

IN SITU SOUND ABSORPTION COEFFICIENT MEASUREMENT OF VARIOUS SURFACES

PACS REFERENCES : 43.20.EI, 43.20.Ye, 43.55.Ev, 43.58.Bh

Michel Bérengier¹ ; Massimo Garai²

¹Laboratoire Central des Ponts et Chaussées
Centre de Nantes, Route de Bouaye, BP 4129
44341 Bouguenais Cedex
France

Tel : +33 2 40 84 59 03

Fax : +33 2 40 84 59 92

E-mail : Michel.Berengier@lcpc.fr

²DIENCA, University of Bologna

Viale Risorgimento, 2

40136 Bologna

Italy

Tel : +39 051 2093298

Fax : +39 051 2093296

E-mail : massimo.garai@mail.ing.unibo.it

ABSTRACT : The measurement of various surfaces sound absorption, requires an *in situ* test method. After having tested several impulsive techniques, we selected the method currently included in the ISO standard 13472-1. This paper presents this method based on the use of a sequence of repeatable impulses and, compares the results with other techniques. This method allows the acquisition of the impulse response of the surface under test, even in presence of a high level of non-stationary background noise. Results obtained for various road pavements, for natural and industrial absorbing surfaces are presented and compared to the last theoretical predicting models.

INTRODUCTION

Since the development of new absorbing materials including industrial products, natural grounds or new low-noise pavements, the sound absorption coefficient has always been considered as one of the most important physical parameter to measure in order to characterise their acoustical efficiency. This characteristic can be measured independently *in labo*, on small samples, by the impedance tube technique [1] or *in situ* using various non destructive testing procedures. These procedures based on an impulse approach have been progressing for about twenty years according to the signal processing techniques evolution. The method definitively accepted for ISO standardisation, and detailed in this paper, is based on the use of a sequence of repeatable impulses [2]. So, the sound absorption coefficient can be estimated under normal incidence and compared to the last theoretical models. When possible, results obtained under perpendicular incidence will be also directly compared to the impedance tube values.

THE SOUND ABSORPTION COEFFICIENT MEASUREMENT

Whatever the method used, the sound absorption coefficient is estimated through the sound reflection coefficient measurement. If $R_p(f)$ is the frequency dependent sound reflection factor, the sound absorption coefficient $\alpha(f)$ is identified by the following equation :

$$\alpha(f) = 1 - |R_p(f)|^2 \quad (1)$$

A sound source and one microphone are located over the surface under test. The sound source produces a transient sound wave which travels past the microphone position to the surface under test and is reflected. The microphone receives both the direct sound pressure wave travelling from the sound source to the surface and the sound pressure wave reflected by the surface under test. These signals are processed as detailed in the following.

The measurement must take place in an essentially free field, i.e. a field free from reflections coming from surfaces other than the surface to be tested. For this reason, the acquisition of an impulse response having peaks as sharp as possible is recommended. Thus, the reflections coming from other surfaces than the absorbing surface to be tested can be identified from their time delay and rejected. To ensure an accurate averaged result, the test impulses emitted by the sound source must be as reproducible as possible.

The direct and the reflected wave, received by the same microphone, are corrected for the path length difference; the power reflection factor of the absorbing surface is then given by the ratio between the direct and reflected waves power spectra.

$$|R_p(f)|^2 = 1 - \frac{1}{K_r^2} \left| \frac{P_r(f)}{P_d(f)} \right|^2 \quad (2)$$

where: K_r is the geometrical spreading factor [3,4] accounting for the path length difference between the direct and the reflected sound pressure wave. $P_r(f)$ is the spectrum of the sound pressure wave reflected by the absorbing surface, as detected by the microphone and $P_d(f)$ the spectrum of the direct sound pressure wave travelling from the sound source to the surface under test, as detected by the microphone.

