# Porous material parameters identification from in situ acoustic measurements

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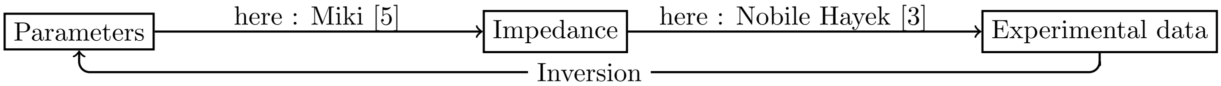
The present paper focuses on the identification of porous material parameters, especially porous asphalt, based on acoustics measurements. Previous work on identification has been made taking into account the absorption [1] and the impedance [2] of the material to be characterized. The limitation is that impedances are difficult to measure directly. The identification from experimental data has to follow a global approach : it is necessary to consider a model for the material but also for the sound propagation. This is why in the following, two choices are made for the direct problem. The direct resolution is then analytical, which makes the inversion of the whole chain possible though the use of the simulated annealing. The reason of considering acoustic measurements in this method is the development of a non destructive method. The goal here is to provide an identification method from the acoustical pressure at microphones to the parameters of the material.




## 1 Choices of the direct problem

### 1.1 Propagation model

The choice that has been made here is to use the Nobile and Hayek model [3] which is well used in open field, or in anechoïc chamber. The pressure is given by $(r, z)$ :

$$\begin{cases} P(r,z) &= \dfrac{e^{-ik\,R_1}}{R_1} + \dfrac{-e^{ik\,R_2}}{R_2} - \dfrac{4ik\beta B e^{ik\,R_2}}{\beta + sin(\Psi)} I_3 \quad (1) \\ I_3 &= \displaystyle\int_0^\infty \frac{e^{-ik\,R_2(t^2+2Bt)}}{\sqrt{1-t^2/H-2Bt/H}} dt \quad (2) \\ B &= -i\sqrt{1+\beta\sin\Psi - \sqrt{1-\beta^2}\cos\Psi} \quad (3) \\ H &= 1+\beta\sin\Psi - \sqrt{1-\beta^2}\cos\Psi \quad (4) \end{cases}$$

where $k$ is the wave number, $\beta = \frac{c_0\rho_0}{Z}$ the material normalized admittance, $R_1$ the distance from the source to the material, $R_2$ the distance from the microphone to the material, $\Psi$ the incidence angle.
Two measurements are made by moving the microphone at $zz = d_1$ and at $z = d_1 + s$ on a vertical axis. Then the quotient of the two pressure give the transfer function $H$.

The main difficulty to calculate (1) is the numerical computation of the integral $I_3$ (equation 2). [3] proposes some approximations but theses techniques are rather slow. As it will be calculated a lot of times, it has been decided here to compute (2) by a Monte-Carlo method.

### 1.2 Impedance model

The choice of the impedance model is the Delaney-Bazley-Miki model [5]. This choice relies on the fact that there are only 4 parameters to identify. Three intrinsic parameters (air flow resistivity $\sigma$, the porosity $\Phi$ and the oblic tortuosity $q$) and one geometric parameter (the thickness $d$). This model gives the impedance $Z$ of the material, which is directly used in the propagation model in (1,3,4) with $\beta$.

## 2 Description of the inversion

The inversion is carried out with a modified version of the simulated annealing [4]. This algorithm is a combination of a random walk in a $n$-dimensional space and the Metropolis criterion. It is described at figure 1.
The cost function has been constructed from the real and the imaginary parts of the transfer function $H$, by a sum on

the quadratic differences as in [2]. This cost function deserves some attention, because the way it is built is conditioning the optimum research. It is possible for example to combine optimization criteria by using a weighted cost function.

