Measurement of the sound-absorption coefficient on egg cartons using the Tone Burst Method

QUINTERO RINCON ANTONIO
Departamento de Ingeniería Electrónica
Instituto Tecnológico de Buenos Aires
Av. Eduardo Madero 399
ARGENTINA
aquinter@itba.edu.ar

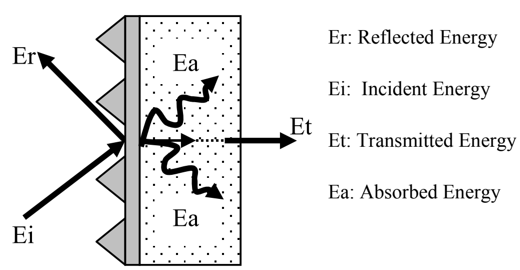
Abstract: A low-cost solution for noise level reduction in an enclosed space, such as a room, is the installation of egg carton materials or fruits box materials (for example apple, pear or peach tree). The Tone Burst method may be used to measure the sound absorption coefficient of a material at any desired angle of incidence. The goal for this paper is to demonstrate that egg cartons are a myth when they are used to reduce sound level in an enclosed space.

Key-words: Tone Burst – Absorption Materials – Reflection Factor - Egg Cartons – NRC - Sound Power Level.

1. Introduction

The basic parameters of acoustic materials are impedance and surface shape. Other information such as angle-dependent impedance, porosity, and tortuosity are required. Material data include all necessary information essential to calculate reflected and transmitted field. In many sound prediction cases, however, the absorbed or transmitted energy is a sufficient quantity [1].

The law of the conservation of energy states that energy can neither be created nor destroyed, but it can be changed from one form to another. Absorption converts sound energy into heat energy. It is useful when reducing sound levels within rooms but not between rooms. Each material interacting with a sound wave absorbs some sound. The most common measure is the absorption coefficient, typically denoted by the greek letter α. The absorption coefficient is a ratio of absorbed (Ea) to incident sound energy (Ei). The reflect coefficient is a ratio of reflect (Er) to incident sound energy (Ei). A material with an absorption coefficient of 0 reflects all incident waves. On the contrary, if a material absorbs all incident sound, its absorption coefficient is 1. An opposite coefficient τ, denotes reflection of sound waves on a surface. If the reflection coefficient is near zero, then the transmitted energy is minor. Therefore, both coefficients range between 0 and 1. See figure 1.



Absorption coefficient range $0 \leq \alpha \leq 1 \rightarrow \alpha = Ea / Ei$

Reflection coefficient range $0 \leq \tau \leq 1 \rightarrow \tau = Et / Ei$

Fig. 1. Sound Absorption and Sound Reflection

In practice, all materials absorb some sound, so this is a theoretical limit [2]. Sound absorptive materials are widely used for the control of noise in a variety of different situations. Sound-absorptive materials exist in many different forms: Glass-fiber materials, open-cell acoustical foams, fiber board, hanging baffles, felt materials, curtains and drapes, thin porous sheets, head liners, carpets and hollow concrete blocks with a small opening to the outside – to create a Helmholtz resonator. One characteristic common to nearly all sound-absorptive materials is that they are porous. That is, there is air flow through the material as a result of a pressure difference between the two sides of the material. Porous materials are frequently fragile, and, as a result, it is necessary to protect the exposed surface of the material. Typical protective surfaces include: thin impervious membranes of plastic or other material; perforated facings of metal, plastic or other material; fine wire-mesh screens; spayed-on materials such as neoprene, and thin porous surfaces [3]. An egg carton is a carton designed for carrying and transporting whole eggs, no for acoustic. These cartons have a dimpled form in which each dimple accommodates an individual egg and isolates that egg from eggs in adjacent dimples. This structure helps protect eggs against stresses exerted during transportation and storage by absorbing a lot of shock and limiting the incidents of fracture to the fragile egg shells. An egg carton can be made of various materials, including Styrofoam, clear plastic or may be manufactured from recycled paper and molded pulp by means of a mechanized Papier-mâché process. An "egg crate mattress", while following a similar form, is not used for egg transport. It is a light weight camping mattress which makes use of the dimpled structure to distribute and cushion human weight. This foam structure is also occasionally used in packaging to dampen impact of sensitive material during travel.

