Applied Acoustics 108 (2016) 26–30

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Multi-levels inverse identification of physical parameters of porous materials

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ARTICLE INFO

Article history:
Received 27 April 2015
Received in revised form 14 September 2015
Accepted 16 September 2015
Available online 1 October 2015

Keywords:
Porous material
Physical parameters
Acoustic absorption coefficient
Multi-levels minimization

ABSTRACT

The identification of the physical parameters of porous materials presents an important field of research, in which many identification methods are developed. One of those methods is presented in this paper. In fact, a multi-levels inverse identification method is developed in order to estimate these physical parameters. The proposed method is based on the minimization of the difference between a reference acoustic absorption coefficient of a porous material and the computed values. The minimization is done according three levels, in each level an acoustic model of porous material is used to evaluate one or two parameters. Finally, the five physical parameters of the porous materials are deduced. The proposed method is applied to Polyurethane foam material. The obtained results are satisfying with small values of errors and with estimated acoustic absorption coefficient reaching the reference one.

1. Introduction

Physical parameters of porous materials like the air flow resistivity, the porosity, the tortuosity and viscous and thermal characteristic lengths are important to predict the acoustic behavior of this kind of material. In fact, many models of the acoustic behavior of porous materials are developed. Delany–Bazley model [1], Hamet–Berengier model [2,3], Johnson–Allard and Lafarge–Allard models [4,5], Johnson model [6], Johnson–Champoux–Allard model [7] and the Attenborough model [8–10] allowing the computation of the surface characteristic impedance, the wave number and the acoustic absorption coefficient of a porous material.

These physical parameters can be measured directly, but a set of experimental setups to measure each parameter separately which demands a lot of time is needed. To surpass this problem, inverse methods present an alternative technique to evaluate these parameters. Instead of making five experiences to evaluate each parameter, one has to measure only a single acoustic parameter, such as the surface acoustic impedance or the acoustic absorption coefficient of the material, using an impedance tube. This measurement is coupled with one of previous acoustic models of porous materials to evaluate the rest of physical parameters of the porous materials. For this, an optimization algorithm is used to minimize a cost function presenting the difference between the measured and the computed acoustic absorption coefficient. The physical parameters of the porous materials are used as inputs of this optimization algorithm. After several iterations, the optimal physical parameters are those which give the minimum of this cost function.

Several researchers developed this kind of inverse techniques to estimate the physical parameters of porous materials. We can cite Bonfiglio and Pompoli [11] and Shravage et al. [12], who used the difference between the amplitudes of measured and computed normalized surface impedances of the porous material as a cost function. In this study the Johnson–Champoux–Allard model [7] is used. The obtained results are compared to analytic ones obtained by methods computing the physical parameters directly and to results obtained by a genetic algorithm. Based on the computation of the relative error of each parameter, the authors concluded that the results obtained by the indirect and genetic methods are better than those obtained by the direct one. This result is confirmed when computing and comparing the acoustic absorption coefficient deduced respectively by the excepted and the obtained physical parameters.

Attalla and Panneton [13] developed an inverse method for the characterization of porous materials based on the measurement of the material surface acoustic impedance, the Johnson model [6] is used and the developed method presented its efficiency even in the multilayered porous materials case. Mareze and Lenzi [14] developed an inverse method to evaluate the physical parameters of

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http://dx.doi.org/10.1016/j.apacoust.2015.09.013
0003-682X/

porous materials by using Allard [4] and Johnson [6] models. It is based on the minimization of the difference between measured and computed surface acoustic impedances of the porous material. The minimization is assured by genetic and gradient methods. The obtained results present a good agreement with direct measurements of each parameter. Mareze and Lenzi [14] have shown, also, that the inverse method, based on the gradient method, is the fastest one to estimate the porous material parameters.

Garoum et al. [15,16] have developed an inverse numerical procedure based on the genetic algorithms and the Levenberg–Marquardt method, in order to estimate the physical parameters of two sustainable materials (loose granular cork and esparto fibers). They minimize a cost function based on the difference between the experimental and computed acoustic absorption coefficients. Two models of porous materials: Johnson model [6] and Attenborough model [8] are used. An agreement between parameters estimations given by models and experimental data is shown. The grain size effect is also investigated. Alba et al. [17] developed an inverse technique to estimate the porosity of a porous material by using measurements of the normal incidence sound absorption coefficient. They demonstrate that the numerical results agree well with experimental ones. Zielinski [18,19] developed an inverse identification method based on the Johnson–Champoux–Allard model [7] and a minimization of the difference between theoretical and experimental acoustic absorption coefficients. This minimization is not made directly using dimensionless parameters. Also a microscopic estimation of the acoustic parameters of the porous materials is presented.

