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Noise and Vibration Control with Constrained Layer Damping Systems

**RAM 6 Workshop
October 15 & 16, 2013**

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Overview

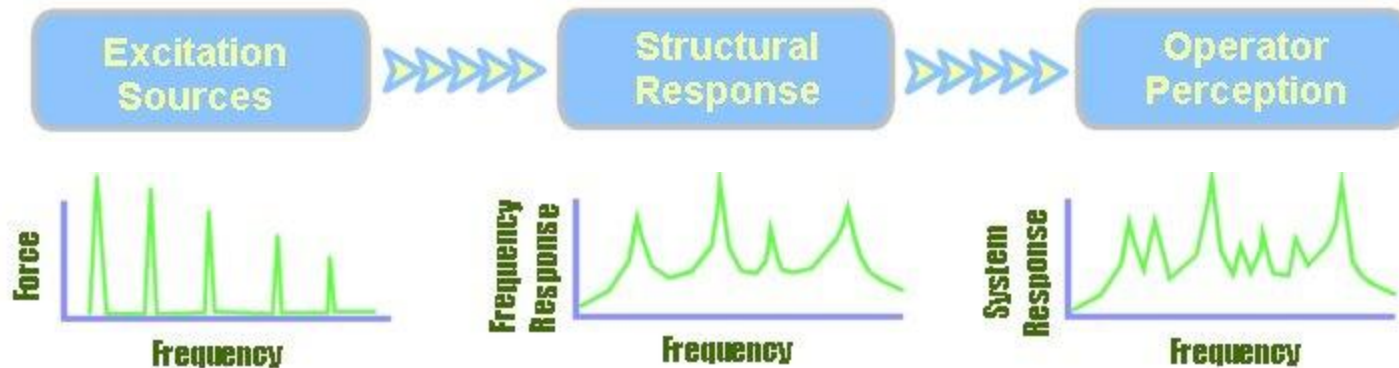
- Background

RAM 5 Workshop, October, 2012

“Viscoelastic Material Behavior Considerations for Design and Durability”

- Structural Resonance Issues and Control
- Constrained Layer Damping Theory
- Constrained Layer Damping Design and Simulation
- CLD Examples
 - Helicopter Skin, Disk Drive Cover, Engine Front Cover

Source and Receiver Behavior



- Unbalance
- Impact
- Misalignment
- Load Fluctuations

- Mass
- Stiffness
- Damping

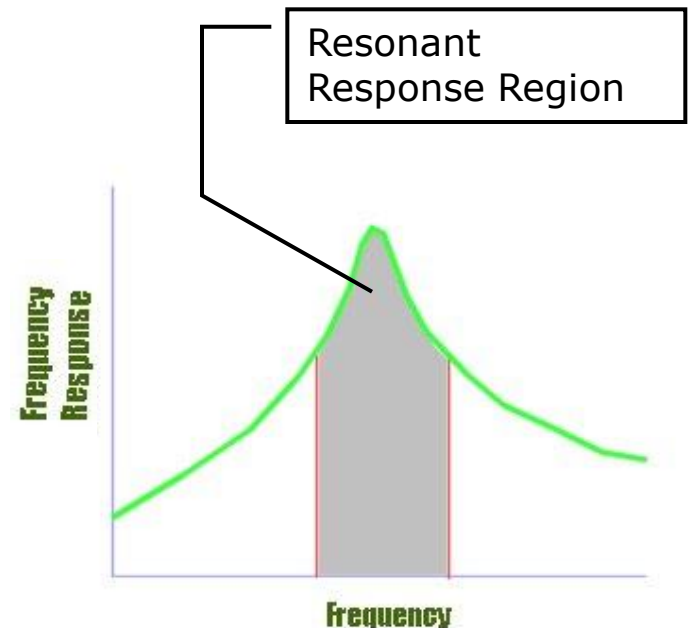
- Tactile Vibration
- Sound (SPL)
- Durability

Resonant Response Solutions



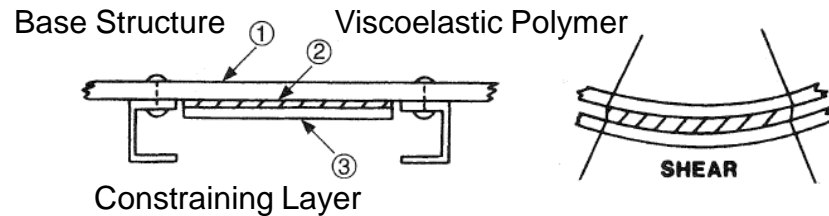
- **Resonant Response Solutions**

- **Mass Control**
- **Stiffness Control**
- **Damping Control (most effective)**
 - **Material Selection**
 - **Friction Damping**
 - **Particle Damping**
 - **Active Damping**
 - **Viscous Damping**
 - **Damping Links**
 - **Tuned Mass Damper**
 - **Free-layer Damping Treatment**
 - **Constrained Layer Damping Treatment**



Constrained-Layer Damping Theory

Energy dissipation using constrained-layer damping (CLD) is achieved by shearing a viscoelastic polymer between a base structure and a constraining layer as depicted below.



The energy dissipation created by a CLD is typically quantified in terms of loss factor (η), a dimensionless quantity that can be measured or predicted from the modal damping of a dynamic system.

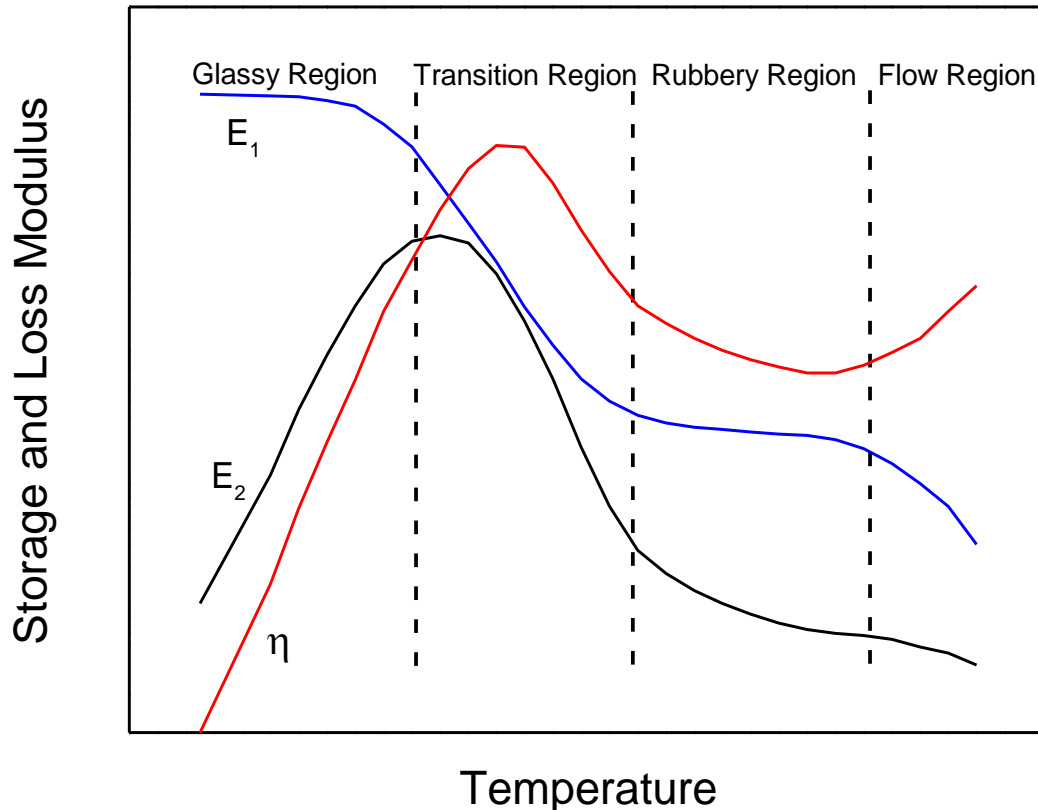
Performance Variables:

