

Vibration Control

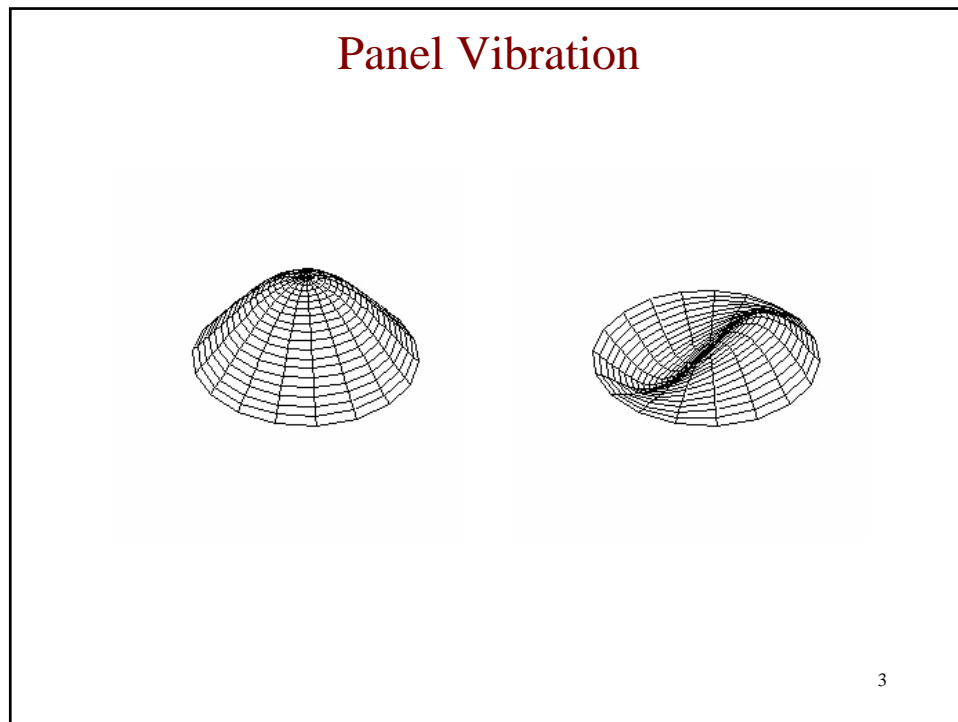
© 2002-2006 Steven E. Guffey, PhD, CIH

1

Modify Surface Areas

- E.g., machine casing
- Identify the cause of vibration
 - Reduce at source
 - Interrupt transmission path
- Examples:
 - Stiffen panel
 - Perforate panel (reduces radiation efficiency)
 - Isolate panel from source (e.g., felt washers)
 - Vibration dampening materials

2



Damping material

Constraining layer

Structure

Dampening

- Two types
 - Free layer treatment
 - Place energy dissipating material on one or both sides of vibrating surface.
 - If one side only, doesn't matter which side. Place to avoid wear or to enhance cosmetic appeal.
 - Can be preformed (e.g., PVC with stick-on or magnetic back) or painted or sprayed on
 - For very thin structure of light damping needed, duct tape is temporary (possibly permanent) solution
 - Constrained layer treatment
 - Same as above except constraining layer added
 - Provides shearing of the dampening materials

4

Dampening - continued

- Damping material characteristics are frequency and temperature dependent
- Two properties important to noise reduction
 - Loss factor, η
 - Measure of efficiency in dissipating energy stored in it
 - Dynamic modulus, E
 - Measure of stiffness
- Conditions required for success
 - Panel treated actually can create noise
 - Structure vibrating at one of its natural frequencies or normal modes of vibration
 - Treatment must cause significant percentage of total energy to be dissipated

5

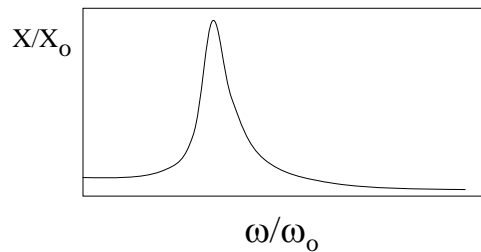
Ability of Panel to Create Noise

- Vibration at low frequencies may not create much noise
- Rules of thumb using wave number effective radius of the plate:
 - Wave number = $2\pi / \lambda$
 - Effective radius of the plate = r
 - r for circle with same area as plate
 - for panel in large rigid structure (no openings)
 - $(2\pi / \lambda) r \geq 0.5$
 - for panel in structure with significant openings
 - $(2\pi / \lambda) r \geq 1.5$

6

Is Panel Vibrating at Natural Frequency?

- Natural frequency is the frequency of vibration if object struck and no damping is present.
- Resonant frequency is the frequency that will occur with a given amount of damping.
- Ratio of vibration amplitude (X) to resting force deflection (X_0) spikes at resonant frequency (ω_0)
- For single-degree of freedom, system is stiffness-controlled when well below ω_0
- At ω_0 must be damping controlled
- Damping ineffective if not $\omega = \omega_0$
- Damping likely ineffective if already damped and still producing noise.
- Note that some damping will occur just due to increased mass of the panel



7

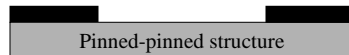
Damping Effectiveness: Energy Stored in Panel Must Be Significant

