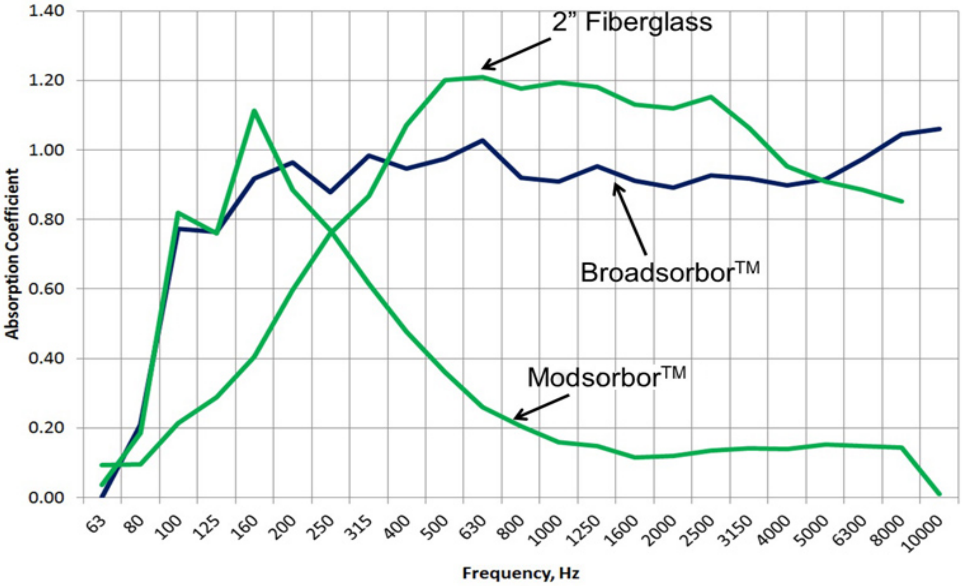
Optimized Multi-Layer Absorbors



Abstract: Traditional 1” or 2” fabric wrapped fiberglass panels suffer from a disproportionate amount of high frequency absorption. This can be improved by thicker panels and mounting with an airspace, however, architectural restrictions usually do not allow this. Therefore, RPG has developed an iterative transfer matrix method to calculate the surface impedance from multiple layers with different characteristic impedances to develop novel absorbors with a specified absorption spectrum. The initial fruits of this research are the Broadsorbor and the Modsorbor, which offer broadband-width and dedicated low-frequency absorption, respectively in a 2” panel. The ultimate goal of the research is to design a multi-layer absorber that offers a specified absorption coefficient spectrum for specific tasks.

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This note describes a method RPG has employed to develop multi-layer absorbors that provide broad bandwidth absorption (Broadsorbor) and dedicated low frequency absorption (Modsorbor) in a 2” panel. The method employs the characteristic impedance of porous absorbers and the transfer matrix method.

We can determine the characteristic impedance, z_c, of various porous materials by measuring the surface impedances, z_1 and z_2 for two different thicknesses, d^1 and $d_2=2d_1$, in our 160 mm square impedance tube, which is fitted with 4 microphones at positions a quarter of the width and height of the tube. By summing the 4 microphones we can cancel the first and third modes. The second mode is at a null as shown in Fig. 1, thereby increasing the upper limit by a factor of 4 and yielding a surface impedance from 63-4,000 Hz by averaging the impedances derived from three microphone positions.

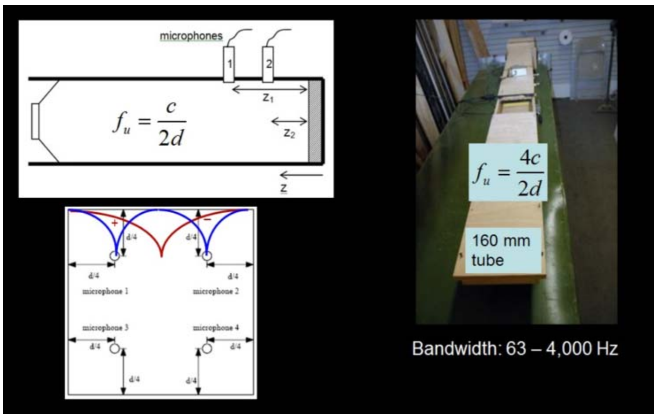

Figure 1. 160 mm square impedance tube using 4 microphones at positions a quarter of the width and height at three positions to determine the surface impedance from 63-4,000 Hz.

