A new impedance tube for large frequency band characterization of absorbing materials

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The standard two microphones technique does not allow the measurement of absorbing materials characteristics at low frequency. Moreover, to cover a range from 100 to 6000 Hz two experiments have to be done with two different sample diameters. By using a sensor with a known volume velocity source developed by the LAUM together with the CTTM, it is demonstrated that the impedance can be obtained from 10 to 6000 Hz by performing only one measurement with a single material sample. Results showing the behaviour of some materials at low frequency are presented. On the other hand a comparison is done with the classical two-microphone impedance tube method.

1 Introduction

A new impedance setup is presented allowing the measurement of the absorption coefficient of absorbing materials as well as the scattering matrix in a large frequency range.

2 Principle

The impedance measurement setup proposed uses a piezo-electric buzzer as a source. This buzzer is fixed on its back to a closed cavity and is connected to the front to the measured pipe (see figure (1)). The pressure p_2 at the input of the pipe is measured by a microphone (mic 2) and a second microphone (mic 1) measures the pressure p_1 in the back cavity, this pressure being at first order proportional to the volume velocity U delivered by the source. The impedance $Z = p_2 / U$ is thus at first order proportional to the transfer function between the two microphones and it can be written:

$$\frac{p_1}{p_2} = -jC\omega Z \qquad (1)$$

where $C = \frac{V}{\rho c^2}$ is the acoustic compliance of the back cavity of volume V, with ρ the air density and c the speed of sound.

In practice this equation (1) is only valid for low frequencies. Moreover, it is necessary to take the relative sensitivity of the two microphones into account, since the measured transfer function is $H_{21} = \frac{p_2}{p_1}\frac{s_2}{s_1}$ with s_1, s_2 the respective sensitivities of microphones 1 and 2.

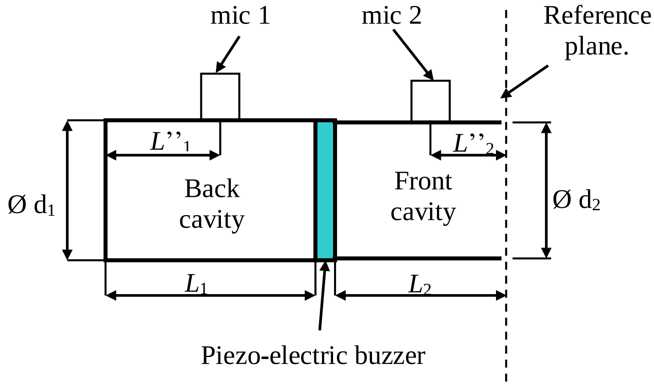

Fig.1 Schematic drawing of the impedance measurement setup and notations

It is also possible to calculate more precisely the expression of the impedance by taking into account the geometrical dimensions of the sensor:

$$Z = \frac{H_{21}/K - \beta}{1 - \delta H_{21}/K} \qquad (2)$$

with $K = -j\frac{1}{Z_{c1}}\frac{s_2}{s_1}\frac{\sin(kL_1)}{\cos(kL''_1)}\frac{\cos(kL''_2)}{\cos(kL_2)}$, $\beta = jZ_{c2}\tan(kL''_2)$ and $\delta = j\tan(kL_2)/Z_{c2}$.

Lengths L_1, L_2, L''_1 et L''_2 are dimensions related to the setup and to the position of the microphones as indicated on figure (1). $Z_{c1} = \frac{\rho c}{S_1}$ and $Z_{c2} = \frac{\rho c}{S_2}$ are the respective characteristic impedances of the front and back cavities ($S_1 = \pi d_1^2/4$ is the cross section of the back cavity with d_1 its diameter and the same for the front cavity).

It is important to notice that only the relative sensitivity of the sensors is unknown, geometrical quantities being accurately measured with a calibre. The relative sensitivity of the sensors is obtained by doing a calibration with an infinite impedance (i.e a rigid plate) at the input of the impedance head.

