EVALUATION OF MATERIALS FOR NOISE CONTROL

Technical Advisor: Dr. W. Eversman
Revised: 1/01/01
2.1 GENERAL OBJECTIVES

1. To evaluate the absorption characteristics of materials used for noise control at various frequencies.

2. To gain insight into the effects of material thickness and air space behind the material on its normal incidence absorption coefficient.

2.2 INTRODUCTION

Control of noise produced by mechanical devices almost always requires the use of acoustical materials, either individually or in combination. Two types of acoustical materials are available. One type “absorbs” incident sound waves by converting most of the acoustical energy into minute amounts of heat. A porous structure is required, so that incident sound waves will propagate into the material where viscous flow losses and friction dissipate some of the energy. The remaining acoustical energy is reflected from the structure or transmitted through it. Examples of absorbing materials are ceiling tile, glass fiber mats and boards of all types, and open cell foams.

A second type of acoustical material serves as a barrier by attenuating incident sound waves from one side to the other. By nature, an acoustical absorber is a poor attenuator (or barrier) because too much of the acoustic energy propagates through its porous structure. On the other hand, the dense, nonporous characteristic of a barrier, make it a good reflector (and a poor absorber) of incident sound waves. Examples of barrier materials are metal panels, “loaded” vinyl sheet, masonry, wood gypsum board, and combinations thereof.

All acoustical materials and structures perform better at some frequencies than others. For this reason, a frequency analysis of the noise to be controlled is almost always required. Once the “worst” frequencies (from an annoyance standpoint) have been identified, acoustical materials and structures can be selected or designed to provide maximum noise reduction at lowest cost.

Measurement of the absorption characteristics of acoustical materials can be accomplished with normally incident, or randomly incident, sound waves. Although random incidence more nearly approximates conditions of actual use, measurements at normal incidence are much easier to obtain and are valuable for rank-ordering of acoustical absorbing materials and structures.

The measurement of the acoustical absorption coefficient for normally incident sound ($\alpha_n$) requires a “standing wave” or “impedance” tube. The coefficient $\alpha_n$ is the ratio of energy absorbed by a sample to the energy incident upon the sample, as a function of the frequency of the incident sound. The dependence on frequency is determined mainly by configuration and a spacing of pores, material thickness, thickness of air space behind the material, and the type of facing (cover, in front of material) employed. Because $\alpha_n$ is frequency-selective, its value is usually measured over a range of frequencies (125 to 4000 Hz) that comprises the range of architectural interest.
2.3 EXPERIMENTAL SETUP

A standing wave tube is shown in Figure 2.1. Sound at a single preselected frequency is broadcast into the tube, where it produces a sound field consisting of incident and reflected sound waves. This field is explored by a probe tube, which is small enough to prevent interference with the field. The sound field itself is plane, providing that the diameter of the tube is less than $\lambda/2$, where $\lambda$ is the wavelength of the test frequency.

The movable microphone probe measures the sound intensity at any desired location in the tube. The sound intensity level at that location in decibels can be read by the sound level meter.

\[
L_p = 10 \log_{10} \left( \frac{P_{\text{rms}}}{P_{\text{ref}}} \right)^2 \text{dB}
\]

Where, \( P_{\text{rms}} \) = root mean squared value of pressure
\( P_{\text{ref}} \) = ANSI value of reference pressure
\[
= 2 \times 10^{-5} \text{ N/m}^2
\]

A variety of acoustic samples of different thickness are provided along with a sample holder. The sample holder is also adjustable so that an airspace can be provided behind the sample.

2.4 DATA ACQUISITION

Let us first identify what data we should acquire to measure the normal incidence absorption coefficient, \( \alpha_n \). Consider location \( x \) along the tube, and an incident plane sound wave with pressure \( p_i \) given by,

\[
p_i = A \sin (\omega t)
\]

(2.1)

The reflected wave at \( x \) is nothing more that an earlier incident wave that has had time to travel to the sample and back. Therefore, its amplitude may be reduced, and it will be shifted in phase relative to the incident wave. This phase shift results from the difference in distance traveled \((2x)\), and a phase angle between incident and reflected waves introduced by the sample.

The combined phase lag is \( 2x(\omega/c) + \theta \)

\( \omega \) = frequency of sound wave, radians/second
\( c \) = propagation velocity of sound wave in standing wave tube, feet/second
\( \theta \) = phase shift at sample, radians
The reflected wave $p_r$ is therefore,

$$ p_r = B \sin \left[ \omega t - \left( \frac{2 \omega x}{c} + \theta \right) \right] $$  \hspace{1cm} (2.2)

At location $x$, the two waves combine to form a single wave (a “standing wave”), with frequency $\omega$.