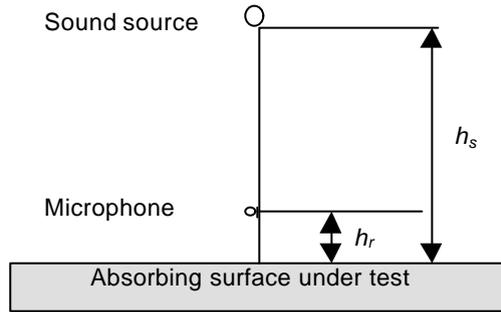


Figure 1. Measurement under normal incidence : Geometrical set-up

The basis of this technique has been developed in the years 1980 and standardised for the first time by the French standard organisation AFNOR in 1990 [5]. At that time, the impulse source was an 8mm alarm pistol. Afterwards, this system has been progressively modified in order to integrate the last evolution of the signal processing techniques. Currently, the sound source is a loudspeaker fed by sequences of repeatable impulses. In both techniques, the general measurement set-up is identical and displayed on figure 1. The active area which contributes to the reflection is about 3 m² [3,5]. Under perpendicular incidence, the radius of the active area is :

$$r = \frac{1}{h_s + h_r + cT_w} \sqrt{\left(h_s + h_r + \frac{cT_w}{2} \right) \left(h_s + \frac{cT_w}{2} \right) (2h_r + cT_w) cT_w} \quad (3)$$

where T_w is the time window length and c the sound velocity (≈ 340 m/s).

Technique Using a Mechanical Impulse

With this kind of source (alarm pistol shot), the signal characteristics were the following : very short impulse (around 1 ms), peak level close to 130 dB at 1 m, good energy distribution

between 250 Hz and 3 kHz and rather good omnidirectionality (± 2 dB) in the perpendicular plane to the pistol barrel.

With this system, $R_p(f)$ is calculated from equation (2) after a windowing operation on the direct and reflected signals as shown in figure 2, and an averaging over 10 shots. Due to the delay between the two signals, function of the system geometry ($h_s = 2$ m and $h_r = 0.50$ m), the window size is about 3ms. Considering this, the low frequency limit is not less than 300 Hz. In addition, the high level of the shots induces some non-linearities in the high frequency domain (up to 2kHz). In spite of these restrictions, some correct results have been found for various road absorbing pavements in the frequency range (400 Hz – 2 kHz). Figure 3 shows a comparison between measurements obtained following this method, the impedance tube standard [1] on bore cores and a phenomenological theoretical model [6].

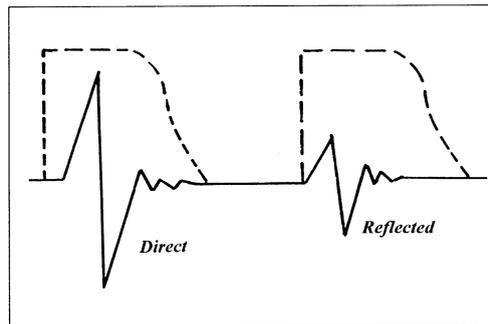


Figure 2. Temporal windows

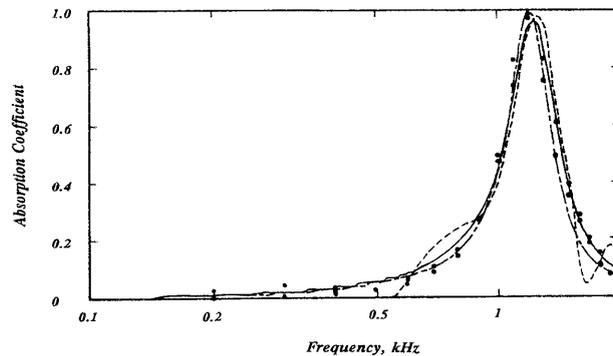


Figure 3. Comparison between measurements (--- : impulse technique ; ●●● : impedance tube) and prediction [6] (—)