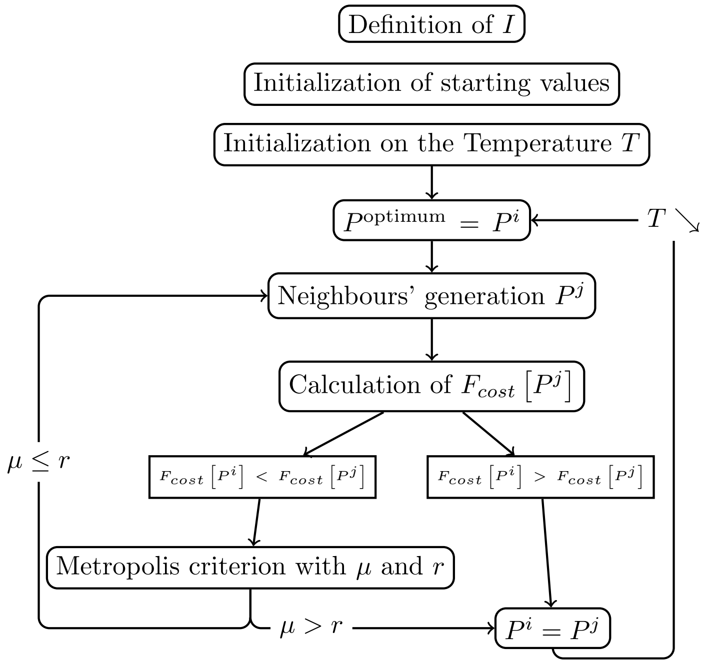



Figure 1: The Simulated Annealing

The set of parameters, denoted by $P$, is composed of 4 parameters $(p_k)_{k=1..4}$. Each parameter has a interval of definition $I_{p_k}$. The first step is to define $I$ which stands for the Cartesian product $\prod_{k=1}^{4} I_{p_k}$, so this step fixes the bounds of the research. Then comes the initialization of the starting values and the temperature that will decrease according to an exponential law. Then the algorithm begins by fixing a value for $P^{\text{optimum}}$. The neighbour's generation is the step where the candidates are proposed. At a temperature $T$ from a set $P^j$, a neighbour is generated following (5) where $\eta_1$ and $\eta_2$ are following $\mathcal{U}([0,1])$, which stands for the uniform law of $[0,1]$

$$P_k^{j+1} = P_k^j + \left(1 - \mathrm{e}^{-T}\right) P_k^j \, \eta_1 \frac{\arctan(\eta_2)}{\arctan(1)} \tag{5}$$

Note that this generation depends on temperature $T$. The evaluation by the cost function of the set $P^j$ determines if the solution is better or not. When it is not, ie $\Delta F = F_{cost}\left[P^j\right] - F_{cost}\left[P^i\right] > 0$, the Metropolis criterion is applied, that is the probability $\mu = \mathrm{e}^{-\Delta F/T}$ is compared to an outcome of $r$ following $\mathcal{U}([0,1])$.

# 3 Results

Pure numerical simulations give accurate results, this means that from a simulated transfer function, the algorithm finds the parameters used for the simulation. This constitutes a numerical validation.
But concerning data coming from experimental measurements, the inversion presents some difficulties (Table 1). This has been only done on the foam U150, which can be characterized also in the Kundt's tube. The problem is that parameters $q$ et $\alpha_\infty$ (the tortuosity) can not be compared directly. Furthermore, comparisons on $\sigma$ et $\Phi$ are not satisfactory. The question on this comparison is still open, because in a free-field measurement and the Kundt's tube, the solicitation of the material is very different.

| | $\alpha_\infty$ | q | $\Phi$ | $\sigma$ | d |
|---|---|---|---|---|---|
| Kundt's tube | 1.68 | | 0.87 | 42950 | 0.10 |
| identification from experimental data | | 4.5 | 0.73 | 56678 | 0.1312 |

Table 1: Values for the foam U150 with the Kundt's tube and from identification from experimental data

# 4 Conclusion

This paper is a first attempt to provide a non destructive method of direct characterization from acoustical measurements. The method has been tested on only one measurement and comparisons with values obtained with the Kundt's tube show that the method needs improvements.
The first thing to do is to test the method on several measurements, which has not been made yet because of a lack of time.
The second point is that the method can certainly be improved by using other impedance models, like the Johnson-Allard model for example, but then there are more parameters to identify.
Finally, the most important is that the cost function can be adapted to the inversion problem, especially regarding the sensitivity of the parameters on the frequency band. To construct an efficient cost function, there is a strong need of a criteria dealing with this aspect of the models. The construction of this characterization method with such a cost function would certainly lead better and faster to the physical solutions.

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