- Noise reduction (NR) from damping is estimated from loss factor (η):
 - $NR = 10 \log(\eta_{\text{After}}/\eta_{\text{Before}})$, dB
 - Since $\eta_{\text{After}} < 0.1$
then η_{Before} must be very small
 - $\eta_{\text{After}} = \frac{(\eta, \text{ energy stored in the damping matrl})}{\text{total energy stored in the system}}$
 - η_{After} provided by suppliers

8

Placement on Vibrating Panel

- For pinned-pinned structure (clamped in two places), most energy in middle 2/3.
- Therefore, if partial covering, do in middle
- Covering ends does little
- Estimated effective loss factor:
 - $\eta_{\text{After}} = \eta / \{1 + [1/e_2 h_2 (3 + 6h_2 + 4h_2^2)]\}$
 - $e_2 = E_2/E_1$, ratio of dynamic moduli of damping matrl to that of material being treated
 - $h_2 = H_2/H_1$, ratio two thicknesses
 - In practice, NR rarely greater than 1-3 dBA because resonate structure is rarely the predominant source



9

Vibration Isolation

- Rotary or oscillatory mechanisms vibrate many machines
- Produce noise, affect production
- Vibration isolation reduces transmission of vibration to other structures
- Transmission reduced by blocking unbalanced forces (making resonant frequency much lower than exciting frequency)
- Vibration can be along all 3 axii and from torsion
- Transmission, $Tr = 20 \log (F_t/F_o)$, dB
 - F_t = force transmitted
 - F_o = exciting force
- To reduce force, $\omega > 1.414 \omega_o$
- At higher frequencies, damping reduces effectiveness of springs

10

Finding Resonant Frequency

- $\omega_n = \omega_o = \text{natural} = \text{resonant} = \text{fundamental}$
- $\omega_n = (k/m)^{0.5}$, rad/s
- K = static deflection
m = mass
- $f_n = (1/2\pi) (k/m)^{0.5}$, Hz

11

Vibration Isolation Steps

- Determine the frequency of the machine to be isolated
- Determine the equivalent weight each isolator must support
- Select the percent of isolation, R, desired
Calculate equivalent transmissibility (T)
- Compute frequency ratio, w/w_o
- Compute required static deflection
- Select isolator from supplier

12

Cautions and Guidelines

- Weight of vibrating equipment may be unevenly distributed, so be prepared to deal with it.
- All isolators must have same deflection
- Common mistake to avoid: Failing to consider stiffness of the supporting structure.
 - Soft supporting structure can show *increased* amplitude if error.
 - Solve by:
 - over-isolating system
 - or put system on inertial block (large mass, not size) and isolate combined system
- Consider stability of system for large deflections
 - Could fall over or turn over when switched on.
 - Place motor on large inertial base and isolate combined system

13

Cautions and Guidelines -- Continued

- Damping in isolators increases transmissibility and reduces degree of isolation.
- Isolated system more flexible, so vibrates at larger amplitudes.
 - Critical when connecting to external
 - Solution: locate all system components on same inertial block to reduce connections that are external
- For connections that cannot be put on same block, isolate connection
 - Example: fan connected to ducts
 - Solution: flexible connections
- If several parts are vibrating, likely that one with lowest frequency is exciting the rest

14

Cautions and Guidelines – continued

- Cleaning fluids, oils, ozone, etc. can affect isolators
- Not all systems show only rigid-body resonant frequencies. Can have natural frequency, also. Clas: look up difference.
- Not all isolators (and supports) show only stiffness. Can have natural frequency, also.
- Isolating equipment usually can reduce annoyance, not significantly reduce exposures.

15

Dealing with the Isolated Mechanism's Natural Frequency

- Greatest isolation with little damping, springs only
- Downside of using only springs: pass through resonance
 - During start up, stopping
 - Worse during stopping since slower
 - Solutions:
 - Speed-braking
 - Isolators with excursion limits
 - Some damping (but reduces isolation)

16

Table 9.7: Damping Factors for Commonly Used Resilient Media

Material	Approx. Damping Factor, $\xi = C/C_c$
Steel spring	0.005
Elastomers:	---
Natural rubber	0.05
Neoprene	0.05
Barry Hi Damp	0.15
Barry LT	0.11
Friction damped springs	0.33
Metal mesh	0.12
Air damping	0.17
Felt and cork	0.06

17

Example 9.4

18

Vibration Control: M.P. Norton

- Some additional general rules to be observed in relation to industrial noise and vibration control are listed below.
 - 1. Changes in force, pressure, or speed lead to noise - rapid changes generate higher dominant frequencies.
 - 2. Low frequency sound waves readily bend around obstacles and through openings.
 - 3. High frequency sound waves are highly directional and very easy to reflect.
 - 4. Close to a source, high frequency noise is more annoying than low frequency noise.
 - 5. High frequency noise attenuates quicker with distance than low frequency noise.
 - 6. Sound sources should be positioned away from reflecting surfaces.
 - 7. Structure-borne vibrations require large surface areas to be converted into air-borne sound - thus small vibrating objects radiate less noise than large vibrating objects.
 - 8. Structure-borne sound propagates over very large distances.
 - 9. Vibrating machinery should be mounted on a heavy foundation wherever possible.
 - 10. Damped mechanically excited structures produce less noise radiation.
 - 11. Resonances transferred to a higher frequency (via stiffening a structure) are easier to damp.
 - 12. Correctly chosen flexible mountings isolate machine vibrations.
 - 13. Free edges on panels allow pressure equalisation around them and reduce radiated noise levels - thus when covers are only used for protection, perforated mesh panels are more desirable than solid covers.

19

The End

20