12-1986

Acoustic Energy Propagation in Noise Control Foams: Approximate Formulae for Surface Normal Impedance

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

E. R. Green

Follow this and additional works at: http://docs.lib.purdue.edu/herrick

http://docs.lib.purdue.edu/herrick/8

This document has been made available through Purdue e-Pubs, a service of the Purdue University Libraries. Please contact epubs@purdue.edu for additional information.
ACOUSTIC ENERGY PROPAGATION
IN NOISE CONTROL FOAMS:
APPROXIMATE FORMULAE FOR
SURFACE NORMAL IMPEDANCE

J. S. Bolton
E. R. Green

Ray W. Herrick Laboratories
School of Mechanical Engineering
Purdue University
West Lafayette, IN 47907

HERRICK LABS / PURDUE UNIVERSITY
INTRODUCTION

Noise Control Foam:
- has two phases
  - solid ("frame")
  - air
- supports two wave types
  - frame wave
  - airborne wave

Investigate:
- division of acoustic energy between phases
- division of acoustic energy between wavetypes

Why:
- to identify possible simplifications in acoustical modelling.

HERRICK LABS / PURDUE UNIVERSITY
TYPE OF FOAM

Industrial grade polyurethane foam most often used in noise control applications is:

— RELATIVELY STIFF

— PARTIALLY RETICULATED

- Relatively stiff: Static bulk modulus of elasticity
  \[ \geq \rho_0 c^2 \]

- Partially Reticulated: Foam cells are partially closed by residual membranes
MODEL OF ELASTIC POROUS MATERIAL

Generalized Rayleigh Model

- Angled pores in elastic matrix

\[ V_1 \rightarrow \text{frame velocity} \]
\[ V_2 \rightarrow \text{fluid velocity} \]
\[ P_1 \rightarrow \text{force/unit area applied to solid component} \]
\[ P_2 \rightarrow \text{force/unit area applied to fluid component} \]

Coupling:

- Inertial
- Viscous
- Pressure
STRESSES IN FOAM - SEALED

1. FRAME (P₁):

![Graph of Frame Wave]

- - - - - - , Total
- - - - - - , F - Wave
- - - - - - , A - Wave

2. Air (P₂):

![Graph of Air Wave]

- - - - - - , Total
- - - - - - , F - Wave
- - - - - - , A - Wave

CONCLUSION: Frame wave dominates

HERRICK LABS / PURDUE UNIVERSITY
VELOCITIES IN FOAM - SEALED

1. FRAME \( (V_1) \):

| \( |V_1| \times 10^{-3} \) |
|--------------------------|
| 8.0                      |
| 6.0                      |
| 4.0                      |
| 2.0                      |
| 0.0                      |

- , Total
- , F - Wave
- , A - Wave

Depth [m]

2. Air \( (V_2) \):

| \( |V_2| \times 10^{-3} \) |
|--------------------------|
| 8.0                      |
| 6.0                      |
| 4.0                      |
| 2.0                      |
| 0.0                      |

- , Total
- , F - Wave
- , A - Wave

Depth [m]

CONCLUSION: Frame wave dominates

HERRICK LABS / PURDUE UNIVERSITY
**IMPEDANCE CALCULATIONS - SEALED**

\[ Z = Z_1 + Z_2 \quad \text{(both wave types),} \]
\[ = Z_1 + Z_2 \quad \text{(frame wave only),} \]
\[ = Z_1, \quad \text{(\(\zeta_n = Z/\rho_o c\))} \]

---

**Graphical Representation:**

- **Real Part (Re(\(\zeta_n\))):**
  - Constant values across frequency.
  - Frequency range from 0.00 to 10.0 kHz.
  - Values range from 0.00 to 20.0.

- **Imaginary Part (Im(\(\zeta_n\))):**
  - Constant values across frequency.
  - Frequency range from 0.00 to 10.0 kHz.
  - Values range from 0.00 to 2.50.

---

**Legend:**

- **HERRICK LABS / PURDUE UNIVERSITY**
STRESSES IN FOAM - OPEN

1. FRAME ($P_1$):

CONCLUSION:

At Surface:  - No simplification of $P_1$ possible.
  - $P_2$ mostly airborne wave (eventually frame wave).

HERRICK LABS / PURDUE UNIVERSITY
CONCLUSION:
At Surface:  - No simplification of $V_1$.
            - $V_2$ approximately airborne wave (eventually frame wave).

HERRICK LABS / PURDUE UNIVERSITY
IMPEDEANCE CALCULATIONS - OPEN

\[ Z = \left[ \frac{(1-h)^2}{Z_1} + \frac{h^2}{Z_2} \right]^{-1} \quad \text{(both wave types)}, \]

\[ = \frac{Z_2}{h^2} \quad \text{(both wave types)}, \]

\[ = \frac{Z_2}{h^2} \quad \text{(airborne wave only)}, \]

\[ \begin{array}{c}
\text{Re}\{\xi_n\} \\
\text{Im}\{\xi_n\}
\end{array} \]

\[ \text{Frequency [kHz]} \]

HERRICK LABS / PURDUE UNIVERSITY
CONCLUSIONS

FOR NOISE CONTROL FOAMS:

1. Surface Normal Impedance of Infinite Layers:
   - Sealed: - Airborne wave negligible
     - Air component contribution small
   - Open: - Both wave types must be considered
     - Frame component contribution is small due to porosity effect.

2. Surface Normal Impedance of Finite Depth Layers:
   - Sealed: - Airborne wave negligible
     - Air component contribution small
     (continuously bonded to backing).
   - Open: - No simplification possible in general.