The pressure at a point $x$ from the termination of the pipe is the sum of the incident and reflected pressure waves.

$$ p_i = p_r + p_r = A \sin \omega t + B \sin \left[ \omega t - \left( \frac{2 \omega}{c} x + \theta \right) \right] $$  \hspace{1cm} (2.3)

The amplitude of this combined pressure wave is then,

$$ |p_i| = \sqrt{A^2 + B^2 + 2AB \cos(2\left(\frac{\omega}{c}\right)x + \theta)} $$  \hspace{1cm} (2.4)
As \( x \) is varied, \( |p_x| \) will reach maximum and minimum values:

\[
|p_{t,\text{Max}}| = \sqrt{A^2 + B^2 + 2AB} = A + B \quad (2.5)
\]

\[
|p_{t,\text{Min}}| = \sqrt{A^2 + B^2 - 2AB} = A - B \quad (2.6)
\]

Recall that for sound waves,

Particle velocity \( \mathbf{v} = p / \rho c \)

Intensity \( I = p \cdot \mathbf{v} = p_{\text{rms}}^2 / \rho c \)

(energy per unit time per unit area)

where,

\[
c = \text{Propagation velocity} = 1130 \text{ fps (air at standard temperature and pressure)}
\]

\[
\rho = \text{mass density of medium}
\]

\[
\rho c = \text{“characteristic impedance” of medium}
\]

If no attenuation of sound waves occurs within the standing wave tube, the intensity of the incident wave at the face of the sample is proportional to \( A^2 \); the intensity of the reflected wave is proportional to \( B^2 \). Since no energy can escape (a rigid piston is located behind the sample), the energy absorbed is proportional to \( A^2 - B^2 \).

The normal absorption coefficient \( \alpha_n \) is defined as,

\[
\alpha_n = \frac{\langle \text{intensity absorbed} \rangle_{\text{avg}}}{\langle \text{intensity incident} \rangle_{\text{avg}}}
\]

where

\[
I_{\text{Avg}} = \frac{1}{T} \int_0^T \frac{P^2(t)}{\rho c} dt = \frac{P_{\text{rms}}^2}{\rho c}
\]

\[
\alpha_n = \frac{\begin{bmatrix} A^2 \\ 2\rho c \end{bmatrix} - \begin{bmatrix} B^2 \\ 2\rho c \end{bmatrix}}{\begin{bmatrix} A^2 \\ 2\rho c \end{bmatrix}} = 1 - \frac{B^2}{A^2} \quad (2.7)
\]
Using equations (2.5) and (2.6),

\[ \alpha_n = \frac{4|p_{r1}|_{\text{Max}}|p_{r1}|_{\text{Min}}}{(|p_{r1}|_{\text{Max}} + |p_{r1}|_{\text{Min}})^2} \]  

(2.8)

Therefore, by measuring standing wave maxima and minima (pressures) at various frequencies, the performance of an acoustical material or structure (\( \alpha_n \) vs \( \omega \)) can be determined.

2.4.1 PROCEDURE

See the attached data sheet

1. In order to qualify the standing wave tube, to begin with use no sample or airspace and mount the sample holder so that the tube is terminated with the rigid piston.

2. Set the frequency \( f \) (displayed on the electronic counter) to 125 Hz.

3. Traverse the receiver (microphone probe) to locate the first minimum pressure level (as shown by the sound level meter, set on the .Flat. scale with no filter). Record this value as \( L_{p,\text{min}} \) and the x-location as \( x_{\text{min}} \).

4. Continue traversing until the corresponding maximum pressure level is observed. Record this value as \( L_{p,\text{max}} \) and the x-location as \( x_{\text{max}} \).

5. For the next reading, double the frequency and repeat steps 3 and 4. Continue until the reading for 2000 Hz has been recorded.

6. Select an acoustic sample from the materials provided. Mount it using the sample holder. To start with use no airspace behind the sample, i.e., the sample is flush with the surface of the piston.

7. Repeat steps 2 to 5 for this case of sample thickness.

8. Increase the airspace behind the material to first 1” and then 2”and repeat steps 2 to 5.

9. Now set the frequency at 1000 Hz. With no airspace behind the sample, but choosing at least five samples with different thicknesses, repeat steps 3 and 4.

2.5 CALCULATIONS

1. \[ L_{p,\text{max}} - L_{p,\text{min}} = 20 \log_{10} \left( \frac{|p_{r1}|_{\text{max}}}{|p_{r1}|_{\text{min}}} \right) dB \]
2. Define Standing Wave Ratio, \( SWR = \frac{|p_r|_{\text{max}}}{|p_r|_{\text{min}}} \)

SWR can be found from Step 1.

3. Normal incidence absorption coefficient \( \alpha_n \) as given by equations (2.7) and (2.8) can now be calculated.

\[
\alpha_n = 1 - \left( \frac{SWR - 1}{SWR + 1} \right)^2
\]

### 2.6 RESULTS OF INTEREST

Normal incidence absorption coefficient \( \alpha_n \) varies with the frequency of the sound. To see the dependence of this variation with the airspace behind the sample, plot, and discuss,

(a) \( \alpha_n \) vs \( f \) (frequency in Hz) on a plot. Overlay the plots for airspace behind the sample of 0”, 1”, and 2”.

