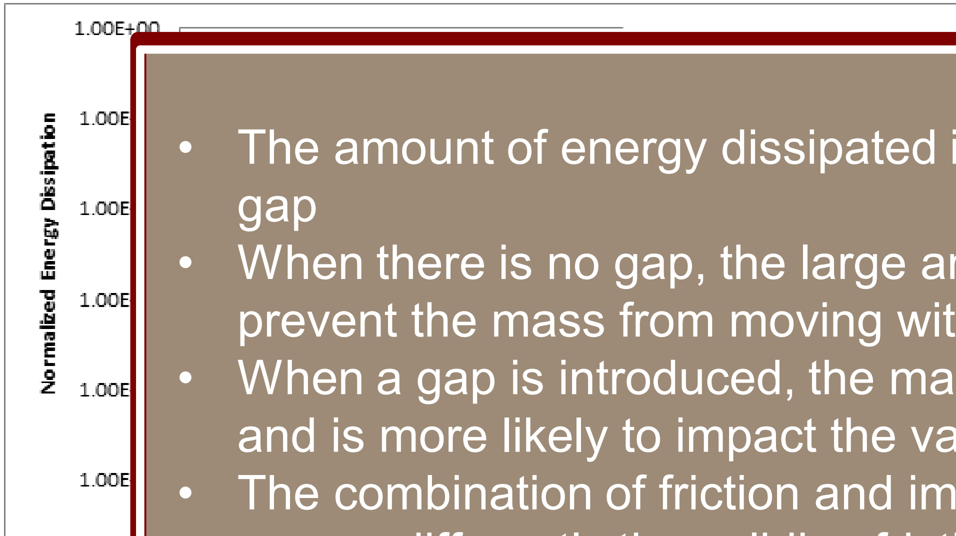
- Where f_n is the natural frequency of the first axial mode in Hz, A_b is the amplitude of the excitation in g's and Q is the amplification factor of the response

Effects of Sweep Order



- The natural frequency decreases and the amount of energy dissipation increases as the excitation amplitude increases
- This suggests the foam to metal interface loses stiffness at high excitation levels due to micro- or macro-slip
- There is little difference in the natural frequency and energy dissipation when the amplitude of excitation starts high and gets lower. However, when the amplitude of excitation is applied in an increasing order, the natural frequency and amount of energy dissipation are lower
- The higher amplitude of sine sweeps can cause wear or loss of preload in the specimen, which could explain why the stiffness and damping shift when the excitation is applied in an increasing order, but no change when the excitation is applied in a decreasing order

Effects of Snugness of Fit



- The amount of energy dissipated is greatest when there is a radial gap
- When there is no gap, the large amount of sliding friction could prevent the mass from moving within the container
- When a gap is introduced, the mass can move in the container, and is more likely to impact the various surfaces
- The combination of friction and impacts is likely to dissipate the energy differently than sliding friction alone
- These results suggest that it is important to understand the amount of friction and coefficient of restitution for impacts
- The data show a power law relationship between energy loss per cycle and the input acceleration.
- The slopes of the fitted results range from 1.65 to 1.89, where the theoretical value is 2 for a linear system with contact friction