The surface impedance is measured for two different thicknesses of the absorbent with a rigid backing. For a thickness of d1 the surface impedance is z1:

$$z_1 = -jz_c \cot(kd_1)$$

Where z_c is the characteristic impedance of the sample. A similar relationship gives the surface impedance $z_2 = -jz_c\cot(kd_2)$ for a depth d_2. For simplicity, assume that $d_2 = 2d_1$; typically d_1 would be a couple of centimeters. The equations for z_1 and z_2 can then be rearranged using trigonometric identities and solved to give the characteristic impedance z_c :

$$z_c = \sqrt{z_1(2z_2 - z_1)}$$

Once the characteristic impedances are known, it is necessary to convert these to the surface impedance and absorption coefficient for a particular thickness of the porous material with known boundary conditions. In this case, the most flexible way of predicting the surface properties of the porous material is to use the transfer matrix method. Consequently, this section starts by discussing the general case of propagation in one layer of porous absorber in a multilayered system.

Figure 2 shows the arrangement being considered. Only plane wave propagation in the absorbent will be considered, and for now normal incidence only is considered. At

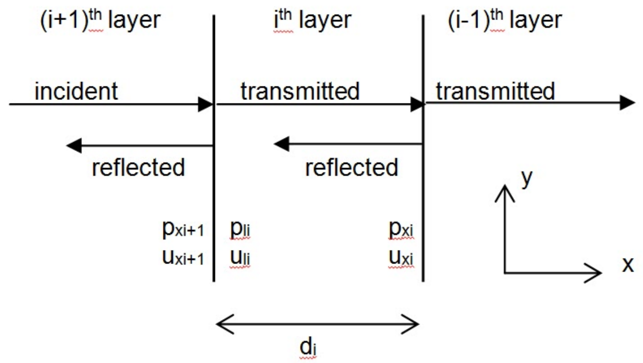

Figure 2. Geometry for propagation of sound through a layer of an acoustic medium.

each interface between the layers, continuity of pressure and particle velocity is assumed. This allows a relationship between the pressure and particle velocity at the top and bottom of a layer to be produced which is compactly given in matrix format:

$$\begin{Bmatrix} p_{li} \\ u_{li} \end{Bmatrix} = \begin{Bmatrix} p_{xi+1} \\ u_{xi+1} \end{Bmatrix} = \begin{Bmatrix} \cos(k_{xi}d_i) & j\frac{\omega\rho_i}{k_{xi}}\sin(k_{xi}d_i) \\ j\frac{k_{xi}}{\omega\rho_i}\sin(k_{xi}d_i) & \cos(k_{xi}d_i) \end{Bmatrix} \begin{Bmatrix} p_{xi} \\ u_{xi} \end{Bmatrix}$$

where p_{xi} and u_{xi} are the pressure and particle velocity at the bottom of the ith layer; p_{xi+1} and u_{xi+1} are the pressure and particle velocity at the bottom of the (i+1)th layer; p_{li} and u_{li} are the pressure and particle velocity at the top of the ith layer; d_i is the thickness of the layer; ρ_i the density of ith layer, and k_{xi} the wavenumber for the ith layer. The prediction model can be extended to multiple layers of absorbent.

By appropriately using layers of different absorbent materials, it is possible to gain additional absorption from porous absorbers. Ideally, a porous absorbent should offer an impedance which matches that of air to remove reflections, while offering high internal acoustic attenuation. These two requirements are difficult to achieve in a thin layer of a single material, and can be more easily achieved in multi-layered linings. The front material has the necessary impedance matching that of air, and the inner layers attenuate the sound wave. Ideally, the impedance should only change gradually between internal layers to minimize reflections. This arrangement can be modeled by repeated application of the transfer matrix equations.

The first fruits of this research are a broad bandwidth 2” fabric wrapped panel called the Broadsorbor. In addition, RPG has developed a 2” thick dedicated low frequency absorbor called the Modsorbor. The absorption coefficients for these are compared in Figure 3 with a comparable 2” fabric wrapped fiberglass panel.

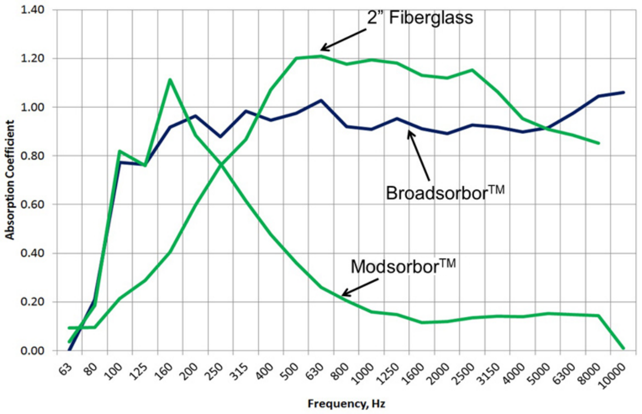

Figure 3. 2” Fiberglass, Broadsorbor and Modsorbor absorption coefficient comparison.

The ultimate goal of this research is to design a multi-layer absorber that offers a specified absorption coefficient spectrum for specific tasks.