- Base Structure Dynamic Properties
- Materials (modulus, damping and density)
- Thicknesses
- Coverage (location and coverage on base structure)
- Temperature

Viscoelastic Material Property Behavior

High damping viscoelastic polymers by their nature behave very nonlinearly with respect to temperature and frequency. Typical behavior of the modulus and loss factor of a viscoelastic polymer at a fixed frequency is shown below.

$$E^* = \frac{\sigma_0}{\epsilon_0} e^{i\theta} = E(1 + i\eta) = E_1 + iE_2$$

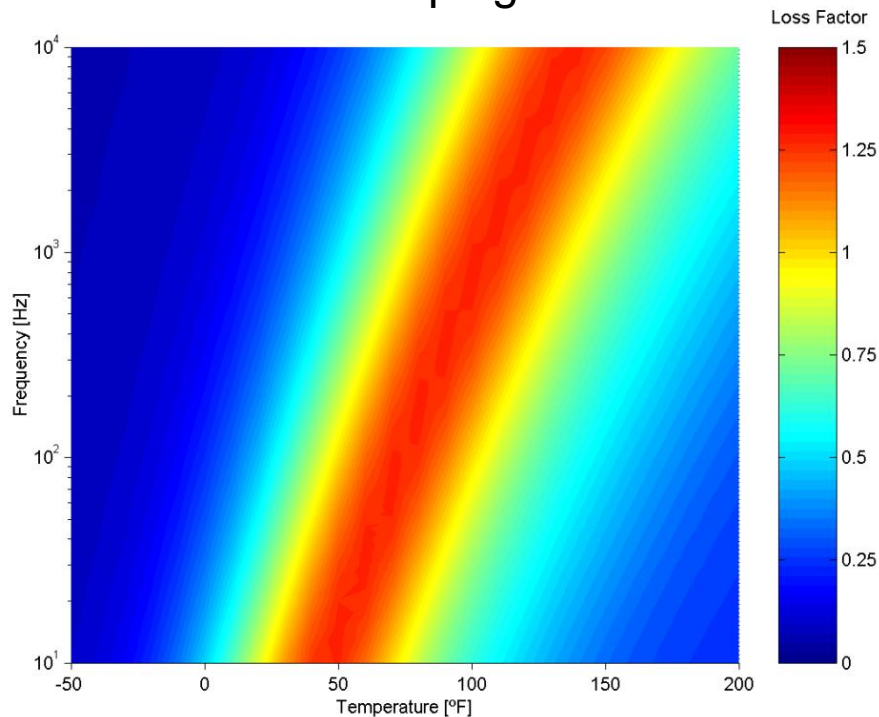


- E^* : complex modulus
- θ : loss angle
- η : loss factor = $1/Q$
- E_1 : storage modulus (real part)
- E_2 : loss modulus = ηE_1 (imaginary part)

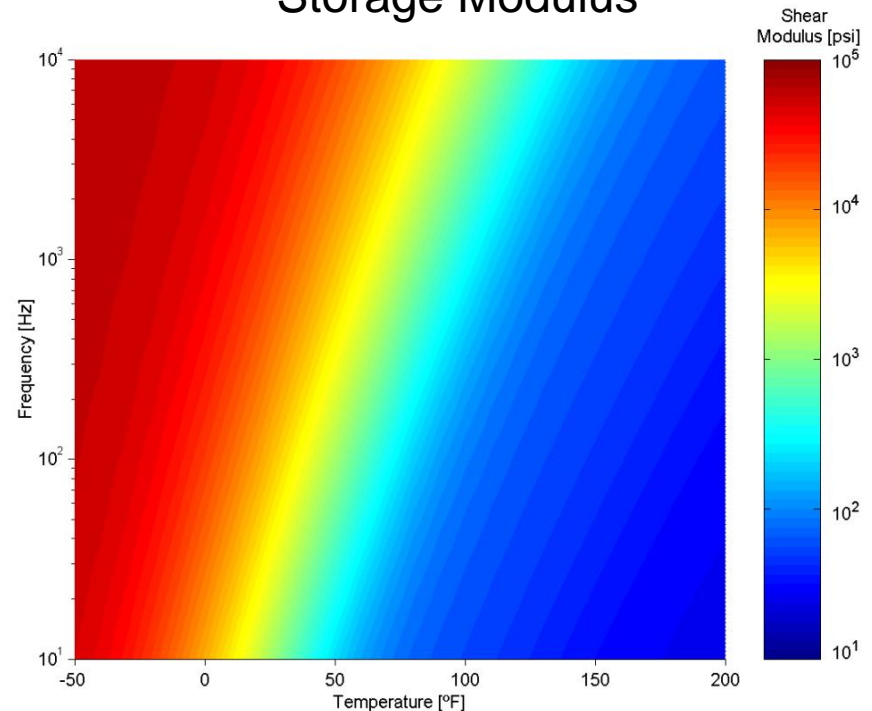
Viscoelastic Material Property Behavior

Typical behavior of the modulus and loss factor of an acrylic-based pressure sensitive polymer with high damping near room temperature is show below. Many design variables and material choices exist for CLD treatments.

Damping

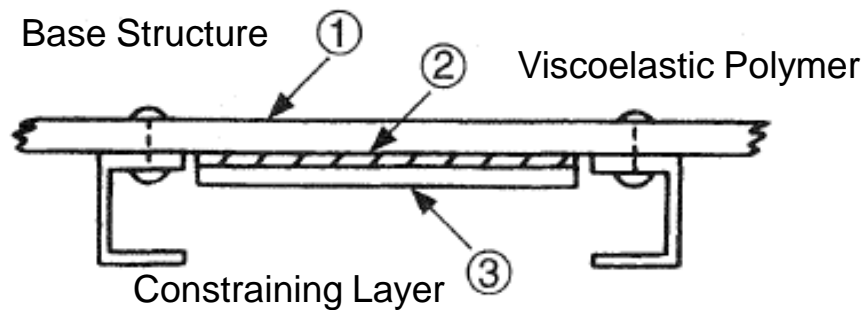


Storage Modulus



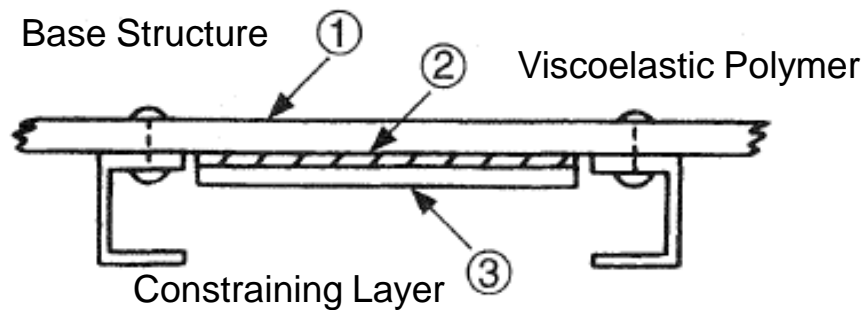
RKU Damping Models of CLD Treatments

The design of CLD treatments requires the knowledge of the complex viscoelastic material properties (shear modulus (G'), shear loss modulus (G''), and loss factor (η)), and the effects of geometric factors. Ross, Kerwin and Ungar (RKU) developed methodology and equations for predicting the damping performance of CLD treatments for simple beams and plates that take all the relevant variables into account.