Fig 2. Egg Carton

Similarly, acoustic foam tiles help in sound absorption and the limitation of acoustic resonance have a similar characteristic to egg crates. For that reason, egg crate mattresses are occasionally used as an inexpensive substitute [4].

Sound absorption coefficients are frequently measured in octave bands, and the noise reduction coefficient (NRC) is the average absorption in the 250 Hz, 500 Hz, 1000 Hz and 2000 Hz bands. This average is expressed to the nearest multiple of 0.05.

Reflection can occur when a wave impinges on a boundary between two media with different wave propagation speeds. Some of the incident energy (Ei) of the wave is reflected back into the original medium, and some of the energy is transmitted (Et) and refracted (Er) into the second medium (See Fig. 1). This means that the wave incident on a boundary can generate two waves: a reflected wave and a transmitted wave, whose direction of propagation is determined by Snell's law.

2. Measurement Methodology

At a given frequency, the absorption coefficient of any material varies with the angle of incidence of the sound waves. In a room, sound waves strikes materials at many different angles. For this reason, published coefficients of commercial materials are generally measured in a laboratory reverberation room in which sound waves are nearly diffuse, so that they strike the test sample from many directions.

A tone burst is a short signal used in acoustical measurements to make possible differentiating desired signals from spurious reflections. The American Society for Testing and Materials (ASTM) has developed this method; in Acoustics the technique is applicable in many areas such as measurement of distortion, early reflections, absorption, and phase response [5]. In our experiment the tone burst was generated with the Spectral Lab software and the loudspeaker is a E-MU's PM5 Precision Monitor.

One of the basic problems in room acoustic measurements has always been to determine the direction of a certain reflection, and more important, its frequency content. For example, ¿what is the acoustic influence of an eggs carton in an enclosed space?

The simple implementation of the Tone Burst measurement procedure, as described in [5], is:

1. Place the loudspeaker and measuring microphone (B&K Type 2250) along the longest axis of the room. Center the microphone/loudspeaker combination with respect to all three axes of the room. Assume a room (see Fig. 3.) with the transducers equally spaced between floor and ceiling (*h*, the height of the room is assumed the smallest of the room's dimensions). First, we will only consider reflections from side walls, ceiling and floor. The pulse length (*t*) must then be shorter than the difference between the time it takes to travel the reflected (*2l/c*) and the direct path (*d/c*). Hence

$$t \le \frac{2l-d}{c} = \frac{\sqrt{h^2+d^2}-d}{c} \qquad (1)$$

$$d = \frac{h^2 - c^2t^2}{2ct} \qquad (2)$$

The criterion that the microphone should be at least one wavelength from the loudspeaker gives

$$d \ge ct \qquad (3)$$

where *t* is the period at the lowest frequency which also corresponds to the pulse length. It contains one period at the lowest frequency. Setting Equations (2) and (3) equal we obtain the optimum pulse length and corresponding transducer spacing:

$$ct = \frac{h^2 - c^2t^2}{2ct}$$

$$t = \frac{\sqrt{3}h}{3c} = \frac{h}{595} \qquad (4)$$

The reciprocal of which gives the lower frequency limit f_{min}

$$f_{\min} = \frac{595}{h} \qquad (5)$$

At the distance between transducers of

$$d = ct = c\left(\frac{\sqrt{3}h}{3c}\right) = 0.577h \qquad (6)$$

which is the optimum spacing between transducers for a given minimum room dimension *h*.

For reflections from the end walls of the room along its longest dimension (*L*), the length of the pulse must be shorter than the difference between the time it takes for the first reflection to return to the microphone (*L/c*) and the time it takes for the direct sound to reach the microphone (*d/c*).