Technique Using Sequences of Repeatable Impulses

The overall impulse response measured over the absorbing surface consists of direct sound, reflection from the surface and other parasitic reflections. For further processing, the direct and the reflected sound wave from the surface must be separated. This can be done in the time domain by a simple time windowing, identical to the previous method, when the time delay between the direct and reflected signals is sufficient or by cancellation of the direct sound wave from the overall impulse response by subtraction of an identical signal [7]. For this operation, the incident sound wave must be exactly known in shape, amplitude and time delay. In principle, this can be obtained performing a free-field measurement with the same geometrical configuration of the set-up keeping the distance between the microphone and the sound source strictly constant. This signal subtraction technique allows to position the microphone very close to the surface under test and to take a temporal window for the reflected sound wave as large as allowed by the time delay between the reflected sound wave from the surface and the first parasitic reflection. The subtraction technique can be illustrated by the following figure 4.

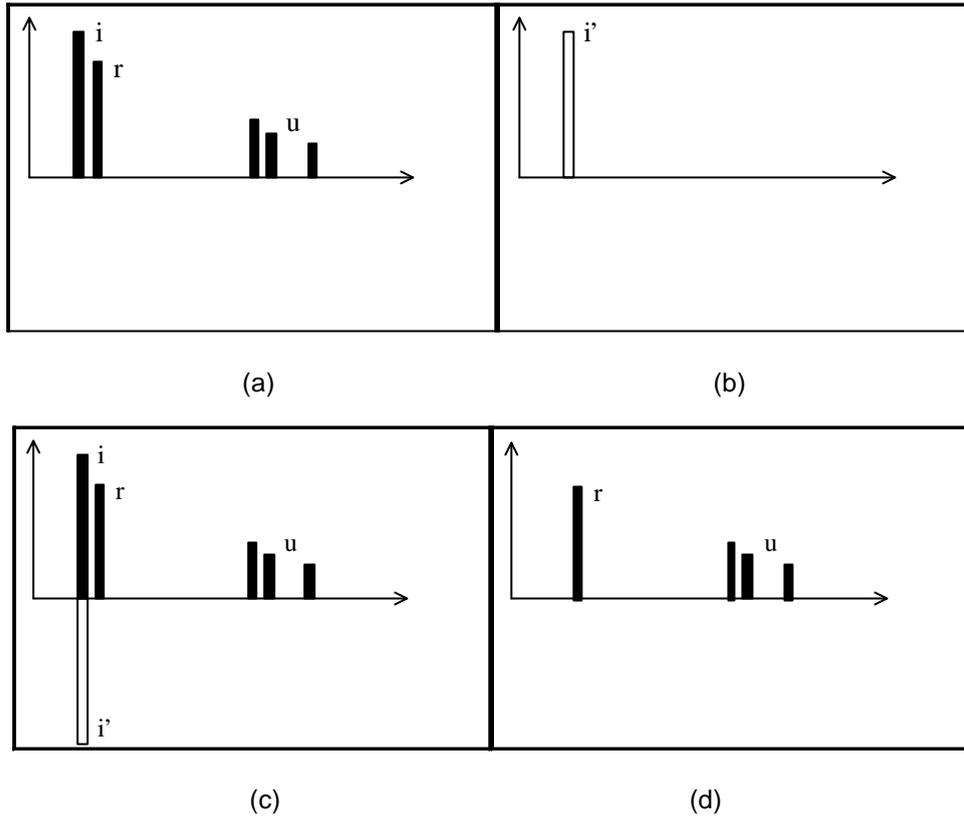


Figure 4 . Principle of the signal subtraction technique. (a): Overall impulse response including: direct incident wave (i), reflected wave (r), unwanted parasitic reflections (u). (b): FREE FIELD direct wave (i'). (c): Direct wave cancellation from the overall impulse response using the free field direct wave (i'). (d): Result