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Sample RK Equations:

$$(EI)^* = \frac{E_1 H_1^3}{12} + \frac{E_2^* H_2^3}{12} + \frac{E_3 H_3^3}{12} - \frac{E_2^* H_2^2}{12} \left(\frac{H_{31} - D}{1 + g^*} \right)$$

$$+ E_1 H_1 D^2 + E_2^* H_2 (H_{21} - D)^2 + E_3 H_3 (H_{31} - D)^2$$

$$- (0.5 E_2^* H_2 (H_{21} - D) + E_3 H_3 (H_{31} - D)) \left(\frac{H_{31} - D}{1 + g^*} \right)$$

with:

$$D = \frac{E_2^* H_2 (H_{21} - 0.5 H_{31}) + g^* (E_2^* H_2 H_{21} + E_3 H_3 H_{31})}{E_1 H_1 + 0.5 E_2 H_2 + g^* (E_1 H_1 + E_2 H_2 + E_3 H_3)}$$

$$H_{21} = 0.5 (H_1 + H_2)$$

$$H_{31} = H_2 + 0.5 (H_1 + H_3)$$

$$g^* = \left(\frac{G_2^* \lambda^2}{E_2 H_2 H_3 \pi^2} \right)$$

RKU Damping Models of CLD Treatments

Advantages of RKU Models:

- Quick evaluation of many types of viscoelastic materials and their temperature effects
- Quick evaluation of many types of constraining layers
- Quick evaluation of viscoelastic material and constraining layer thickness effects

Limitation of RKU Models:

- Complex shapes and boundary conditions can not be modeled
- Not applicable for CLDs with less than 100% surface area coverage

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Note: If you can not find proper materials for your application, please contact Roush Industries, Inc.
12011 Market Street
Livonia, MI 48150
Telephone: (734) 779-7400
Fax: (734) 779-7403

Structure Type: Simply Supported Plate

Number of Layers: 3

Length [in]: 21.50

Width [in]: 5.00

Mass [lb]: 1.00

Temperature Range

Minimum [F]: -10.00

Maximum [F]: 200.00

Layer Configuration

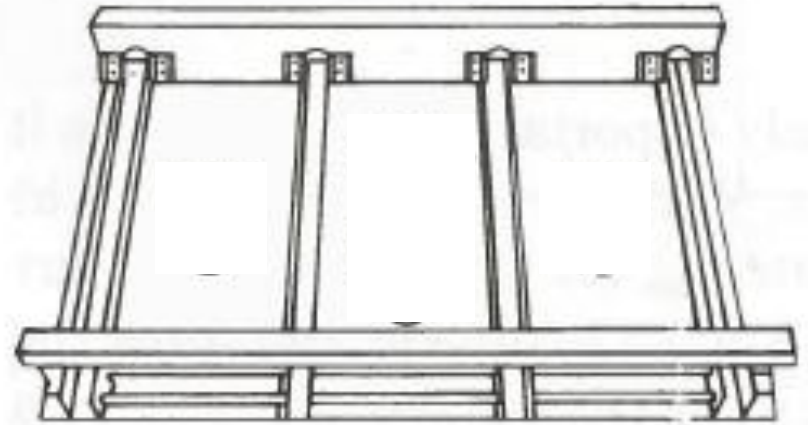
Layer Number	1	2	3	4
Layer Type	Constraining	Damping	Constraining	
Material	Aluminum	38RA960.db	Aluminum	
Thickness [in]	0.0250	0.0050	0.0100	0.0100
Young's Modulus [psi]	10.00E+6	30.00E+6	10.00E+6	30.00E+6
Loss Factor	0.0250	0.0000	0.0010	0.0000
Density [lb/in³]	0.0980	0.0441	0.0980	0.2860
Poisson Ratio	0.3000	0.4900	0.3000	0.3000

Roush uses its proprietary RKU tool, Predict™, and its proprietary viscoelastic material database to determine the optimum design parameters and material selection.



RKU Damping Model Results

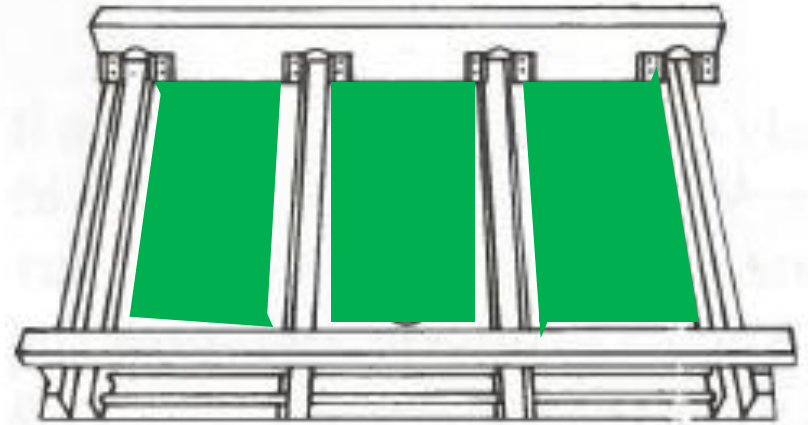
Typical Helicopter Skin Panel
Geometry with Frame and Longerons
Construction.



RKU Damping Models Results

Typical Helicopter Skin Panel
Geometry with Frame and Longerons
Construction.

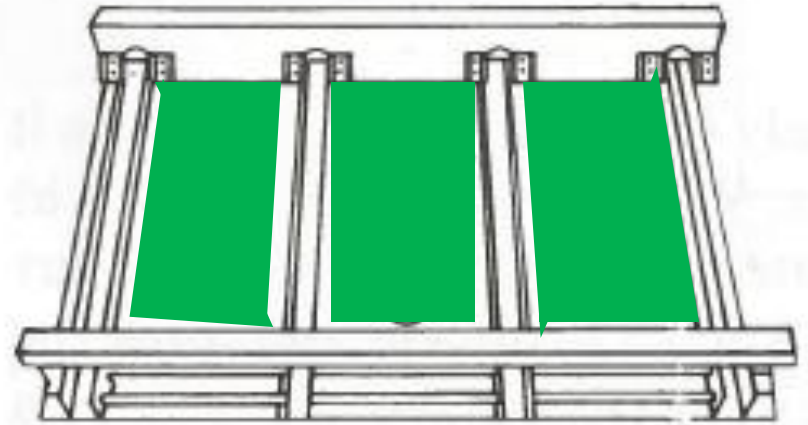
Goal: Add CLDs to Skin Panels to
Reduce Structurally Radiated
Interior Noise with Minimal
Weight.



RKU Damping Models Results

Typical Helicopter Skin Panel
Geometry with Frame and Longerons
Construction.

Goal: Add CLDs to Skin Panels to
Reduce Structurally Radiated
Interior Noise with Minimal
Weight.