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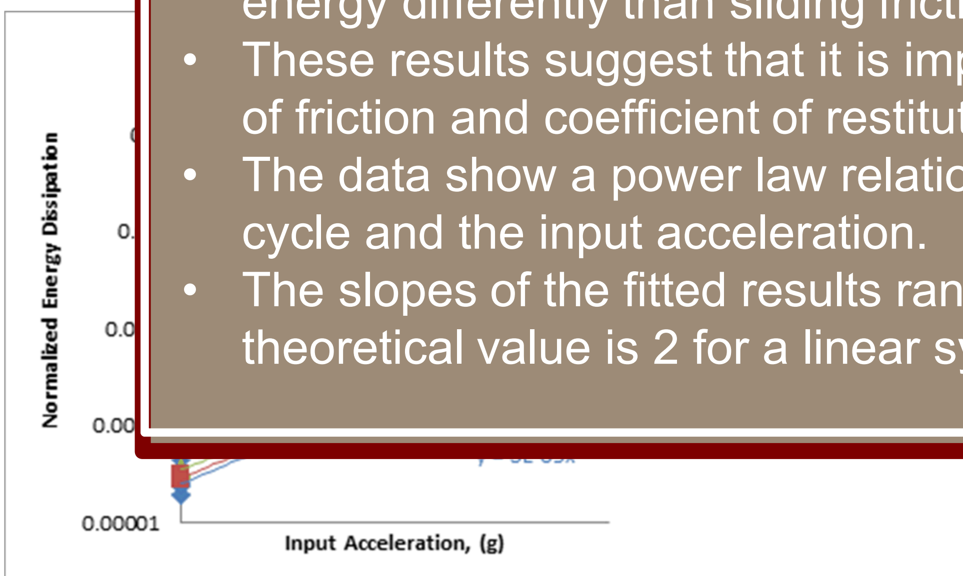
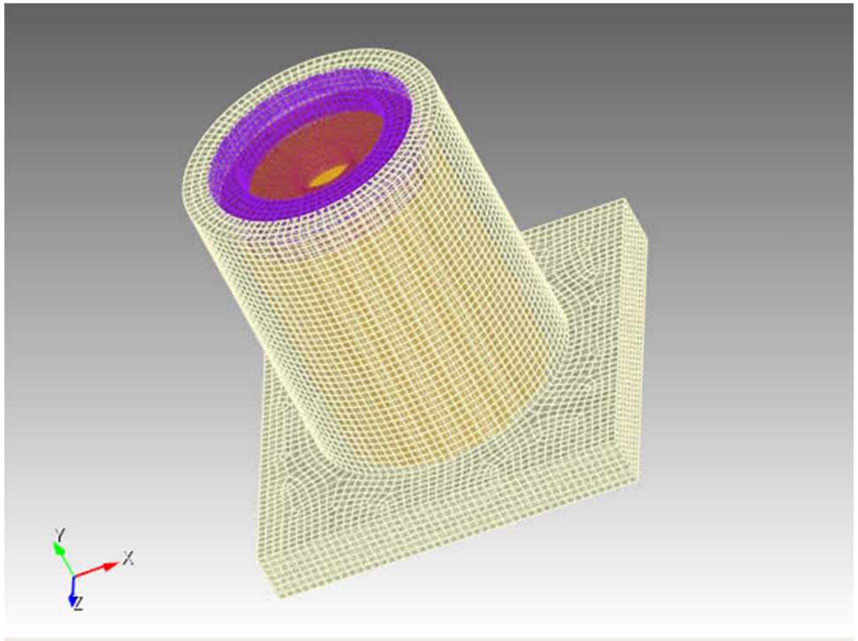


Computational Model - Mesh



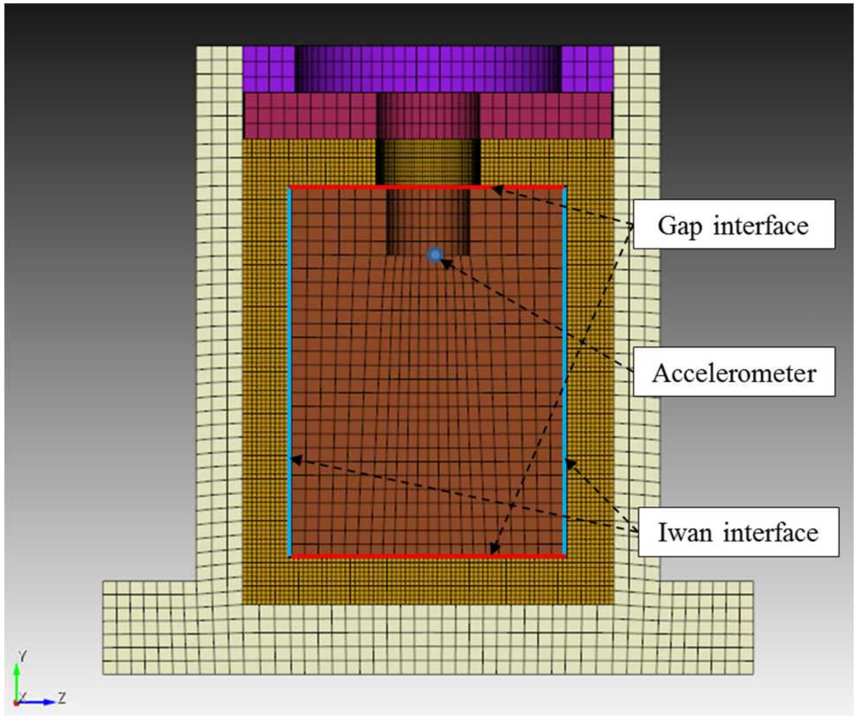
- A high fidelity finite element model was created in Sierra/SD
- 198,856 8-noded hexahedral elements, and 15,888 beam elements

