

A new tests bench for a wide band measurement of poroelastic material absorption coefficient

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Abstract: 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 are usually done with two different sample diameters (29mm and 100mm). 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 20 to 5000 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. Other possible applications for the sensor are also presented

Keywords: acoustic impedance, low frequency measurements, poroelastic materials.

1. Introduction

In the present paper, a new impedance measurement setup is presented. It was first designed for the measurement of the input impedance of musical wind instruments in the frequency range 20-4000Hz. It is used here to measure the absorption coefficient of absorbing materials.

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 figure1). 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:

$$Z = -\frac{1}{j\omega C} \frac{p_1}{p_2} \quad (1)$$

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.

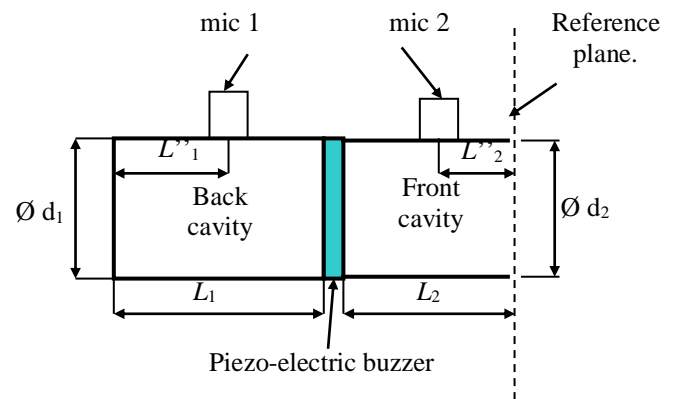


Figure 1: Schematic drawing of the impedance measurement setup and notations

In practice 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 $H_{21} = \frac{p_2 s_2}{p_1 s_1}$ with s_1, s_2 the respective sensitivities of microphones 1 and 2.

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

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

with

$$K = -j \frac{1}{Z_{c1}} \frac{s_2}{s_1} \frac{\sin(kL_1) \cos(kL_2'')}{\cos(kL_1'') \cos(kL_2)}$$

$$\beta = jZ_{c2} \tan(kL_2'')$$

$$\delta = j \tan(kL_2) / Z_{c2}$$

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 microphones “ s_2/s_1 ” is unknown, geometrical quantities being accurately measured with a calibre. For this reason, the first sensors (figure 2 and 3) were built with low cost microphones (Panasonic electret microphones) and a dedicated calibration procedure was developed. But the microphones needed to be paired so that their relative sensitivity remains close to unity, even at low frequencies, that is difficult to obtain with electret microphones. Thus, a new sensor version will be proposed including $1/4$ ” condenser microphones in order to improve accuracy and to extend the frequency range up to 6400Hz.



Figure 2: Impedance sensor (including a rigid plate at the input of the impedance head)



Figure 3: Head of the impedance sensor + adaptor and “infinite impedance load”

3. Calibration

A complete calibration of the sensor can be done by using three known acoustic loads [1]. A calibration with three non resonant loads as in reference [2] has been performed showing a good matching between experimental and theoretical values of parameters β and δ . Then it appears that a partial calibration of the sensor with a single load is sufficient to obtain the ratio of the microphones sensitivity. Therefore, only the “infinite impedance” load (i.e. a rigid plate at the input of the impedance head, as shown in figure 2) is used for calibration. In that case, the microphones sensitivity ratio is deduced from the measured transfer function H_∞ by using the relation:

$$H_\infty = KZ_{c2} / \delta \quad (3)$$

4. Application to absorption coefficient measurement

The reflection coefficient is obtained from the impedance by:

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

with $Z_c = \frac{\rho c}{S}$ where S is the cross section of the sample holder. The absorption coefficient α can then be deduced by:

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

5. Comparison with the standard two microphones method

In order to illustrate the advantages of our sensor, comparisons are made with the standard two microphones measurement method. The objective concerns the characterization of absorbing materials. Various absorbing materials have been measured both with our sensor and with the standard two microphones method [3]. The same sample holder (29mm diameter) is used for both measurements so that the materials are measured in the same conditions, without being dismantled from the sample holder (figure 4).

Experimental results are shown in figures 5 and 6. 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. Some discrepancies appear for the melamine sample, and may be associated to a different mechanical behaviour of the material skeleton: with our sensor the sample holder was mounted vertically (figure 4) while it was placed

horizontally for the two microphones method. Also the excitation level is different.