Example RKU Plate Model:

Boundary Conditions: all sides simply-supported

Base Skin Layer: Aluminum 21.5" x 5" x 0.025"

Base Skin Layer Loss Factor: 0.023

Damping layer thickness: 0.005"

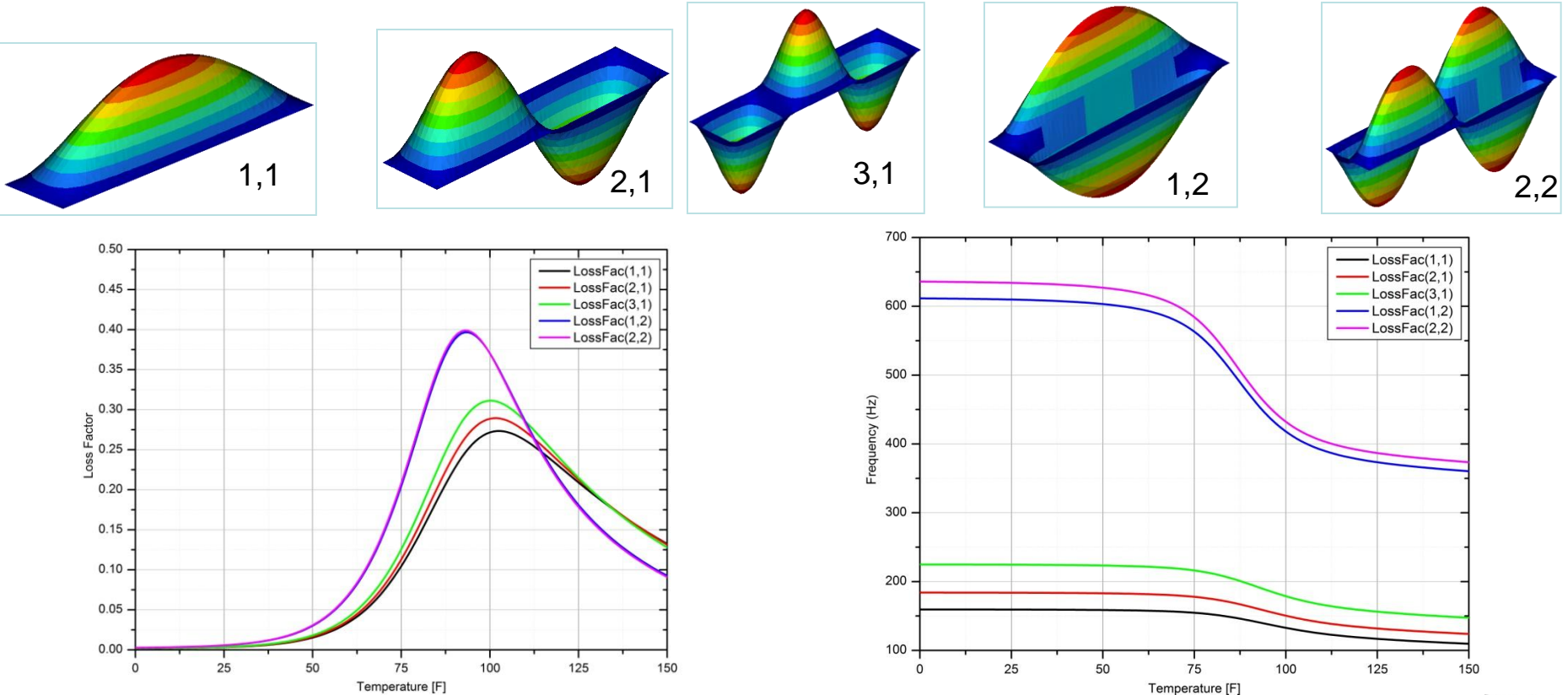
Damping Polymer: RA960

Constraining Layer Material: Aluminum

Constraining Layer Thickness: 0.010"

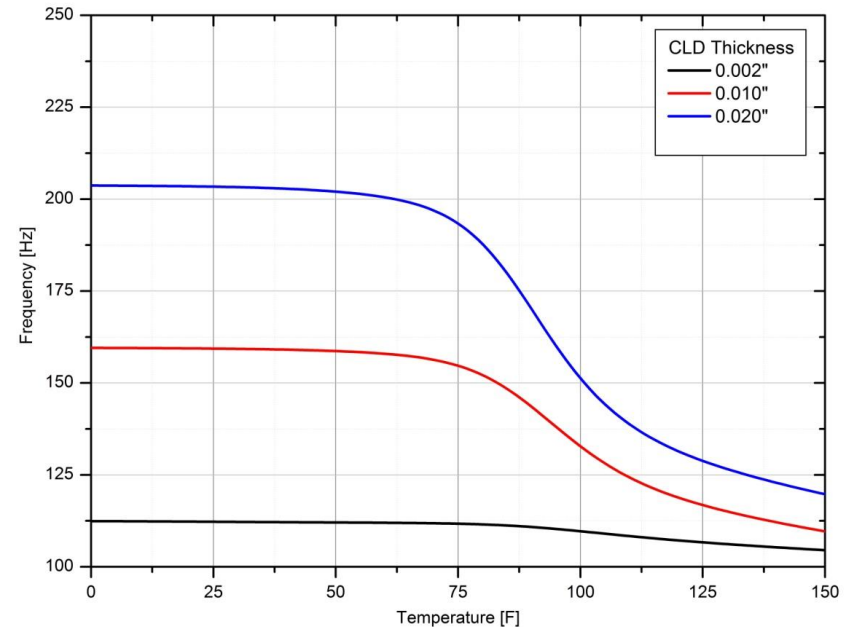
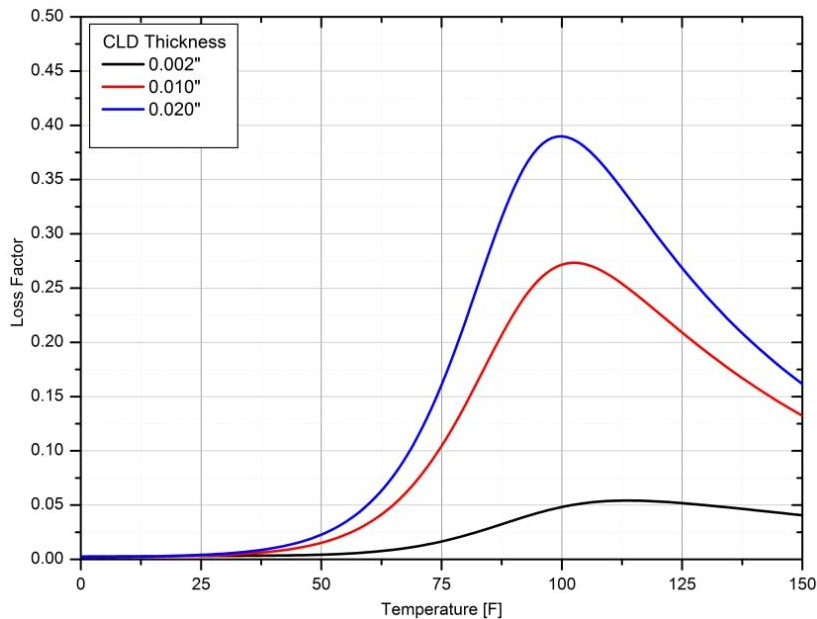
RKU Damping Models Results

- RKU Damping Models predict modal frequencies and damping values for beam and plates.
- Viscoelastic material effects of temperature and frequency are modeled.