Hence $$t \le \frac{L-d}{c} \quad \cong \quad d < L - ct \qquad (7)$$

Now reflections from the far wall only become a limitation when the minimum distance of Equation (7) is equal to, or less than that of Equation (3). Setting the two equal

$$L = 2ct \qquad (8)$$

and substituting t from Equation (4) we get

$$L = \frac{2}{3}\sqrt{3}h = 1.15h \qquad (9)$$

Hence the length of the room must be at least 15% longer than the smallest dimension in order for Equations 4-6 to be valid.

However, with reflections from the end walls setting the limits, the pulse length must be (from Equation 8.)

$$t = \frac{L}{2c} = \frac{L}{688} \qquad (10)$$

with an optimum distance between transducers (combining Equations 3. and 8.)

$$d = \frac{L}{2} \qquad (11)$$

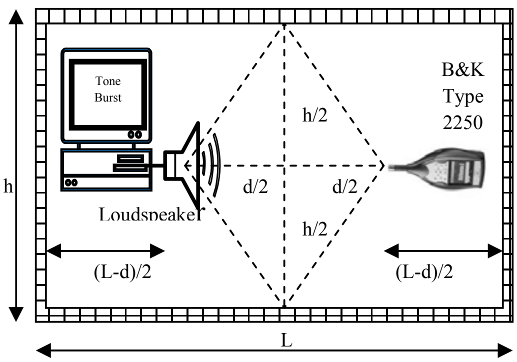


Fig. 3. The geometry environment

2. Begin with a relatively short tone burst about 3 ms at the wished frequency and observe the received waveform on the B&K Type 2250. See Fig. 4.

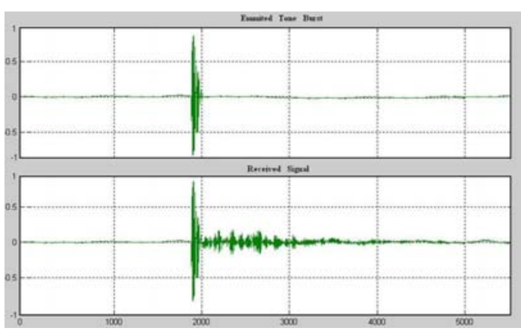


Figure 4. Emitted Tone Burst and Received Signal

At the same time, the size of the loudspeaker must be considered in determining the far field. The microphone should be placed at a distance at least equal to the largest dimension of the loudspeaker. Unfortunately, due to practical restrictions on room size, these criteria are often ignored, thus leading to non reproducible measurements. Certain standards, of course, also call for fixed distances.

3. At a given angle between the loudspeaker and the barrier, we set a distance d/2 between the loudspeaker and the B&K type 2250. Note that the total distance for the wave is d, see fig. 6. The short tone burst is emitted again and the B&K type 2250 receives the direct and reflected signals, see fig 5. Note the point of the first reflections and increase the duration of the tone burst. If the tone burst is too long, the received signal will have overlaps.

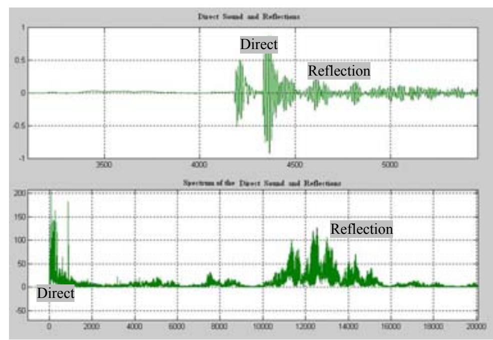


Fig. 5. The Direct and Reflect Sound

4. With direct and reflected signals, the Sound Power Level (L_w) is calculated and compared for a same way: incident angle and frequency, in octave bands. Sound intensity may be used when measuring sound absorption in situ.