However, our sensor provides data for frequencies in the range 100 Hz- 5 kHz with only one measurement and one material sample. For the example shown in figure 6, better results can be obtained at lower frequency with an optimised measurement procedure (by increasing the number of average or by using a more suited signal).



Figure 4: Impedance sensor with 29mm diameter sample holder

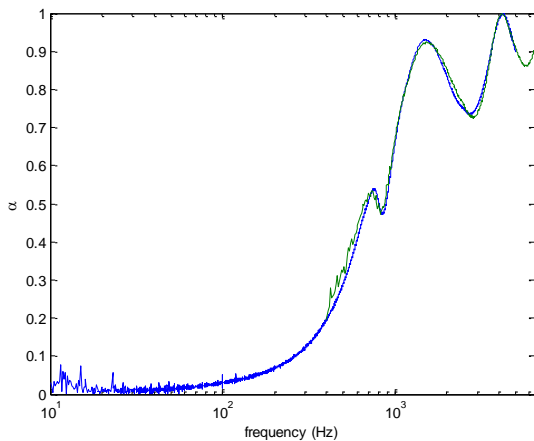


Figure 5: Measured absorption coefficient for a foam (thickness: 40mm)

Green line: standard two microphones measurement method

Blue line: measurement with our impedance sensor

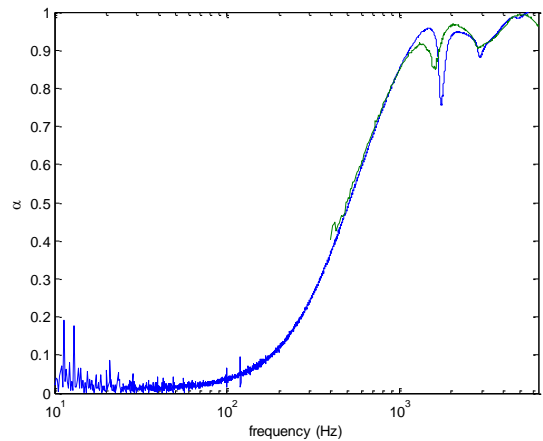


Figure 6: Measured absorption coefficient for a melamine foam (thickness: 51.5mm)
Green line: standard two microphones measurement method
Blue line: measurement with our impedance sensor

6. Low frequency measurements

The main advantage of our setup is that it allows measurement of absorbing materials in the low frequency range (under 100Hz) which is not possible with usual techniques. As an example, the bulk modulus of the equivalent fluid at low frequency for the same sample as in figure 5 is plotted in figure 7. The bulk modulus χ is deduced from impedance Z by using the following expression:

$$\chi = \text{Re}(j\omega ZSL)^{-1} \quad (6)$$

valid for $kL \ll 1$, with L the thickness of the sample.

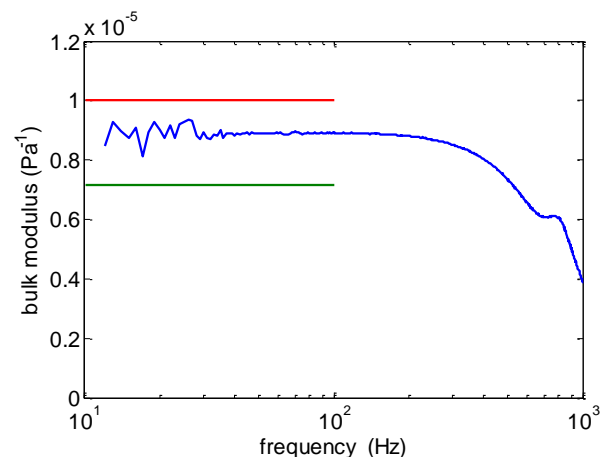


Figure 7: Bulk modulus of the equivalent fluid of a piece of foam

blue line: experiment with impedance sensor

green line: air (adiabatic model)

red line: air (isothermal model)

7. 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 8).

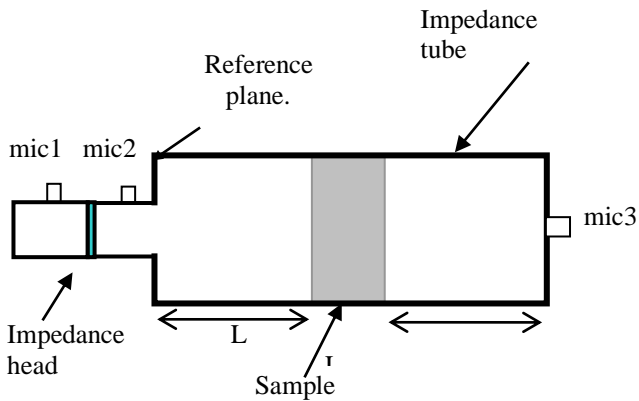


Figure 8: Schematic drawing for a scattering matrix measurement setup

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:

$$Z_T = \frac{H_{31}}{\delta K_T} (1 + \delta Z), \quad (7)$$

where

$$K_T = -\frac{s_3 Z_{c2}}{s_1 Z_{c1}} \frac{\sin(kl_1)}{\sin(kl_2) \cos(kl_1)}$$

with s_3 the sensitivity of the third microphone.

