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THE USE OF INTERNAL CONSTRAINTS TO ENHANCE THE SOUND TRANSMISSION LOSS OF POROELASTIC LININGS

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Introduction

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

- Internal constraints may be used to selectively enhance the transmission loss of lining materials at low frequencies.

- Implications for design of low frequency noise control barriers following from constraint of porous lining materials around their edges.
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
Transfer Matrix Approach II

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

- Anechoic Reflection Coefficient

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

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

\[
Z_n = \frac{1 + R_a}{1 - R_a}
\]

- Anechoic Transmission Coefficient

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

\[
TL = 10 \log(1/|T_a|^2)
\]
Anechoic Transmission Loss

Frequency (Hz)

TL (dB)

- Experiment
- Prediction using FEM (with edge constraint)
- Prediction without edge constraint

Increase in TL due to edge constraint

Shearing mode
Surface Normal Impedance
(Change from mass-like reactance to stiffness reactance)

Re(Zn)

Frequency (Hz)

Im(Zn)

Frequency (Hz)
Variation of Shear Modulus
(As $G$ increases, the shearing resonance moves to higher frequency)
**Flow Resistivity**

(Controls TL in low and high frequency limits)

**Loss Factor**

(Loss factor controls depth of TL minimum)

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**Flow Resistivity**

- Flow resistivity = 20,000 MKS Rayls/m
- Flow resistivity = 40,000 MKS Rayls/m
- Flow resistivity = 60,000 MKS Rayls/m

**Loss Factor**

- Loss factor = 0.1
- Loss factor = 0.3
- Loss factor = 0.5
Effect of Sample Size

Experimental Setup for Low Frequency Tube

B & K Type 3560 Pulse System (Four Channel)

Signal Generator

Signal Amplifier

Microphones

Anechoic Termination

New Sample Holder

Two-Microphone Impedance Measurement Tube B & K Type 4206

Aviation grade glass fiber

\[ \rho = 9.61 \frac{Kg}{m^3} \]

10 cm

7.5 cm
Constrained around Edge (50 Hz - 1600 Hz)
Constrained along Plane (50 Hz - 1600 Hz)
Constrained Cross (50 Hz - 1600 Hz)
Transmission Loss (FEM)

- Unconstrained case
- Constrained around edge
- Constrained along plane
- Constrained cross

Frequency (Hz) vs. Transmission Loss (TL) (dB)
Effect of flow resistivity on TL for cross constrained case

- Flow resistivity = 20,000 MKS Ralys/m
- Flow resistivity = 40,000 MKS Ralys/m
- Flow resistivity = 60,000 MKS Ralys/m

![Graph showing TL (dB) vs Frequency (Hz) for different flow resistivities.](image)
△ TL constrained and unconstrained cases

[Panel (Al, 0.762 mm)+Air+Glass fiber (7.5 cm)+Air+panel (Al, 0.762 mm)]
Δ TL constrained and unconstrained cases

[Panel (Al, 0.762 mm)+Air+Glass fiber (7.5 cm)+Air+panel (Al, 0.762 mm)]
Transmission Loss (100 Hz - 6400 Hz)

(10 cm samples very nearly approximates unconstrained case)
Conclusions

- Acoustical performances of fibrous layers such as transmission loss and absorption coefficient are affected by constraint on the boundary of the samples.
- The various constrained effects are well predicted by using poroelastic FEM model (COMET/SAFE).
- Light and stiff fibrous materials combined with edge and internal constraint mechanisms can be used to design, light, high performance low frequency noise control barriers.