Sellen et al. [20] used the active control method to identify the characteristic parameters of porous materials. The principle of this method is based on varying the boundary conditions at the rear face of the material by an active control system. The modification of boundary conditions aims to approach theoretical results given by Lafarge–Allard model [4,5] to experimental ones. A very good agreement is observed between predictions and measurements for the different studied configurations. Chazot et al. [21] presented an inverse characterization method to get poroelastic intrinsic parameters of porous materials. This method is based on a Bayesian approach getting probabilistic data of each parameter allowing the determination of the confidence interval of each parameter.

In this paper, a multi-levels inverse identification method is developed to estimate the physical parameters of porous materials. The proposed method is based on the minimization of the difference between a reference and the computed values of the acoustic absorption coefficient of the porous material. The minimization is done according three levels. In each level an acoustic model of porous material is used to evaluate one or two parameters. Finally, the five physical parameters of the porous materials are deduced. The outline of the paper is as follows: in Section 2, a presentation of used acoustic models of porous materials to compute the acoustic absorption coefficient of this kind of materials according its physical parameters. Section 3 presents in details the developed multi-levels identification method. Finally, the proposed identification results in the case of a porous material are presented, compared with other results and discussed in Section 4.

2. Computation of the acoustic absorption coefficient of porous materials

The acoustic absorption coefficient of an absorbing material is computed from its surface acoustic impedance as follows [22]:

$$\alpha = \frac{4\mathrm{Re}(Z)}{(1+\mathrm{Re}(Z))^2 + (\mathrm{Im}(Z))^2} \tag{1}$$

with

$$Z = Z_c \coth(jk_c d) \tag{2}$$

d is the porous material depth. Z_c and k_c are respectively the normalized acoustic impedance and the wave number of the porous material. These two quantities are estimated by different models using porous materials parameters and according to the frequency.

In this work, three models are chosen: the first is the Delany–Bazley model [1] which expresses the normalized acoustic impedance and the wave number for the porous material according to the flow resistivity σ as follows:

$$Z_c = Z_0\left(1 + 9.08\left(\frac{f}{\sigma}\right)^{-0.754} - 11.9j\left(\frac{f}{\sigma}\right)^{-0.732}\right) \tag{3}$$

$$k_c = \frac{\omega}{c_0}\left(1 + 10.8\left(\frac{f}{\sigma}\right)^{-0.700} - 10.3j\left(\frac{f}{\sigma}\right)^{-0.595}\right) \tag{4}$$

Z_0 is the characteristic impedance of the air, f is the frequency, ω is the pulsation and c_0 is the sound celerity in the air.

The second used model is the Hamet–Berengier model [2,3] which expresses these two quantities using three porous materials parameters which are the material flow resistivity σ, porosity ϕ and tortuosity α_∞ as follows:

$$Z_c = Z_0\sqrt{\frac{\alpha_\infty}{\gamma}}\frac{1}{\phi}\sqrt{1 - j\frac{f_u}{f}}\left[1 - \left(1 - \frac{1}{\gamma}\right)\frac{1}{1 - j\frac{f_\theta}{f}}\right]^{-1/2} \tag{5}$$

$$k_c = \frac{\omega}{c_0}\sqrt{\alpha_\infty \gamma}\sqrt{1 - j\frac{f_u}{f}}\sqrt{1 - \left(1 - \frac{1}{\gamma}\right)\frac{1}{1 - j\frac{f_\theta}{f}}} \tag{6}$$

with

$$f_\theta = \frac{\sigma}{2\pi\rho_0 N_{pr}} \tag{7}$$

$$f_u = \frac{\sigma\phi}{2\pi\rho_0\alpha_\infty} \tag{8}$$

$\gamma = \frac{C_p}{C_v}$ is the ratio of specific heats at respectively constant pressures and volumes, ρ_0 is the air density and N_{pr} is the Prandtl number. f_θ and f_u are describing respectively the thermal and viscous dependences of the porous material.

The third used model is the Lafarge–Allard model [4,5] which expresses Z_c and k_c using the five porous materials parameters which are the material flow resistivity σ, porosity ϕ, tortuosity α_∞, viscous length Λ and thermal length Λ' as follows:

$$Z_c = \sqrt{\rho K_{LA}} \tag{9}$$

$$k_c = \omega\sqrt{\frac{\rho}{K_{LA}}} \tag{10}$$

with

$$\rho = \alpha_\infty\rho_0\left[1 - j\frac{\sigma\phi}{\rho_0\alpha_\infty\omega}\sqrt{1 + \frac{4j\rho_0\alpha_\infty^2\omega\eta}{\sigma^2\phi^2\Lambda^2}}\right] \tag{11}$$

$$K_{LA} = \gamma P_0\left[\gamma - \frac{(\gamma-1)}{1 + \frac{\eta\phi}{j\omega\rho_0 N_{pr} k_0'}\sqrt{1 + \frac{4j\omega\rho_0 N_{pr} k_0'^2}{\eta\phi^2\Lambda'^2}}}\right]^{-1} \tag{12}$$

η is the dynamic viscosity, P_0 is the atmospheric pressure and k_0' is the thermal permeability $\left(k_0' = \frac{\phi\Lambda'^2}{8}\right)$.