Effect of Circumferential Edge Constraint on the Transmission Loss of Glass Fiber Materials

J. Stuart Bolton  
*Purdue University*, bolton@purdue.edu

Bryan Song

Yeon June Kang  
*Seoul National University*

Follow this and additional works at: [http://docs.lib.purdue.edu/herrick](http://docs.lib.purdue.edu/herrick)
Effect of Circumferential Edge Constraint on the Transmission Loss of Glass Fiber Materials

Bryan H. Song and J. Stuart Bolton
Ray W. Herrick Laboratories
Purdue University

Yeon June Kang
Seoul National University
Introduction

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

- **How:** Comparison of TL and impedance measurements with FEM predicted results using an axisymmetric model COMET / SAFE (Y. J. Kang et al., JASA 1999). Demonstration of how the materials’ mechanical and physical properties control TL

- **What:** Implications for design of low frequency noise control barriers following from constraint of porous lining materials around their edges.
Experimental Setup High Frequency Tube

- Dual Channel Signal Analyzer B & K Type 2032
- Computer
- Signal Amplifier
- Microphones
- Two-Microphone Impedance Measurement Tube B & K Type 4206
- Anechoic Termination
- New Sample Holder

- 2.9 cm diameter samples, 7.5 cm deep
- Aviation grade glass fiber, 9.61 Kg/m³
Transfer Matrix Approach I

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

\[
T_{11} = T_{22} \quad \text{(symmetry)}
\]

\[
T_{11}T_{22} - T_{12}T_{21} = 1 \quad \text{(reciprocity)}
\]

- Solve for transfer matrix elements

\[
\begin{bmatrix}
12 \\
11
\end{bmatrix} \quad \begin{bmatrix}
2221 \\
12
\end{bmatrix}
\]

\[
\begin{bmatrix}
11 \\
22
\end{bmatrix}
\]

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

\[
(\text{symmetry})
\]

\[
(\text{reciprocity})
\]
Transfer Matrix Approach II

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

- **Anechoic Reflection Coefficient**

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

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

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

- **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

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

Increase in TL due to edge constraint
Shearing mode

Frequency (Hz)

TL (dB)
Anechoic Absorption Coefficient

![Graph showing absorption coefficient vs frequency]

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

Frequency (Hz)

Absorption coefficient
Surface Normal Impedance

- Change from mass-like reactance to stiffness reactance
Estimation of Material Mechanical Properties

- **Error surface**

- **Objective Function**

\[
J = \sum_i \left| \frac{\alpha_{m_i} - \alpha_{FEM_i}}{\alpha_{m_i}} \right|^2 + \sum_i \left| \frac{TL_{m_i} - TL_{FEM_i}}{TL_{m_i}} \right|^2
\]

<table>
<thead>
<tr>
<th>Bulk density (kg/m(^3))</th>
<th>Measured Flow resistivity (MKS Rayls/m)</th>
<th>Porosity</th>
<th>Tortuosity</th>
<th>Young's modulus factor (Pa)</th>
<th>Loss factor</th>
<th>Poisson ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.61</td>
<td>24400 / 40000</td>
<td>0.99</td>
<td>1.1</td>
<td>8250</td>
<td>0.5</td>
<td>0.45</td>
</tr>
</tbody>
</table>

+ Minimum location
• **Shear modulus** controls minimum location in TL curve

\[ G = \frac{E}{2(1+v)} = 2845 \text{ Pa} \]
• As shear modulus increases, the minimum location moves to higher frequencies.

Variation of Shear Modulus

![Diagram showing the variation of shear modulus with frequency.](image-url)
Flow Resistivity

- Flow resistivity controls TL in **low and high frequency limit**

![Graph showing flow resistivity controls TL](Image)

<table>
<thead>
<tr>
<th>Flow Resistivity (MKS Rayls/m)</th>
<th>TL (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20000</td>
<td>15</td>
</tr>
<tr>
<td>40000</td>
<td>10</td>
</tr>
<tr>
<td>60000</td>
<td>5</td>
</tr>
</tbody>
</table>

Loss Factor

- Loss factor controls depth of TL minimum

![Graph showing loss factor controls TL](Image)

<table>
<thead>
<tr>
<th>Loss Factor</th>
<th>TL (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>15</td>
</tr>
<tr>
<td>0.3</td>
<td>10</td>
</tr>
<tr>
<td>0.5</td>
<td>5</td>
</tr>
</tbody>
</table>
Axial Particle Velocity at the Front of Sample

- Solid phase (unconstrained)

- Fluid phase (unconstrained)

- Solid phase (constrained)

- Fluid phase (constrained)
Solid Phase of Constrained Sample (SDX)

- **200 Hz**
- **1100 Hz**
- **500 Hz**
- **1800 Hz**
Fluid Phase of Constrained Sample (ADX)

- **200 Hz**

- **1100 Hz**

- **500 Hz**

- **1800 Hz**
Effect of Sample Size
Experimental Setup for Low Frequency Tube

- 10 cm diameter samples, 7.5 cm deep
- Aviation grade glass fiber, 9.61 Kg/m³
Transmission Loss (50 Hz - 1600 Hz)

![Graph showing Transmission Loss (TL) in dB vs Frequency (Hz)]
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 edge constraint effect is well predicted by using poroelastic FEM model (COMET/SAFE).
- Light and stiff fibrous materials combined with edge constraint mechanisms may enable us to design, light, high performance low frequency noise control barriers.