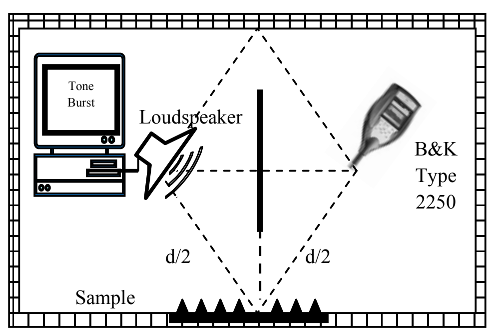


Fig. 6. The geometry environment with angles

A tone burst contains not only the frequency of the sine wave contained in the burst but also a band of harmonic frequencies originated by the sine wave frequency. These frequencies arise due to the square wave by which the sine signal is gated.

Advantages: It is not necessary to have a reverberation chamber to accomplish the test; samples of different material can be measured in situ with different angles.

Disadvantage: The tone Burst Method is truly effective beginning at 1000 Hz, consequently it is somewhat limited to test low frequencies.

3. Experiment and Results

The sound power level of a source in decibels, is given by

$$L_w = 10\log_{10}(\frac{W}{W_0}) \quad dB \qquad (12)$$

Where W is the power of the source in watts and W_0 is the reference power in watts.

The reflection factor R is related to the wall impedance Z by:

$$R = \frac{P_r}{P_i} = \frac{Z\cos\vartheta - Z_0}{Z\cos\vartheta + Z_0} \qquad (13)$$

$Z_o=\rho_o c$ is the characteristic impedance of air. The wall impedance Z is defined as the ratio of sound pressure to the normal component of particle velocity, both determined at the wall [1].

The absorption coefficient, is given by

$$\alpha = \frac{|\rho_i|^2 - |\rho_r|^2}{|\rho_i|^2} = 1 - |R|^2 \qquad (14)$$

And the specific impedance

$$\xi = \frac{1}{\cos\vartheta}\frac{1+R}{1-R} \qquad (15)$$

For example for a frequency of 2 KHz with an angle of 45°, the power W measurement in the B&K type 2250 was 3.16 watts, can be corroborated with the Power Spectral Density of the signal

(16)

We can use the following data: the reflection factor $R=0.31$ (Equations 12. and 13.), the specific impedance $\zeta=2.68$ (Equation 15.), the absorption coefficient $\alpha=1-0.31=0.69$ (Equation 14.) and the *NRC= 0.4725.*

The absorption coefficients measured in octave bands are:

Hz	α_0
125	0.04
250	0.30
500	0.42
1000	0.48
2000	0.69
4000	0.69

Table 1. Absorption coefficients in octave bands.

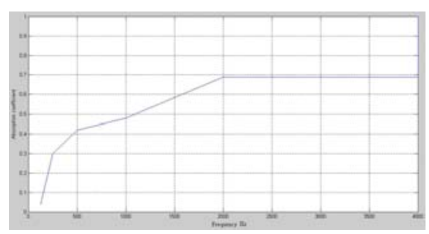


Fig. 7. Absorption coefficients in octave bands

This method was corroborated using the Bell Acoustic Panel and the result was similar to the technical specifications of the material (α= *0.75)* for the data shown in the example.

4. Conclusions

The egg carton has a good absorption coefficient from 2 KHz on. For frequencies lower than 2 KHz it has poor absorption properties. It is important to point out that the test has no significance below 1 KHz, but the absorption measured at that frequency is bad enough to disregard this material.

Along with it, the egg carton does not have reflection properties, so it cannot be used for acoustic purposes.

5. References

[1] Michael Vorländer, *Auralization*, RWTH First Edition (Springer 2008).

[2] Cyril M. Harris, *Handbook of Acoustical Measurements and Noise Control*, 3 Edt. (Acoustical Society of America 1998)

[3] Thomas D. Rossing Edition, *Springer handbook Acoustic*, (Springer 2007).

[4] http://en.wikipedia.org/wiki/Egg_carton.

[5] MΦller Henning and Thomsen Carsten, *Electro Acoustic free field measurements in ordinary rooms using gating techniques*, Brüel & Kjaer, (Applications notes 1975)

In memory of Eng. Fernando von Reichenbach.