Acoustical measurements in poroelastic materials performed with a parametric demodulation ultrasonic method

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Abstract

A new hybrid ultrasonic technique (the so-called parametric demodulation method) [1] is used to generate planar sound waves from powerful low frequency ultrasound being amplitude modulated. These audio plane waves are then utilized to perform fine metrological measurements on poroelastic media, such as felt materials. In the present work several configurations are described both in retrodiffusion and in transmission within the tested material. In any case, one uses a 1/2 inch B&K audio microphone for detection and an hand-made piezoelectric transducer for generation of the ultrasonic amplitude modulated waves. In the transmission configuration, dispersion curves have been obtained on various felt plates over the 4-40 kHz bandwidth, and the experimental results have been compared with the well-known Biot-Johnson-Allard 'equivalent fluid' theoretical model. For retrodiffusion measurements, the coefficient of reflection has been measured on the very same plates for a similar bandwidth. These results exhibit some frequency dependent oscillations which are due to constructive and partially destructive interferences within the porous plates. Agreement between numerical predictions and experimental data is fair, in some cases being excellent.

1. Position of the problem

The Quantitative Non Destructive Evaluation (QNDE) of air-saturated poroelastic materials with low frequency (LF) ultrasonic techniques is quite interesting both for laboratory control purposes as well as for the potential applications to remote characterization "in-situ" measurements, and for the "on-line" monitoring of production of industrial porous materials (such as fibrous felts and plastic foams). During the last 15 years, significant progress was achieved in the field of QNDE laboratory measurements, including reflection and transmission configurations, and using in some cases surface waves above poroelastic layers [2-4]. These numerous ultrasonic techniques allow to determine with high accuracy fundamental physical parameters which are crucial for the theoretical description of the propagation of acoustic waves in porous media, e.g. porosity, tortuosity and the shape factors related to the viscous and thermal dissipative exchanges within the porous medium [5]. Usually, these laboratory measurements are performed between 20 and 60 kHz. At higher frequencies (> 100 kHz), some limitations exist due to the material absorption which becomes drastic, and because the mechanism of scattering (Rayleigh-like, and then multiple scattering) is more and more present as the wavelength decreases and compares to the dimensions of the pores (dimensions or distances between fibres, cells and grains).

2. Theoretical Modelling

$$R(\omega)=\frac{j\left(\phi^2-z_{mat}^2\right)\sin k_{mat}h}{2\,z_{mat}\cos k_{mat}h+\;j\left(\phi^2+z_{mat}^2\right)\sin k_{mat}h}$$

$$K(\omega)=\gamma P_0/[\gamma-(\gamma-1)\{1+\frac{\sigma'\phi}{j\Pr\omega\rho_0\alpha_\infty}G'_J(\Pr\omega)\}^{-1}]$$

$$\rho(\omega)\;=\;\alpha_\infty\rho_0\,[\,1+\frac{\sigma\phi}{j\omega\,\rho_0\alpha_\infty}\,G_J(\omega)]$$

$$G_J(\omega)\;=\;\sqrt{\left(1+\frac{4\;\;j\alpha_\infty^2\eta\,\rho_0\omega}{\sigma^2\Lambda^2\,\phi^2}\right)}$$

$$G'_J(\Pr\,\omega)\;=\;\sqrt{\left(1+\frac{4\;\;j\alpha_\infty^2\eta\,\rho_0\omega\,\Pr}{\sigma'^2\,\Lambda'^2\,\phi^2}\right)}$$

$$\sigma' = \frac{8\ \alpha_\infty \eta}{\Lambda'^2 \phi}$$

where γ the specific heat ratio, P_0 the atmospheric pressure, p the Prandtl number, ϕ the porosity, α_∞ the tortuosity, $\omega = 2\pi f$ the angular frequency, σ the air flow receptivity, ρ_0 the air density at rest, η the air velocity, and Λ, Λ' the viscous, and thermal characteristic lengths.

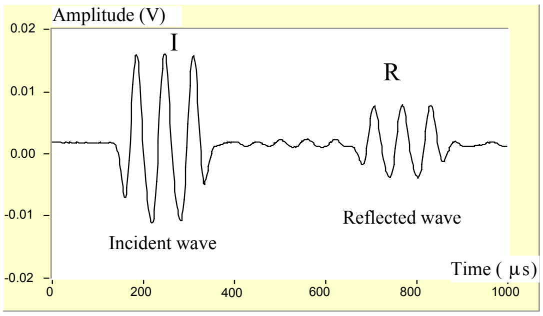

Figure 1 : Example of generated signals.

3. Experimental and theoretical results

The obtained results are shown on Fig. 2 in the format of the coefficient of reflection versus frequency over the obtained bandwidth. The number of bursts in a single wave-packet could evidently be changed. In the performed work, we have used either one, two or three bursts per wave-packet (even if here only the case with 3 bursts has been documented on Fig. 1). We have verified that the results in term of the coefficient of reflection are totally reproducible when changing the number of bursts. It is very useful to decrease to one single burst per wavepacket because in that case the produced bandwidth is increased accordingly. For instance with the same signal as the one shown on Fig. 1, when one single burst is used, the bandwidth at - 6dB extends from 10 to 24 kHz. By modifying as well the modulation frequency, one enables to record the coefficient of reflection over separate bandwidths which superimpose their results. It has been possible to record the coefficient of reflection with the 162 kHz pump transducer over the total frequency range extending from 4 to 35 kHz. The results shown on Fig. 2 concern comparison of the experimental to the numerically predicted coefficient of reflection versus frequency, for the plate of FT2000 thermal felts manufactured by Rieter, having at h = 20 mm, with the modulation frequency taken into steps first at 8 kHz, and secondly at 32 kHz

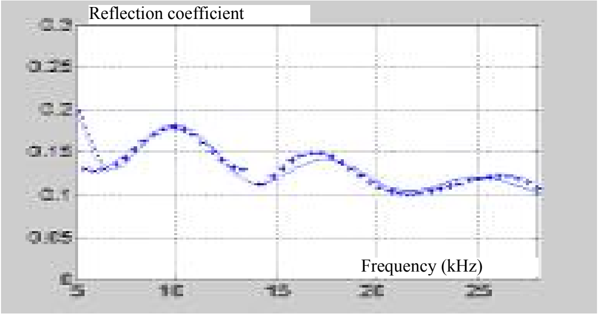

Figure 2 : Reflection coefficient versus frequency. Experiment shown with crosses ; Model is shown as continuous line.

4. Conclusion

A new NDE ultrasonic hybrid method to characterize poroelastic materials has been demonstrated. This technique is working between 4 kHz and 40 kHz, with possible extension at low frequency. It enables to characterize various porooelastic materials. A simple modelling for the reflection coefficient versus frequency has been adequately compared with experiment. It is also possible to obtain the dispersion curve at low frequency .

5. References

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