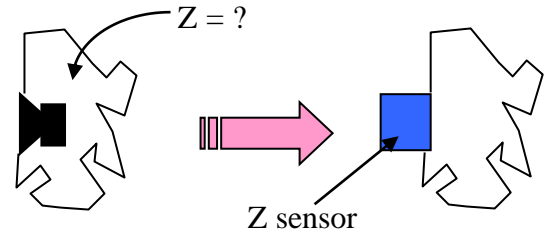
The sample being assumed symmetrical the impedance matrix of the whole impedance tube (including the sample) is given by:

$$\begin{pmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{pmatrix} = \begin{pmatrix} Z & Z_T \\ Z_T & Z \end{pmatrix}, \quad (8)$$

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 material can be estimated.

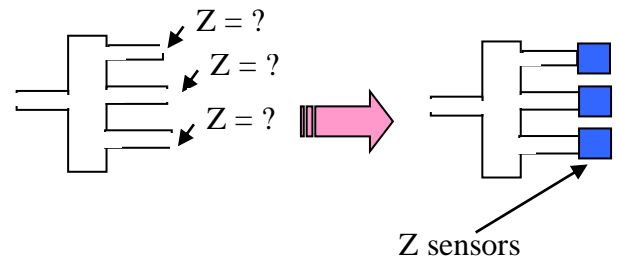
8. Other possible applications

8.1 Measurement of a loudspeaker acoustic load



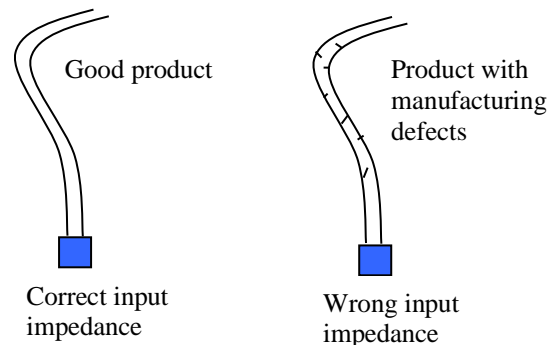
The impedance sensor can be used to measure the acoustic load of the loudspeaker. This can guide the choice of the loudspeaker or can help the design of the structure (door,...) to obtain the desired load.

8.2 Multi port characterisation without air flow



The use of one or several impedance sensors can allow the measurement of the impedance matrix of multi port such as manifolds.

8.3 Acoustic control



The measurement of input impedance can be used to perform acoustic control on industrial products. Moreover, the impedance can be used as a non

invasive technique to determine the exact geometry of a pipe [4]. As an example, the application to a wind musical instrument is given in figure 9.

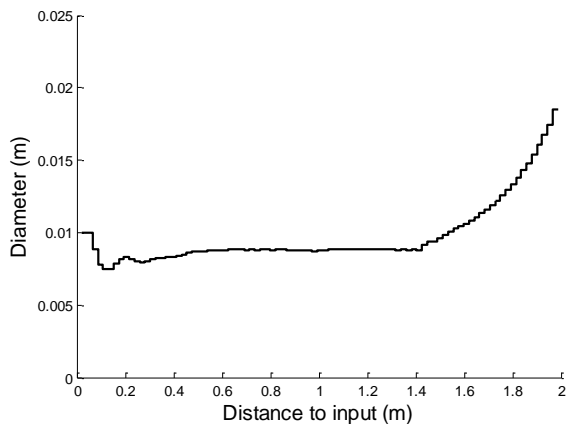


Figure 9: Bore profile of a natural trumpet deduced from input impedance measurement

9. Conclusion

Our impedance sensor is shown to be able to perform measurement of acoustic impedance with the same accuracy as the standard two microphones technique, but on a wider frequency range. It can be used as an alternative because it requires only one sample to cover the frequency range 100Hz – 5000Hz. However, the present setup is actually limited to the frequencies under 5kHz. The frequency range can be extended by slightly reducing the size of the cavities, and the accuracy could be improved by using condenser microphones. These developments are under progress.

10. References

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