To study the dependence on material thickness, plot and discuss,

(b) \( \alpha_n \) vs \( t \) (sample thickness) for no airspace behind the sample and at a frequency \( f \) of 1000 Hz.

(c) Find the percent differences between the experimental speeds of sound from set I and the speed of sound found by assuming that the air in the standing wave tube behaves as an ideal gas. What is the maximum percent difference? What is the significance of the difference between these ideal and experimental values?

(d) Could a frequency of 4000 Hz be used with this standing wave tube? Why or why not?

(e) Could a frequency of 50 Hz be used with this standing wave tube? Why or why not?
DATA SHEET

Room temperature, $T = \underline{\underline{\text{________}}}$ °F

Standing Wave Tube, Diameter = $\underline{\underline{\text{________}}}$. in.

Length = $\underline{\underline{\text{________}}}$. ft. $\underline{\underline{\text{________}}}$ in.

Set I. No sample (reflective termination)

<table>
<thead>
<tr>
<th>Reading Number</th>
<th>Frequency (Hz)</th>
<th>$X_{\text{min}}$ (in)</th>
<th>$L_{p,\text{min}}$ (dB)</th>
<th>$x_{\text{max}}$ (in)</th>
<th>$L_{p,\text{max}}$ (dB)</th>
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Set II. Name of Sample Used:

Thickness of sample: $\underline{\underline{\text{________}}}$. in.

Airspace behind sample: $\underline{\underline{\text{0}}}$. in.

<table>
<thead>
<tr>
<th>Reading Number</th>
<th>Frequency (Hz)</th>
<th>$X_{\text{min}}$ (in)</th>
<th>$L_{p,\text{min}}$ (dB)</th>
<th>$x_{\text{max}}$ (in)</th>
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Set III. Name of Sample Used:

Thickness of sample: $\underline{\underline{\text{________}}}$. in.

Airspace behind sample: $\underline{\underline{\text{1}}}$. in.

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<tr>
<th>Reading Number</th>
<th>Frequency (Hz)</th>
<th>$X_{\text{min}}$ (in)</th>
<th>$L_{p,\text{min}}$ (dB)</th>
<th>$x_{\text{max}}$ (in)</th>
<th>$L_{p,\text{max}}$ (dB)</th>
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Set IV. Name of Sample Used:

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<th>Reading Number</th>
<th>Frequency (Hz)</th>
<th>$X_{\min}$ (in)</th>
<th>$L_{p,\text{min}}$ (dB)</th>
<th>$X_{\max}$ (in)</th>
<th>$L_{p,\text{max}}$ (dB)</th>
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Set V. Name of Sample Used:

Frequency of Sound Waves = 1000 Hz.

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<thead>
<tr>
<th>Run Number</th>
<th>Sample Thickness (in)</th>
<th>$X_{\min}$ (in)</th>
<th>$L_{p,\text{min}}$ (dB)</th>
<th>$X_{\max}$ (in)</th>
<th>$L_{p,\text{max}}$ (dB)</th>
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1/1-Octave and 1/3-Octave Analysis

1/1-Octave and 1/3-Octave Analysis for Instantaneous Value
($L_d, L_c, L_p$)

To make the measurement, carry out the following steps:

1. Set the power switch on the side of the unit to ON. Call up the DISPLAY menu screen by pressing the DISPLAY key, make the necessary settings, and press the DISPLAY key again to close the menu.

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<th>DISPLAY</th>
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   Note: The lab instructor is responsible to see that this display is set appropriately. You should not alter it.

2. Use the SLM / 1/1 / 1/3 key to activate the sound pressure level measurement screen.

3. Use the FREQ WEIGHT key to select the desired frequency weighting setting. For this application “FLAT” weighting is required.

4. Use the TIME CONST key to select the desired time weighting setting. Normally, the “FAST” setting should be used, but for this experiment use “SLOW” as it provides an averaging effect.

5. Use the LEVEL UP/DOWN keys to select the level range. Choose a setting in which the “OVER” and “UNDER” indications do not appear. This matches the range on the displayed plot to the measured sound level.

6. Use the SLM / 1/1 / 1/3 key to activate the 1/1-octave analysis or 1/3-octave analysis screen. 1/3 is preferred.

7. The display is updated every 100 ms. Since this makes the values hard to read, use the PAUSE/CONT key to pause the bar graph, move the marker to the desired position, and read the value. Alternatively, you can also use the GRP/NUM/L-T key to activate the numeric reading.
2.7 REFERENCES

   (pp 4-20 on Wave Nature and Descriptions of Sound. pp 409-413 on Standing Wave Tube Experiments Capt. 8 on Acoustical Materials)