Validation of Micro-Perforated Panels Models

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Validation of Micro-perforated Panels Models

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Validation of Micro-perforated Panels Models

Outline

- Models for the Micro-perforated Panel
  - Maa Model
  - Modified Maa Model
  - FEM Model (based on rigid porous frame)

- Advance for Impedance Tube
  - Four Microphone Impedance Tube Measurement
  - Error Analysis & Calibration Procedure

- Results & Conclusion

- Future Work
  - Modified FEM Model
  - Elastic Porous Frame
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Introduction to the MPP & Maa Model

Classical MPP Models

  - Allard’s Modal Approach
  - Beranek/Ingard Model
  - …..

MPP Models Validation

- Analytical~Maa Model (1987)
- Numerical~Finite Element Method
- Experimental~Four Microphone Impedance Tube

Classical Maa Model (1998)

- Environmentally friendly
- Good low frequency performance
- Affordable in the recent!

- No Flexural Motion
- No hole interaction
- Resistive Underestimation
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Modified Maa Models

MPP Impedance

\[
Z = \frac{Z_1}{\phi \rho_0 c} = r + j \omega m
\]

- **Z_1**: specific acoustic impedance
- **\( \phi \)**: porosity
- **r**: resistance
- **m**: effective mass per unit area
- **x**: perforation constant

Contribution from hole

\[
r = \frac{32 \eta}{\phi \rho c} \frac{t}{d^2} \left( \sqrt{1 + \frac{x^2}{32}} \right) + \beta \alpha \frac{2xd}{8t}
\]

- **End corrections**

- \( \beta = 1.5 \) *Introduce constant parameter to modify the resistive end correction*

End correction

Shearing region

Based on Ingard's semi-empiristic formula for perforated panels

**Account for the hole interaction**

\[
\alpha = 1 - 3\sigma
\]
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Absorption Coefficient & Transfer Impedance

Absorption Coefficient

\[ \alpha_n = \frac{4r}{(1+r)^2 + \left(\omega m - \cot\left(\frac{\omega L}{c}\right) \right)^2} \]

- Resistive part determines absorption peak location
- Reactive part determines absorption peaks height

Transfer Impedance

2-Microphone & 4-Microphone

- A straightforward way to investigate the material impedance
- Avoid the numeric error
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Finite Element Model

\[ \alpha_e = 1 + \frac{2 \varepsilon_e}{t} \]

\[ \varepsilon_e = 0.48 \sqrt{\phi^2 (1 - 1.14 \phi)} \]

\[ \sigma = \frac{32 \eta}{\phi d^2} \]

\[ \Lambda = \Lambda' = \frac{d}{2} \]

\[ \phi : \text{ porosity} \]
\[ \sigma : \text{ flow resistivity} \]
\[ \Lambda : \text{ viscous char length} \]
\[ \Lambda' : \text{ thermal char length} \]
\[ \alpha_e : \text{ equivalent tortuosity} \]

Parameters Required

All the existing models can be obtained from an equivalent fluid model by selecting the appropriate parameters.

Impedance Tube

Software Simulation

Rigid Porous Material

Equivalent Tortuosity

Johnson-Allard Model

MPP
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Recent Development for the Impedance Tube

- Standard Two Microphone Impedance Tube Measurement
- Four Microphone Impedance Tube Measurement

better suited for extraction of material properties

\[
\begin{bmatrix}
T_{11} & T_{12} \\
T_{21} & T_{22}
\end{bmatrix} = \begin{bmatrix}
\cos k_p d & j \rho_p c_p \sin k_p d \\
j \sin k_p d / \rho_p c_p & \cos k_p d
\end{bmatrix}
\]

Transfer Impedance

\[
Z_t = P_0 / V_0 - P_d / V_d
\]
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Non-Switching Approach

- Error Sources
  - Microphone Mismatch
  - Bias Error
  - Tube Attenuation

Single microphone moves to location 1, 2, 3, 4

- For low transmission loss materials, phase mismatch is major concern
- Non-Switching approach can avoid phase mismatch phenomenon
- Accuracy depends on the stationary of electronic systems and FFT average

\[ H_{21}^{'2} = (H_{11}^t \cdot H_{11}^{I1})^{1/2} \]

\[ \tilde{H}_{21} = H_{21} / H_{21}^c \]
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Experiment Setup

Tested Material: Brass Sample

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Diameter d [mm]</th>
<th>Hole Depth t [mm]</th>
<th>Porosity φ [%]</th>
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</table>

Hardware: B&K Type 4206 (2.9cm diameter)

Software: COMET/ACOUSTICS-SAFE
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Results-Low Perforation Rate

- Maa Model underestimate resistive part of the impedance in low perforation rate case
- FEM model is acceptable
- The highlighted peak comes from the flexural panel vibration
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Results-High Perforation Rate

- Maa model overestimates the reactance due to neglect of hole interaction
- Improved Maa Model gives the best match with experimental results
Conclusion

- Analytical, numerical and experimental results for micro-perforated brass panels were compared.

- An improved Maa model was proposed to take into account hole interactions and modification of end corrections.

- An improved impedance tube measurement was set to give more accurate experimental results.
Future Work

- Further experiment should be taken to correct the equivalent tortuosity in the FEM model.

- It's possible to use FEM to take into account the flexural vibration of MPP.

- FEM model also has the potential to be used in the complicated structures.