Whatever the structure to be tested, very small absorption values are measured in the low frequency range. Accurate values in this range are very difficult to obtain. Small variations of the sound pressure levels both of the direct and reflected signal can induce high discrepancies on the sound absorption values. This is due to the approximation concerning the frequency response of the system, which is assumed to be linear and frequency independent. In practice, this is not completely true. In order to avoid this problem, and to improve the accuracy of the method, a reference measurement performed on a totally-reflecting surface such as a smooth dense continuous concrete or a hard and thick plywood plate is used [8]. From the two measurements, one on the reference surface ($R_{p,ref,meas}(f)$) and the other on the surface under test ($R_{p,surf,meas}(f)$), the true sound pressure reflection factor of the absorbing surface to be used in equation (1) is computed as:

$$R_{p,surf}(f) = \frac{R_{p,surf,meas}(f)}{R_{p,ref,meas}(f)} \quad (4)$$

For the measurement, an electro-acoustical source is used. This, receives an input electrical signal consisting of an impulse or a sequence of repeatable impulses. The crest factor of each impulse shall not be so high as to force the loudspeaker to operate in a non linear manner. The usage of a maximum-length sequence (MLS) is recommended [4] to get the maximum noise rejection [4], but other signals like sweep bursts can be also used [9], provided that the S/N ratio is not compromised. The S/N ratio can be improved by repeating the same test signal and synchronously averaging the microphone response. This characteristic is of great importance when the measurements are carried out in a noisy environment such as in industrial halls or close to a high trafficked road.

Results can be given both in the 1/3 octave bands from 250 Hz to 4kHz or in narrow bands. Figure 5 shows a narrow band comparison between the measured and predicted [6] sound

absorption coefficient for a porous pavement while figure 6 shows a 1/3 octave bands comparison between the measured [1,2] and predicted sound absorption coefficient for a mineral wool. In that case, the theoretical model used for the prediction is the Delany and Bazley one [10].

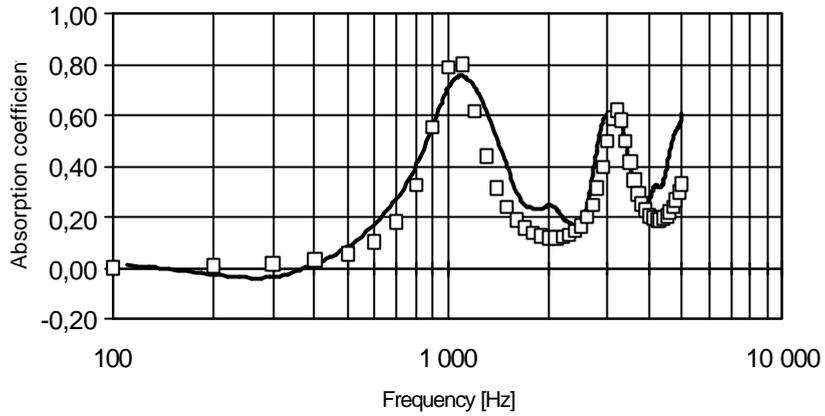


Figure 5. Comparison between predicted and measured values of the absorption coefficient for a porous road pavement. Prediction [6] : (□ □ □) ; Measurement : (—).

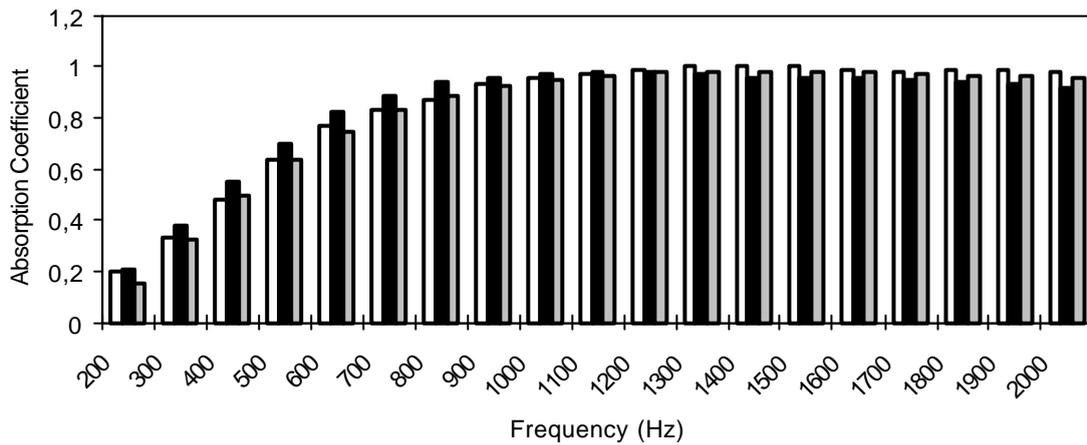


Figure 6. Comparison between predicted and measured values of the absorption coefficient for a mineral wool. Prediction [10] : (□) ; Measurements : (■ : [2] ; ▤ : [1]).