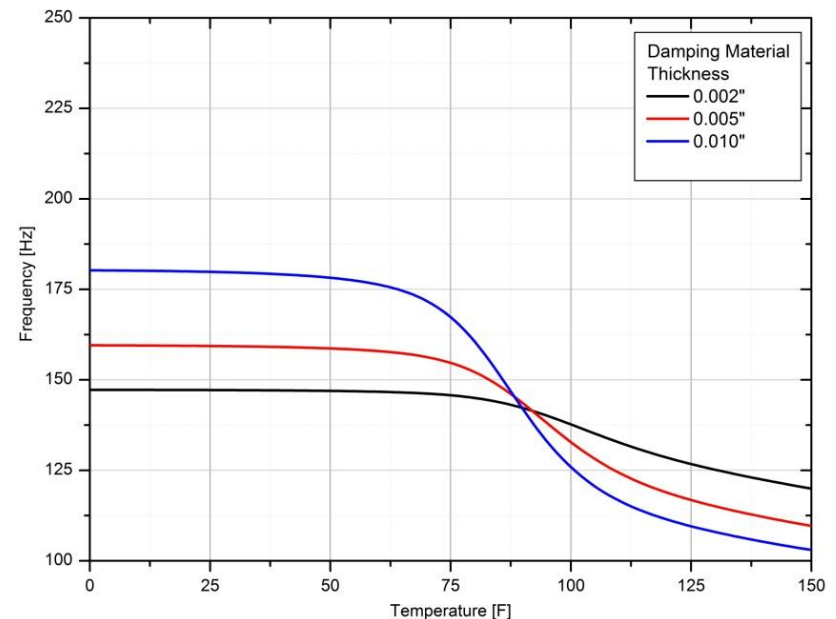
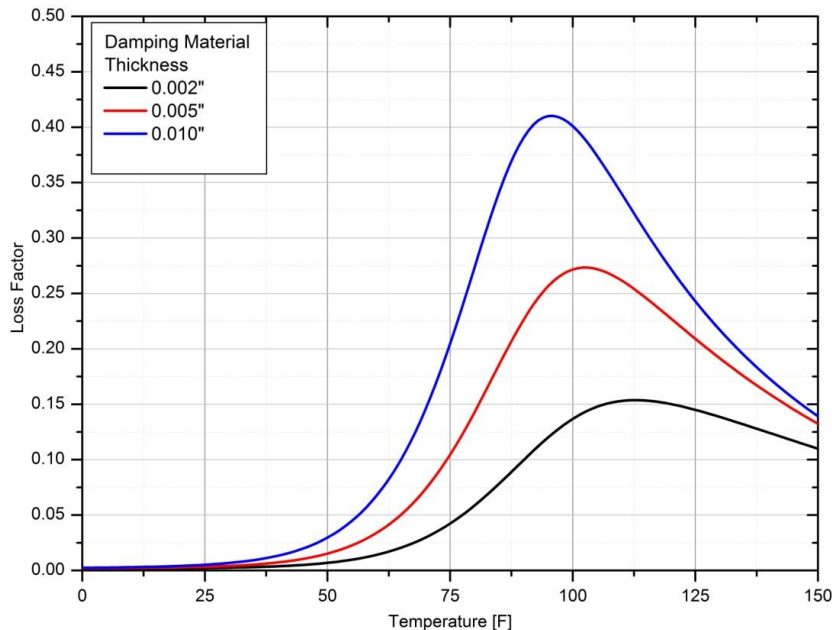
Effects of Constraining Layer Thickness

Increasing the constraining layer thickness creates more damping and increases the resonance frequencies(esp. at low temps), but will increase the CLD weight and may be harder to adhere.



Effects of Damping Material Thickness

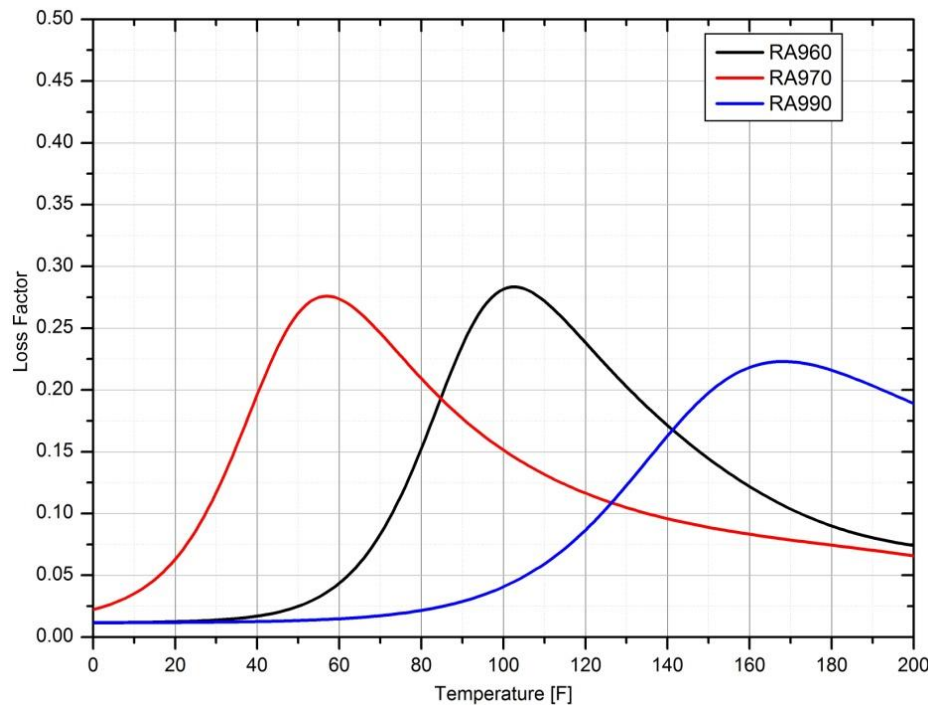
Increasing the damping layer thickness likewise creates more damping and increases the resonance frequencies(esp. at low temps), although to a lesser degree than increasing the constraining layer thickness.



Effects of Damping Material Types

Many viscoelastic material exist and the challenge is to find the one that provides to best damping performance with minimal negative impact on cost, weight and functional performance.

It is the combination of damping material and constraining layer thickness and properties that need to optimized for each application.



FEA Damping Models of CLD Treatments

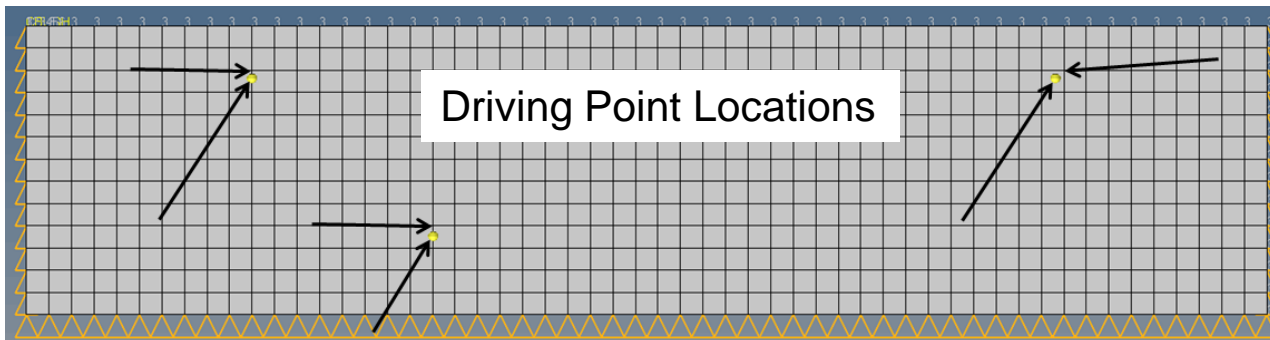
Finite element models are also commonly used for predicting the damping performance of CLD treatments. Like RKU, FEA can account for the complex viscoelastic material properties (G' , G'' and η) and the effects of geometric factors. Typically a Normal Modes analysis and then a Direct Frequency Response analysis are run to obtain the modal frequencies and loss factors.

