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Structural Damping by the Use of Fibrous Blankets

by

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Outline

- Introduction
- Experimental study
- Theoretical study
- Energy analysis
- Conclusions
Introduction

- The damping effect of fibrous materials on a vibrating structure was first studied by direct measurement.
- Light acoustical materials can be used to suppress structural vibrations.
- Study energy dissipation mechanisms based on vibro-acoustic interaction.
- Design an acoustical liner for vibration suppression, as well as noise reduction.
Experimental Results

*: excitation point
: measurement point

Spatially averaged:

\[
\overline{\left(\frac{V}{F}\right)} = \frac{1}{25} \sum_{i=1}^{25} \left(\frac{V}{F}\right)_i
\]

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Theoretical Analysis of Structural Damping

- To represent effect of fibrous material explicitly
- Beam mounted in hard walled duct
- Express beam and acoustical response in a modal form
- Represent the fibrous material as an equivalent fluid
- Obtain beam transverse velocity response based on boundary conditions
Simply Supported Beam:

\[ EI \frac{\partial^4 w}{\partial x^4} + \rho_s h \frac{\partial^2 w}{\partial t^2} = F \delta(x - x_0) e^{i\omega t} - p_1(x,0,t) \]

\[ p_2(x,y,t) = \sum_{l=0}^{\infty} d_l \cos \left( \frac{l\pi x}{L} \right) e^{i(\omega t - k_{y,l} y)} \]

\[ p_1(x,y,t) = \sum_{m=0}^{\infty} \left[ b_m e^{i(\omega - k_{p,ym} y)} + c_m e^{i(\omega + k_{p,ym} y)} \right] \cos \left( \frac{m\pi x}{L} \right) \]
2-D Theoretical Study

Boundary Conditions:

(i) \( y = 0 \rightarrow \text{Beam E.O.M. satisfied} \)

(ii) \( y = 0^+ \rightarrow j \omega W = v_1 \)

(iii) \( y = d \rightarrow p_1 = p_2 \)

(iv) \( y = d \rightarrow v_1 = v_2 \)
From the 4 BC's, rewriting 4 equations into a matrix expression:

\[
\begin{pmatrix}
I_{n \times n} & D_{n \times m} & D_{n \times m} & 0_{n \times m} \\
I_{n \times n} & C_{n \times m} & -C_{n \times m} & 0_{n \times m} \\
0_{m \times n} & \text{Diag}(e^{-jk_{pym}d})_{m \times m} & \text{Diag}(e^{jk_{pym}d})_{m \times m} & \text{Diag}(-e^{-jk_{ym}d})_{m \times m} \\
0_{m \times n} & \text{Diag}(e^{-jk_{pym}d})_{m \times m} & \text{Diag}(e^{jk_{pym}d})_{m \times m} & \text{Diag}\left(-\frac{k_{ym}\rho_c}{k_{pym}\rho_0} e^{-jk_{ym}d}\right)_{m \times m}
\end{pmatrix}
\begin{pmatrix}
a_1 \\
a_n \\
b_0 \\
b_{m-1} \\
c_0 \\
c_{m-1} \\
d_0 \\
d_{m-1}
\end{pmatrix}
= \begin{pmatrix}
f_1 \\
f_n \\
0 \\
0 \\
0 \\
0 \\
0 \\
0
\end{pmatrix}
\]
Theoretical Results

S-S beam:

air loading

\[ x = 0 \quad F \quad x = L \]

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Theoretical Results

Spatially-averaged:

\[
\left( \frac{V}{F} \right) = \left| \frac{1}{L} \int_0^L \frac{v(x)}{F} \, dx \right|
\]
Energy Dissipation

Total Power Input: \[ P_{in} = \frac{1}{2} \text{Re}\{Fv_b^*(x_o)\} \]

Beam Internal Dissipation: \[ P_{diss,beam} = \frac{1}{2} \text{Re}\left\{ \int_0^L \left[ F\delta(x-x_o) - p_1(x,0) \right](v_{1y})^* \, dx \right\} \]

Dissipation in Fibrous Layer: \[ P_{diss,fib} = \int_0^L I_{1y}(x,0) \, dx - \int_0^L I_{1y}(x,d) \, dx \]

Dissipation from Radiation: \[ P_{rad,air}(y) = \int_0^L I_{2y}(x,y) \, dx = \int_0^L \frac{1}{2} \text{Re}\left\{ p_2(x,y)v_{2y}^*(x,y) \right\} \, dx \]
\[ P_{out} = P_{diss,\, beam} + P_{diss,\, fib} + P_{rad,\, air} \]
Conclusions

- A light fibrous blanket provides vibration damping for a structure that responds modally.

- The representation of fibrous material as an equivalent fluid simplifies study of the interactions between fibrous materials and vibrating structures.

- Energy analysis can be used to rank the dissipation resulting from the various damping mechanisms.

- In the present case most energy dissipated interaction of structure’s nearfield and the fibrous blanket