Figure 7 shows a 1/3 octave bands comparison between two measurements on the same porous road pavement using MLS and a sweep burst signals.

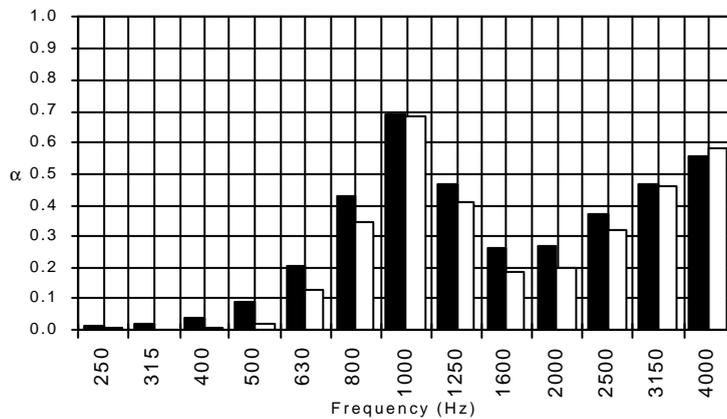


Figure 7. Measured values using MLS (■) and sweep burst (□) signals.

CONCLUSION

The method described in this paper is robust enough and easy to use to be performed directly *in situ*. It is included in the ISO standard 13472-1 [2]. Experimental results compare fairly well with the last theoretical model predictions concerning the acoustic behaviour of absorbing surfaces such as industrial products, natural grounds or new low-noise pavements. With this method, it is also possible, after some modifications in the post-processing software, to determine the acoustic impedance representative of the acoustic properties of the various absorbing surfaces to be introduced in the different theoretical propagating models currently used for environmental predictions.

BIBLIOGRAPHICAL REFERENCES

- [1] ISO 10534-1, Acoustics - Determination of sound absorption coefficient and impedance in impedance tubes - Part 1: Method using standing wave ratio.
- [2] ISO 13472-1, Acoustics - Measurement of sound absorption properties of road surfaces in situ - Part 1: Extended surface method.
- [3] M. Bérengier, Y. Delanne, Caractéristiques acoustiques intrinsèques d'une structure par une méthode impulsionnelle, Bull. liaison Labo P. et Ch. **139**, 113-118 (1985).
- [4] M. Garai, Measurement of the sound absorption coefficient in situ: the reflection method using periodic pseudorandom sequences of maximum-length, Appl. Acoust. **39**, 119-139 (1993).
- [5] AFNOR 31089, Acoustique – Code d'essai pour la détermination de caractéristiques acoustiques installés en champ libre.
- [6] J.F. Hamet, M. Bérengier, Acoustical characteristics of porous pavements : A new phenomenological model, Internoise 93, Leuven, Belgium, 641-646 (1993).
- [7] E. Mommertz, Angle-dependent in-situ measurements of reflection coefficients using a subtraction technique, Appl. Acoust. **46**, 251-263 (1995).
- [8] M. Bérengier, An in-situ method to evaluate the absorption coefficient of road pavements, ICA 95, Trondheim, Norway (1995).
- [9] M. Bérengier, M. Garai, A state-of-the-art of in situ measurement of the sound absorption coefficient of road pavements, ICA 2001, Rome, Italy (2001).
- [10] M.E. Delany, E.N. Bazley, Acoustical properties of fibrous absorbent materials, Appl. Acoust. **3**, 105-116 (1970).