Advantages of FEA Models:

- Complex structural shapes and boundary conditions are easily modeled
- CLD surface area coverage can be of any size

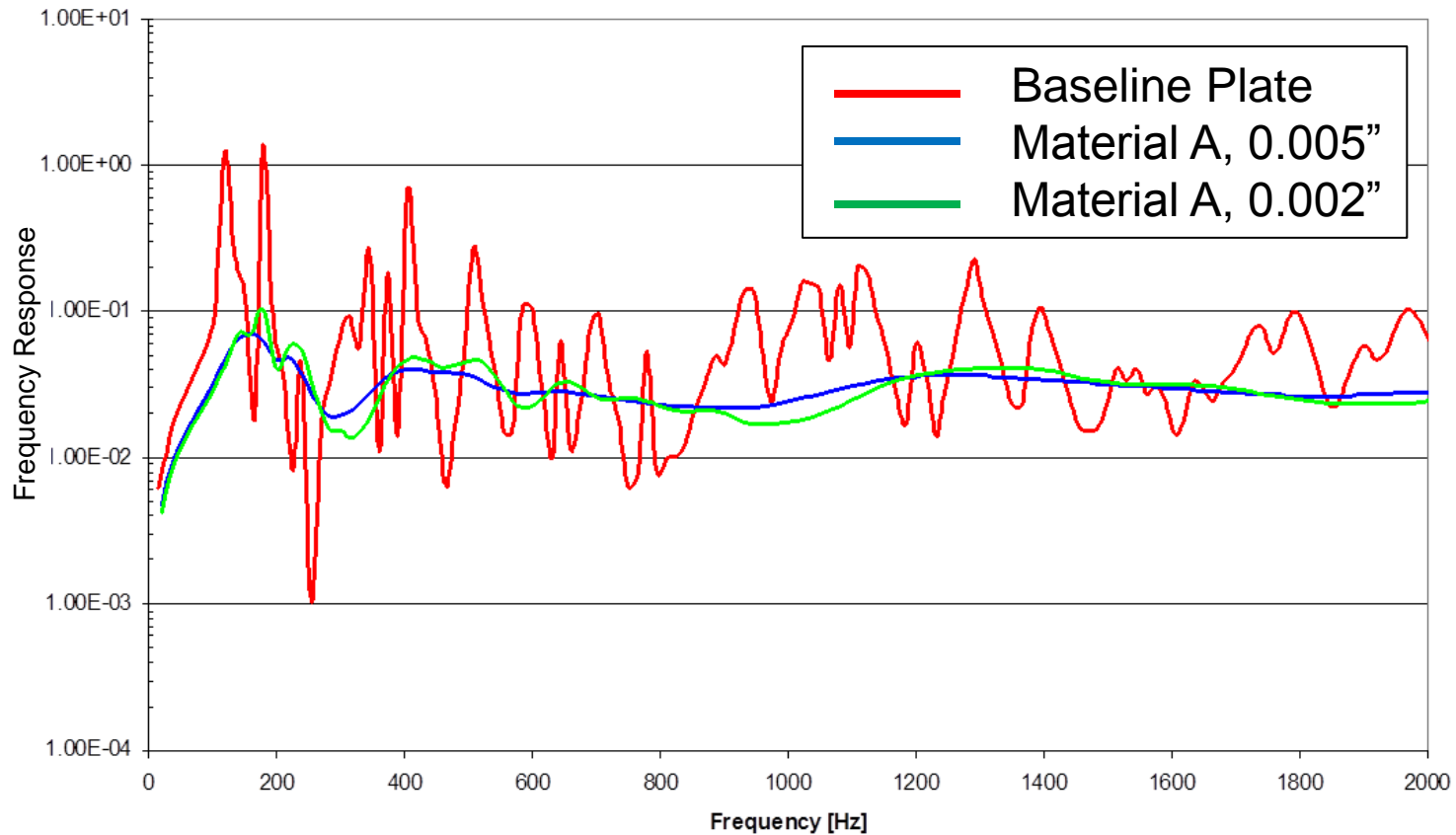
Limitations of FEA Models:

- Computing resources and solve times are significantly greater
- Modal loss factor is not a direct output of the model and needs to be computed using the half-power bandwidth method or the impulse response decay method.



FEA Model Results

Damping Material Thickness Effects on Rectangular Plate with CLD



Computer Hard Disk Drive Top Cover



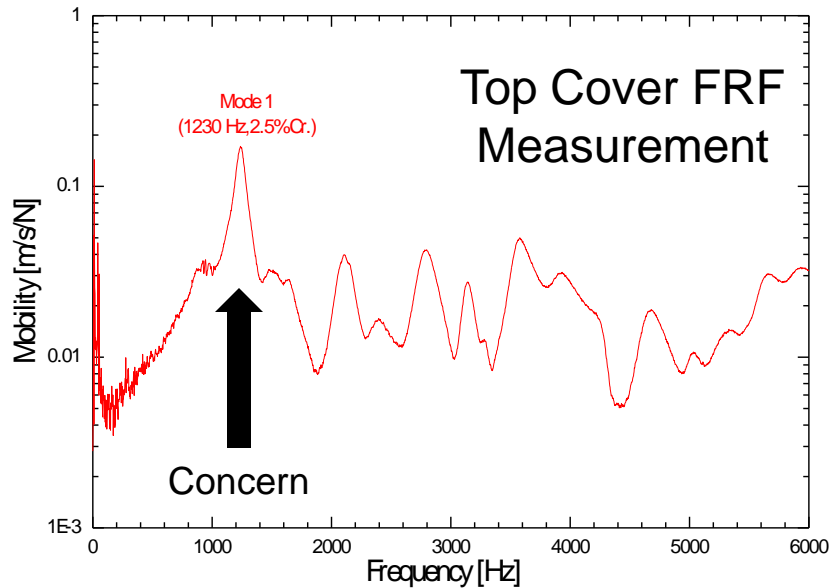
Applications

Requirements/Features:

- Low Noise
- Low Outgassing
- Thicknesses
- Temperature
- Cost



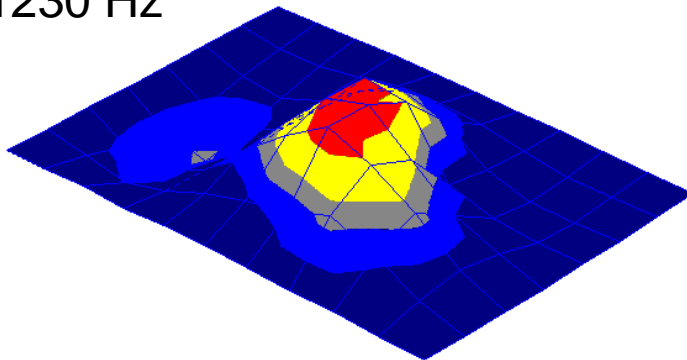
HDD Cover Dynamics



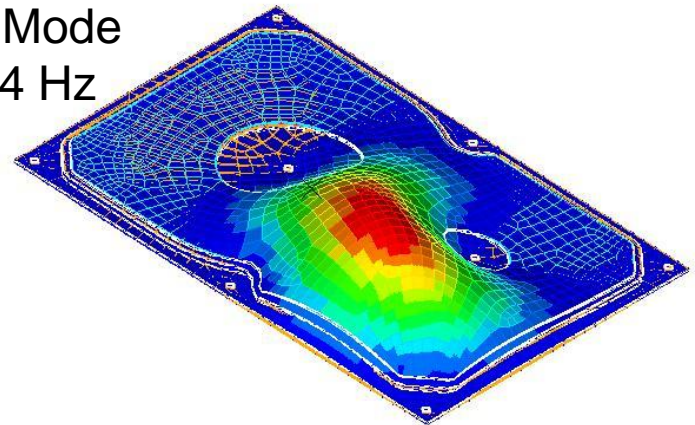
Issue:

Motor/Bearing Forces and Read/Write Actions Excite Top Cover Resonances that Radiate Noise

Measured Mode Shape @ 1230 Hz



Modeled (FEA) Mode Shape @ 1254 Hz



HDD CLD Results

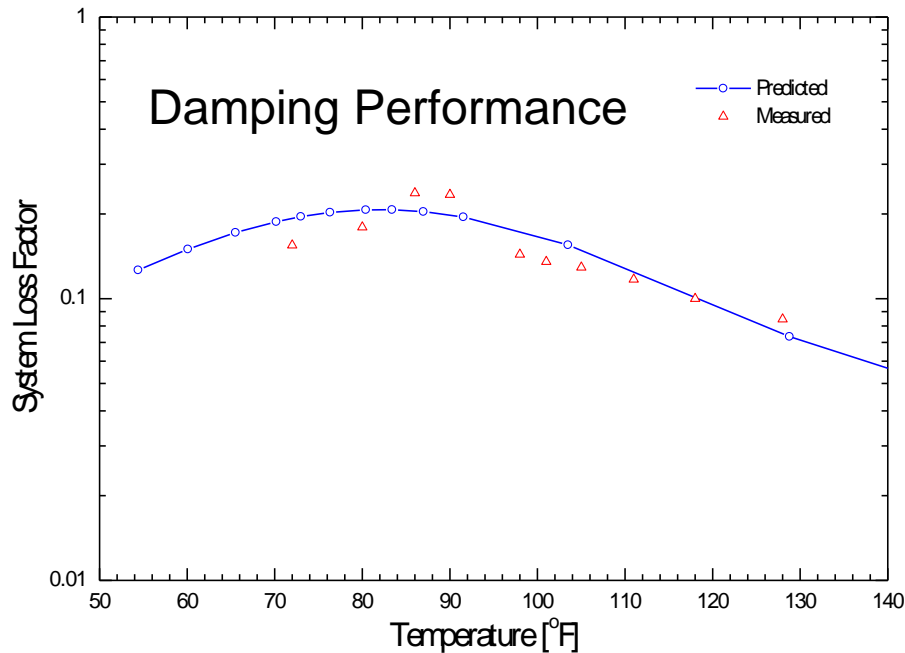
Typical Construction



Constraining Layer: 0.5 mm, SS

Damping Layer: 0.1 mm, RA980

Top Cover: 0.5 mm, SS



Automotive Engine Front Cover CLD

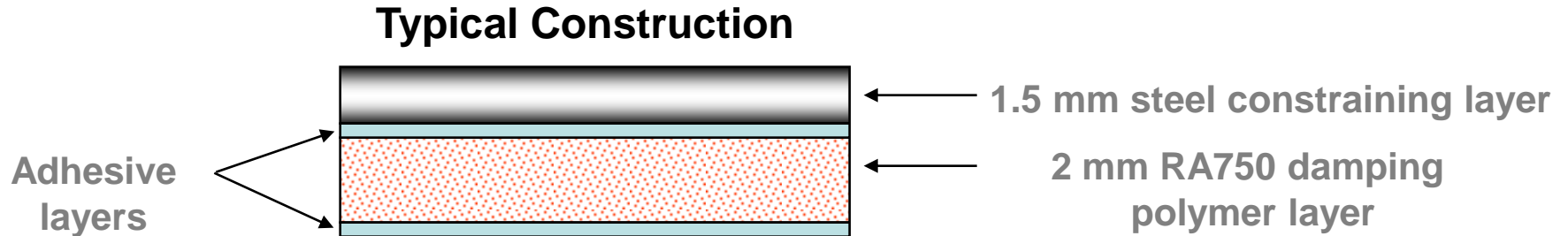


Applications Requirements/Features:

- Oil pump and Cam drive forces excite cover resonances
- Packaging requirements limit space for ribs
- Coverage is limited to high response area
- Temperature and fluid tolerance are critical
- Adhere without machining cast surface
- Minimize cost and weight

Front Cover CLD Solution

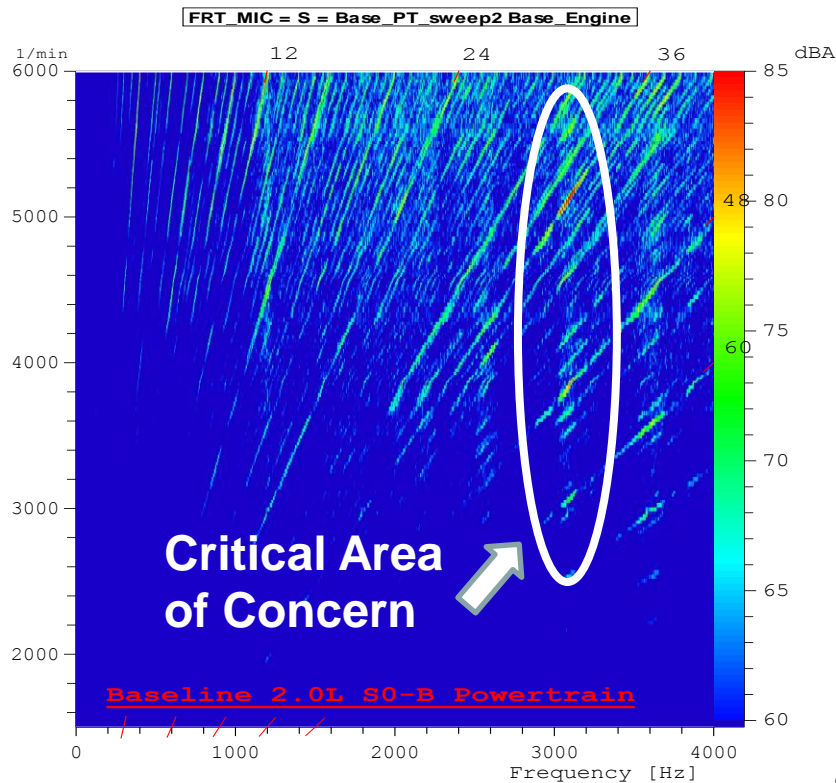
Constrained Layer Damping (CLD) treatment was attached to the engine cover to reduce the radiated noise levels.