Computational Model – Material Properties and Damping

- elements model the component materials with linear elastic properties
- model assumes that the foam cups behave as a linear elastic material, and a modal damping model accounts for the material damping

Material	Component(s)	Young's Modulus	Density	Poisson's Ratio
Aluminum 6061-T6	Slug, Outer Can	68.9 GPa	2640 kg/m^3	0.33
Structural Steel	Ring Nut, Cover Plate	207 GPa	7705 kg/m^3	0.33
PMDI	Foam Cups	162 MPa	289 kg/m^3	0.30

Computational Model - Interfaces



- assume that a majority of the nonlinear energy dissipation occurs at the interface between the inner solid mass and the inner surface of the foam cups
- beam elements in the model are abnormally stiff beams that rigidly tie the interfacing surfaces of either the solid mass or foam cups to a single node

Craig-Bampton Model

- two Craig-Bampton reduced order models (ROMs) are created:
  - one of the solid mass
  - one of the rest of the foam/can assembly.
- solid mass has three boundary nodes (top and bottom gap interface, one Iwan interface),
- high stiffness of the solid mass required only a single fixed-interface mode
- foam/can assembly has 4 boundary nodes with the additional one being an excitation node at the base plate of the can
- keeping 20 fixed-interface modes gives this subcomponent ROM a total of 39 degrees-of-freedom
- The modal damping values were set to 0.5 % for the solid mass and 2.0% for the can/foam assembly

