24th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
23–27 July 2017, London

ESTIMATION OF ACOUSTIC PROPERTIES FOR POROUS MATERIAL WITH SURFACE ACOUSTIC IMPEDNACE

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In this study, estimation of acoustic properties of porous material with surface acoustic impedance was proposed and compared with other methods. To estimate complex characteristic impedance and wavenumber of porous material, four microphone impedance tube or two-thickness method were widely used. In the two-thickness method, complex propagation constant and characteristic impedance was calculated with measured surface acoustic impedances. Through the proposed method, porous material's wavenumber and characteristic impedance is calculated with small different thicknesses of samples. Surface acoustic impedance was measured by two microphone impedance tube method to estimate complex wavenumber, and comparison of acoustical properties estimated through proposed method was performed. Non-acoustical properties of porous materials were also calculated through indirect method. The results showed good estimation compared with other measurement method.

Keywords: surface acoustic impedance, two-microphone impedance tube

1. Introduction

A porous structure is widely used in the field because it has characteristics to reduce noise by simple attachment and application to a noise source. The noise reduction efficiency of a sound absorbing material depends on the porosity, the material stiffness, the damping characteristics, and the thickness. As the thickness increases, the frequency of the noise that can be reduced becomes low. In order to quantitatively compare the acoustic characteristics of the porous structure, it is necessary to consider complex wavenumber and characteristic impedance. In this study, a new method to measure the acoustic properties of porous materials with surface acoustic impedance is presented and compared with the results of other measurement methods. As a method of predicting the characteristic impedance and the complex wavenumber of the porous material, a method such as a 4-microphone impedance tube[1] is widely used. Through the proposed method, the wavenumber and the characteristic impedance of the porous material can be calculated with two specimens having slightly different thicknesses.

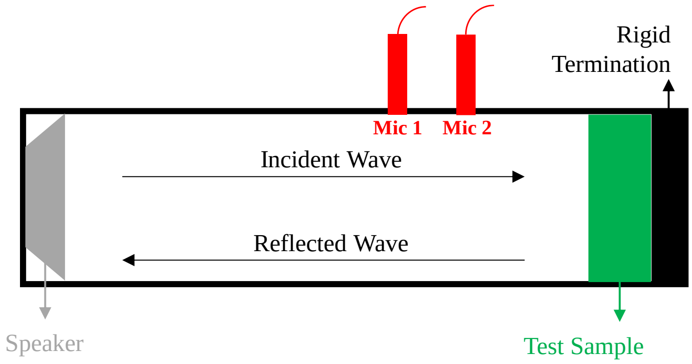

Figure 1. Schematic of two-microphone impedance tube method

2. Numerical approach to calculate acoustic properties

From two microphone impedance tube measurements as shown in Figure 1, surface acoustic impedance can be measured for the porous samples of different thicknesses terminated by hard walls as shown in Figure 2. From two surface acoustic impedances for two different thicknesses, the propagation constants, $\gamma = \mathrm{i}k$, and characteristic impedance of the sample, Z_c, is obtained. The two surface acoustic impedances(Z_1 and Z_2) are related to characteristic impedance and wave number as,

(1) $$Z_1 = Z_c \frac{\cos(kd_1)}{i\sin(kd_1)},\ Z_2 = Z_c \frac{\cos(kd_2)}{i\sin(kd_2)}.$$

where d_1 and d_2 are the thickness of porous samples. Since the above equation is all complex, there are four equations in four unknowns after separating real and imaginary parts. To minimize the number of variables to be solved with numerical method of the Newton-Rapson method, Z_c is removed from equation (1) and results in the following equation as

(2) $$F(k) = \frac{Z_1}{\sin(kd_2)\cos(kd_1)} - \frac{Z_2}{\sin(kd_1)\cos(kd_2)} = 0.$$

Note that the sine functions are located at denominator to prevent the artificial roots resulting from multiplication of sine functions during removal of Z_c in equation (1), for example, when $\sin(kd_1) = \sin(kd_2) = 0$. The above equation is solved using the Newton-Rapson method[2] and the complex wave number is obtained. The iteration to obtain the converged values of the wavenumber are conducted as

(3) $$\begin{bmatrix} k_r \\ k_i \end{bmatrix}_{j+1} = \begin{bmatrix} k_r \\ k_i \end{bmatrix}_j - \begin{bmatrix} \mathrm{Re}\left\{\frac{\partial F}{\partial k_r}, \frac{\partial F}{\partial k_i}\right\} \\ \mathrm{Im}\left\{\frac{\partial F}{\partial k_r}, \frac{\partial F}{\partial k_i}\right\} \end{bmatrix}^{-1} \begin{bmatrix} \mathrm{Re}\{F\} \\ \mathrm{Im}\{F\} \end{bmatrix},$$

where $k = k_r$ - ik_i, and j is the index indicating j^{th} iteration. After obtaining the converged values for the wavenumber, the characteristic acoustic impedance is calculated from equation (1). Due to the periodicity of the sine functions in equation (2), the solution results in multiple roots. It is required to obtain all this multiple roots, and decide the physically acceptable solutions later. To obtain all

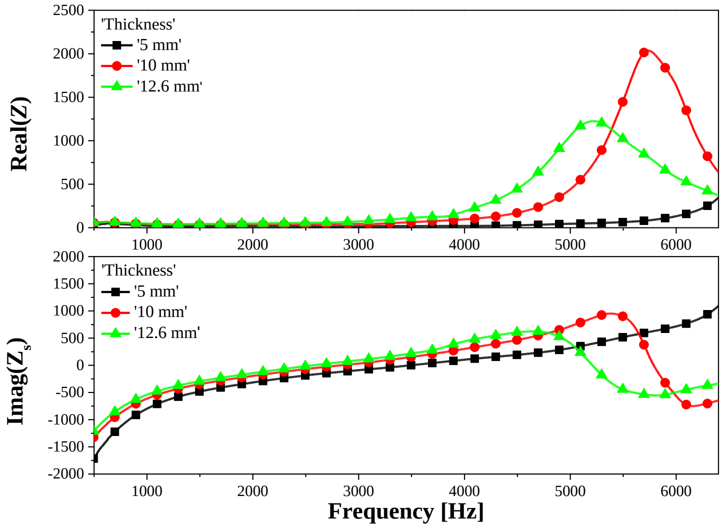

Figure 2. Measured surface acoustic impedance (test specimen : melamine foam)

this multiple roots, different values of the initial values in equation (3), $[k_r, k_i]_{j=0}$, given and the converged values can be calculated. By applying this method, complex acoustic properties were calculated and compared with different measuring methods' results such as 4 microphone impedance tube method and two-thickness method[3].

3. Conclusion

In this study, method of calculating complex acoustic properties of porous material with different samples' thickness was proposed. The acoustic wave speed, characteristic impedance, and internal air density of the porous material were calculated for each frequency by the calculated complex wavenumbers and compared with the values derived from the four-microphone impedance tube and the two-thickness method. The proposed method showed a similar tendency when compared with the results of the existing methods, and it was also possible to derive non-acoustic properties[4-5] based on the calculated results. It has been verified that frequency-dependent complex acoustic properties can be measured in 2 microphone impedance tube specification, and it is expected that it can be widely used for acoustic characteristics of porous materials using minimum equipment.

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