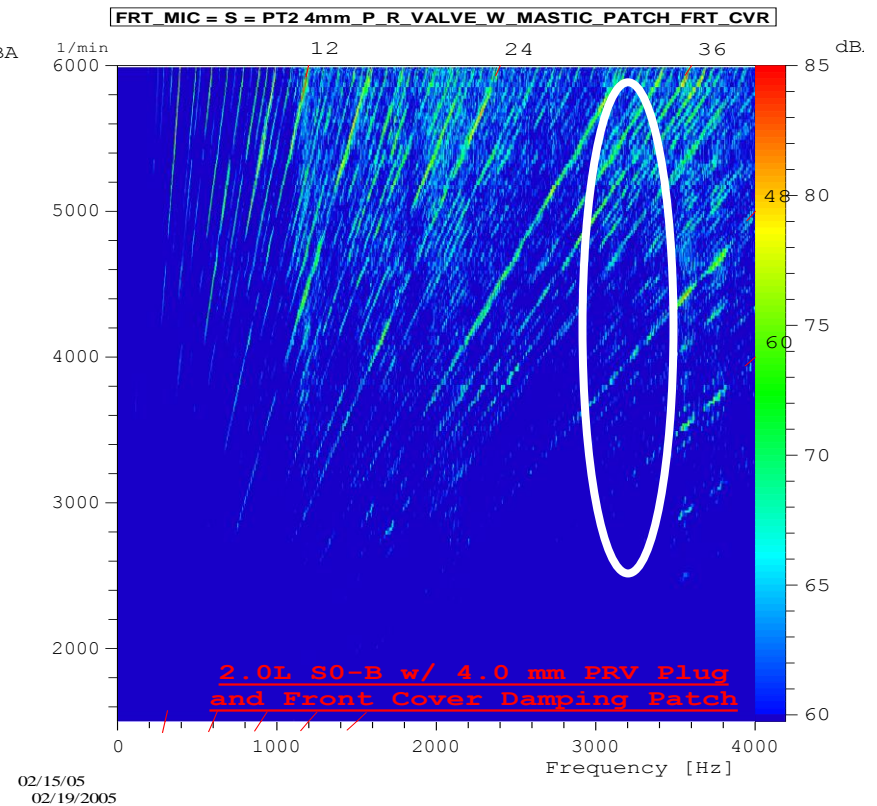
- **Excellent damping performance**
 - loss factors > 0.3
 - broad temperature coverage
- **Excellent physical properties**
 - pressure sensitive adhesive application
 - thickness accommodates surface flatness and die checking concerns
 - withstands typical engine / transmission fluids
- **Cost effective**
 - can be stamped to conform to curved surfaces
 - could eliminate need for expensive acoustic cover or isolation system

Front Cover Noise Measurements

Baseline

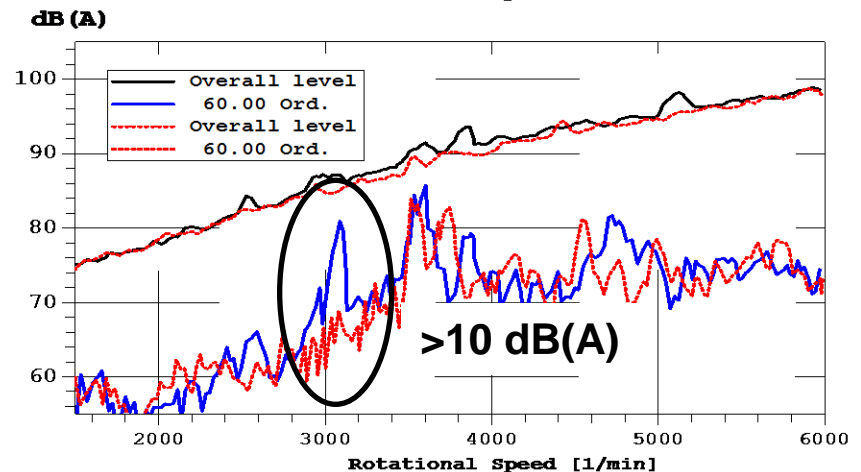
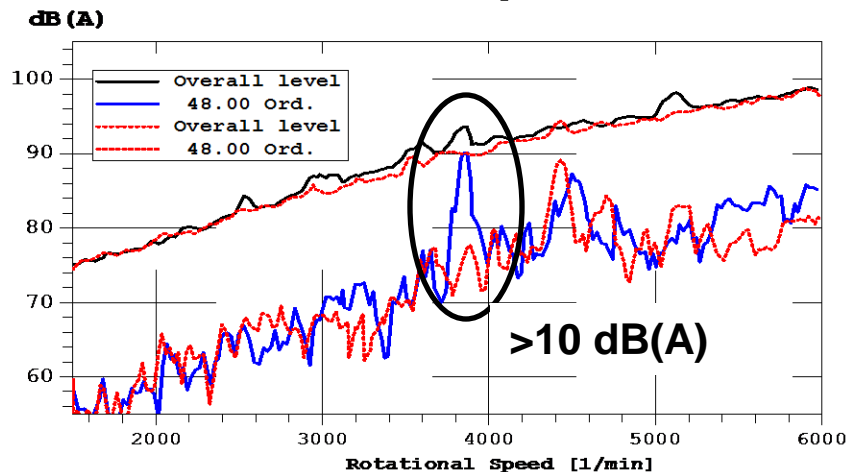
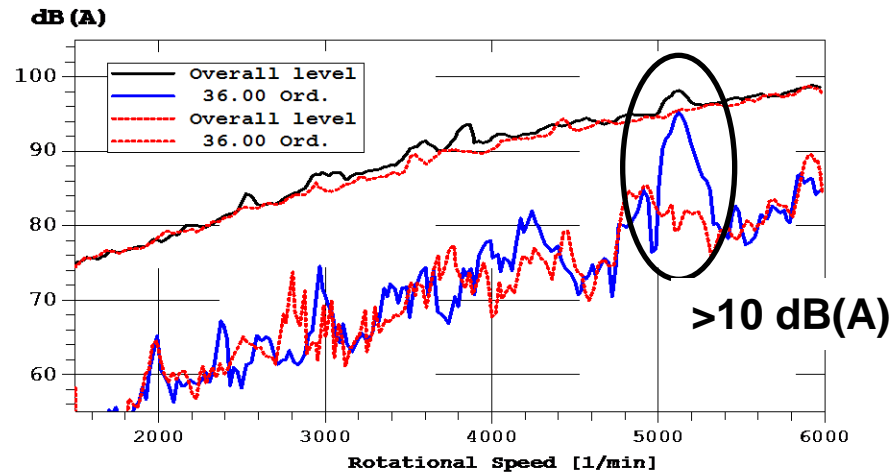
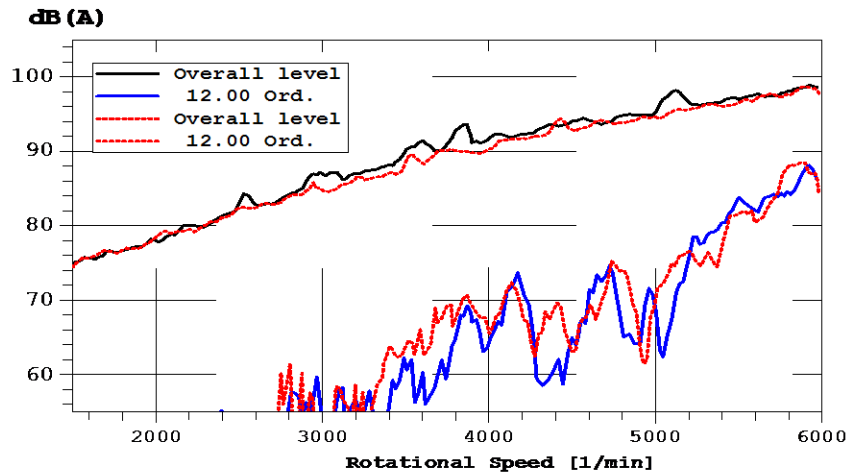


With CLD Applied



Front Cover Noise Measurements

Overall level and crankshaft order content: with and without CLD applied



CLD Advantages

- Very high levels of damping compared to other damping methods
- Can be very weight efficient
- Many viscoelastic damping materials are available to choose from
- Can be selectively applied to highly responsive areas
- Does not require much packaging space due to the thinness
- Easily applied to existing structures

Summary

Constrained layer damping (CLD) systems can be applied to control the resonant response of a variety of structures. CLDs can lower vibration and noise levels as well as increase structural durability and fatigue life.

The most important component in a CLD is the viscoelastic damping material. Selection of the proper damping material is key to maximizing the CLD performance.

Thickness of the damping layer and constraining layer need to be optimized as a system.

Several tools/methods exist to optimize the CLD design parameters.



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Questions?