Craig-Bampton Model

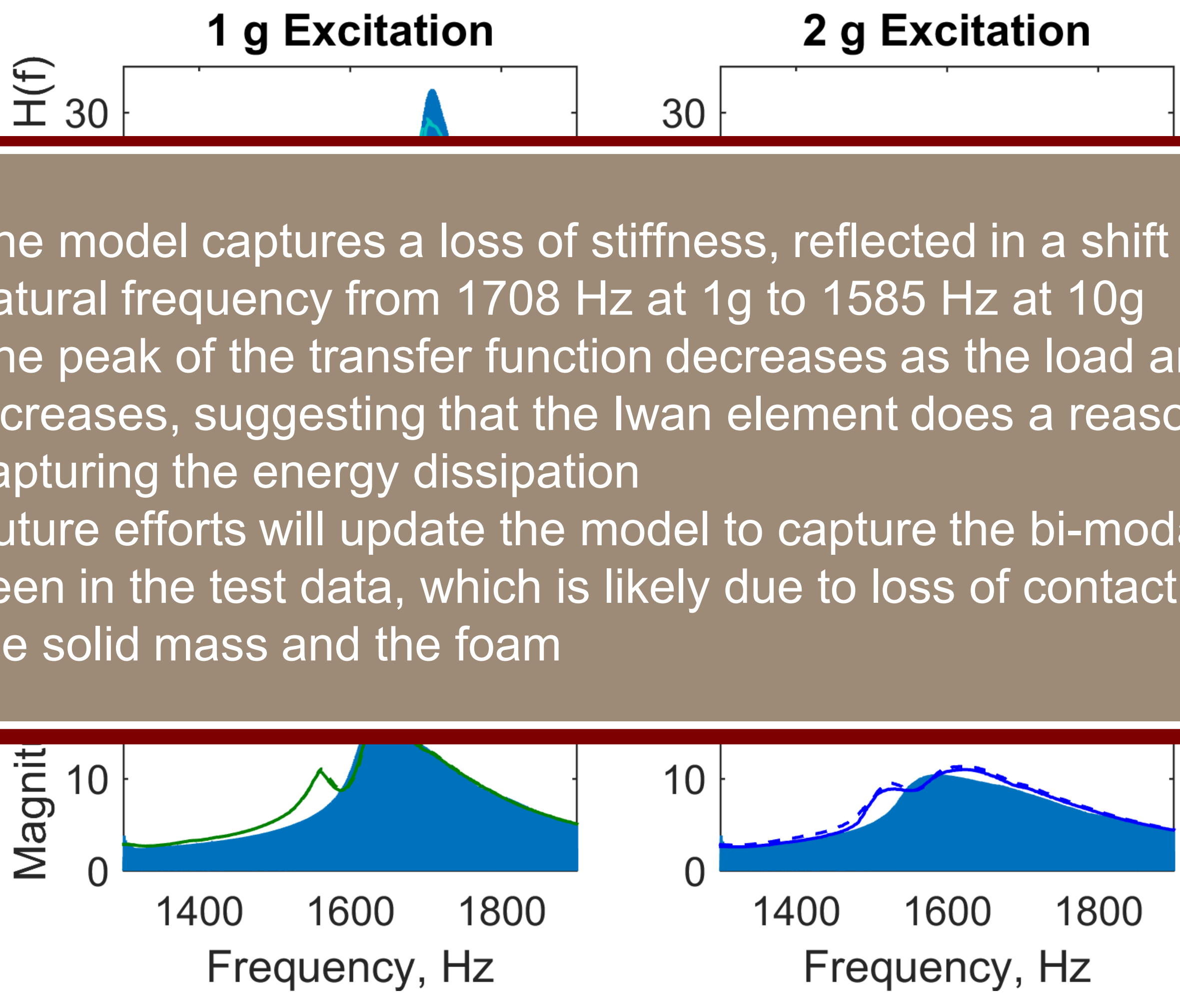
- three boundary nodes of the ROMs are connected to the nodes using a single joint element having 6 different constitutive models for each of the nodal DOF
- top and bottom interfaces between the solid mass and the corresponding inner surfaces of the foam cups are modeled with a gap element
- outer radial surface of the solid mass is tied to a joint element with a four-parameter Iwan model in the y-direction, and stiff elastic springs in all the other directions.
- The stiffness parameters K_T and K_l were adjusted to best match the 1g test data

Element	Parameters			
	K_u	K_l	U_0	-
Top & Bottom Gap	0.0 lbf/in	1.0 E+06 lbf/in	0.0 inch	-
	K_T	F_s	B	χ
Iwan	2.0 E+06 lbf/in	100.0 lbf	0.0	-0.5

Model Simulation

- assembled ROMs with nonlinear connections subjected to upward sine sweep excitation from 1300 Hz to 1900 Hz at a sweep rate of 750 Hz/s
- each sweep applied base acceleration in the y-direction at various amplitudes (1g, 2g, 5g, and 10g)

Comparison Between Model and Experiments



- The model captures a loss of stiffness, reflected in a shift of the natural frequency from 1708 Hz at 1g to 1585 Hz at 10g
- The peak of the transfer function decreases as the load amplitude increases, suggesting that the Iwan element does a reasonable job capturing the energy dissipation
- Future efforts will update the model to capture the bi-modal hump seen in the test data, which is likely due to loss of contact between the solid mass and the foam

Conclusions

- The higher amplitude of sine sweeps can cause wear or loss of preload in the specimen, which could explain why the stiffness and damping shift when the excitation is applied in an increasing order, but no change when the excitation is applied in a decreasing order
- Regardless of load path, the amount of energy dissipated is greatest when there is a radial gap
- It is important to understand the amount of friction that occurs between the contacting surfaces and the coefficient of restitution for impacts
- A first attempt at modeling Ministack was done using a Craig-Bampton model connected with various nonlinear elements. The simulated sine sweeps with an Iwan element and two gap elements matched the test data quite well

Thank you for your attention!

QUESTIONS?