3 Application to absorption coefficient measurement

Comparisons are made with the standard two microphones measurement method for the characterization of absorbing materials. With the standard method, the reflection coefficient is then obtained from:

$$R = \frac{Z - Z_c}{Z + Z_c} \qquad (4)$$

with $Z_c = \frac{\rho c}{S}$. From this reflection coefficient the absorption coefficient α can be deduced as:

$$\alpha = 1 - |R|^2 . \qquad (5)$$

4 Application to scattering matrix measurement

For this measurement, the sample holder is replaced by another tube in the middle of which the sample is placed. The end of this tube is closed by a rigid piston in which a third microphone (mic 3) is placed (see figure 2).

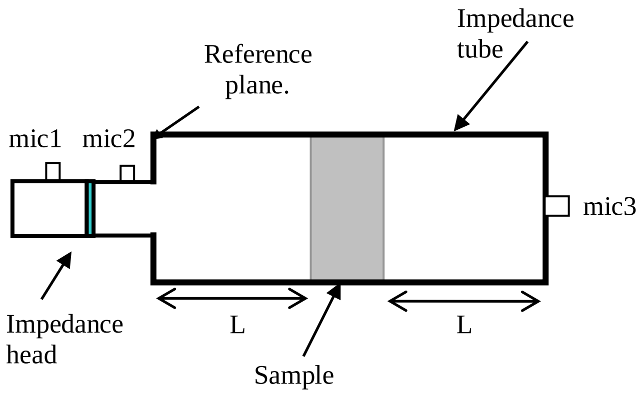

Fig.2 Schematic drawing of the scattering matrix measurement setup

The transfer function H_{31} between the first and the third microphone allows the determination of the transfer impedance $Z_T = p_3 / U$ as it can be shown that:

$$Z_T = \frac{H_{31}}{\delta K_T}(1 + \delta Z), \qquad (6)$$

where $K_T = -\frac{s_3}{s_1}\frac{Z_{c2}}{Z_{c1}}\frac{\sin(kl_1)}{\sin(kl_2)\cos(kl_1'')}$ with s_3 the sensitivity of the third microphone.

The sample being assumed symmetrical the impedance matrix of the whole impedance tube (including the sample) is given by:

$$\begin{pmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{pmatrix} = \begin{pmatrix} Z & Z_T \\ Z_T & Z \end{pmatrix}, \qquad (7)$$

from which the scattering matrix of the tube and that of the sample can be deduced. From this the effective compressibility and density of the absorbing can be estimated. Note that if the sample is not symmetrical a second measurement in a reversed situation has to be performed.

5 Result: comparison with the standard two microphones method

The measurement of various absorbing material samples has been performed both with the standard two microphones method (BK setup [1]) and the present impedance measurement setup. The same sample holder (29mm diameter) is used for both measurements so that the material is being measured in the same conditions. Results for a 20mm long piece of foam are shown on figure (3).

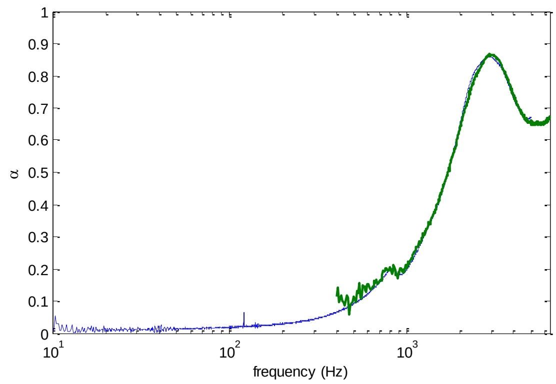

Fig.3 Measured absorption coefficient. Blue line: present impedance measurement setup (range 10-5000Hz). Green line: standard two-microphone impedance measurement tube (range 400-6400Hz)).

It is reassuring to see that both measurement techniques lead to the same result in their common frequency range suggesting that both methods are accurate.

6 Conclusion

Our measurement setup is shown to be able to perform measurements with the same accuracy as the standard two-microphone technique but on a wider frequency range (8 octaves instead of 4). The present setup is actually limited to frequencies above 5kHz. A new setup using slightly smaller cavities with a frequency range extended to 6.4kHz will be presented. Results allowing the determination of absorbing materials parameters will also be presented.

Reference

[1] BRUEL & KJAER 1995 Product data sheet BP 1039-12 Two-microphone impedance measurement tube – Type 4206.