Investigation of the Vibrational Modes of Edge-Constrained Fibrous Samples Placed in a Standing Wave Tube

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INVESTIGATION OF THE VIBRATIONAL MODES OF EDGE-CONSTRAINED FIBROUS SAMPLES PLACED IN A STANDING WAVE TUBE

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• Measurement of the surface normal velocity of vibrating panels or plates [Kruger and Mann (1999) and Muller and Moslehy (1996)]

• Estimation of the mechanical properties (Young’s modulus and Poisson’s ratio) of foam materials by the laser vibration measurement [Mariez et al. (1996) and Dubbelday (1992)]

• Electromagnetic approach for measuring the vibrational velocity of the frame of flexible porous materials (Khirnykh and Cummings, 1999)
Introduction

• Investigation of edge constraint effect on samples placed in a modified standing wave tube (J. S. Bolton et al., SAE 1997; B. H. Song et al., JASA 1999).

• Internal constraints may be used to selectively enhance the transmission loss of lining materials at low frequencies (B. H. Song et al., JASA 2001).

• Implications for design of low frequency noise control barriers following from constraint of porous lining materials around their edges.
Glass Fiber Material inside of Sample Holder
Four Microphone Measurement
Transfer Matrix Approach I

\[
\begin{bmatrix}
P \\
V
\end{bmatrix}_{x=0} = \begin{bmatrix}
T_{11} & T_{12} \\
T_{21} & T_{22}
\end{bmatrix} \begin{bmatrix}
P \\
V
\end{bmatrix}_{x=d}
\]

\[T_{11} = T_{22}\] symmetry

\[T_{11} T_{22} - T_{12} T_{21} = 1\] reciprocity

- Solve for transfer matrix elements

4 Equations
Transfer Matrix Approach II

\[
\begin{bmatrix}
1 + R_a \\
1 - R_a \\
\rho_0 c_0
\end{bmatrix}
= 
\begin{bmatrix}
T_{11} & T_{12} \\
T_{21} & T_{22}
\end{bmatrix}
\begin{bmatrix}
T_a e^{-jkd} \\
T_a e^{-jkd} \\
\rho_0 c_0
\end{bmatrix}
\]

- Anechoic Reflection Coefficient

\[
R_a = \frac{T_{11} + \frac{T_{12}}{\rho_0 c} - \rho_0 c T_{21} - T_{22}}{T_{11} + \frac{T_{12}}{\rho_0 c} + \rho_0 c T_{21} + T_{22}}
\]

\[\alpha = 1 - |R_a|^2\]

\[z_n = \frac{1 + R_a}{\rho_0 c} \frac{1 - R_a}{1 - R_a}\]

- Anechoic Transmission Coefficient

\[
T_a = \frac{2 e^{jkd}}{T_{11} + \frac{T_{12}}{\rho_0 c} + \rho_0 c T_{21} + T_{22}}
\]

\[TL = 10 \log(1/|T_a|^2)\]
Experimental Setup for Low Frequency Tube
Anechoic Transmission Loss
(3” Sample A in a Large Tube)

Increase in TL due to edge constraint

3 dB
Surface Normal Impedance
(3” Sample A in a Large Tube)
Poroelastic Material Properties used in Calculations

<table>
<thead>
<tr>
<th>Material</th>
<th>Bulk density (Kg/m³)</th>
<th>Porosity</th>
<th>Tortuosity</th>
<th>Flow resistivity (MKS Rayls/m)</th>
<th>Shear modulus (Pa)</th>
<th>Loss factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample A</td>
<td>6.73</td>
<td>0.99</td>
<td>1.1</td>
<td>21000</td>
<td>1200</td>
<td>0.35</td>
</tr>
</tbody>
</table>
Investigation of Vibrational Modes of Glass Fiber Materials (1” Sample A)
Laser Measurement Setup
(Large Tube, 1” Sample A)
Three-Dimensional Finite Element Model
Schematic of Edge- and Plane-Constrained Sample with Reflecting Tapes

Edge-constrained Sample

Plane-constrained Sample
Glass Fiber Materials with Reflecting Tape
Effect of Reflecting Tape on TL (1” Sample A)

![Graph showing the effect of reflecting tape on TL (Transmission Loss) at different frequencies. The graph compares TL with and without reflection tapes, along with FE prediction. The x-axis represents frequency (Hz), and the y-axis represents TL (dB).]

- Without reflection tapes
- With reflection tapes
- FE prediction

Frequency (Hz) vs. TL (dB)
Coherence Between Reference Microphone and the Laser Velocity Signal (1” Sample A)
FEM-Predicted Normalized Frame Velocity in Large Tube, Anechoic Termination Case (1"")

1” Sample:
- Edge-constrained Sample
- Plane-constrained Sample
The 1\textsuperscript{st} and 2\textsuperscript{nd} Mode Shapes of the Edge-constrained Sample (1")

1\textsuperscript{st} Mode at 100 Hz

2\textsuperscript{nd} Mode at 350 Hz
The 1\textsuperscript{st} and 2\textsuperscript{nd} Mode Shapes of the Plane-constrained Sample (1”)

1\textsuperscript{st} Mode at 200 Hz

2\textsuperscript{nd} Mode at 500 Hz
Normalized Frame Velocity of Sample in Large Tube, Hard Termination Case (1"")

Edge-constrained

Plane-constrained
Conclusions

- **Direct measurements** show the vibrational velocity of the solid skeleton of fibrous sample placed in a standing wave tube.
- The **vibrational characteristics** are well predicted by using poroelastic FE model (COMET/SAFE).
- **Vibrational modes** of edge- and plane-constrained fibrous layers have been verified using a laser vibrometer measurement.