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ACOUSTICAL PARAMETERS OF POROUS MATERIALS AND THEIR MEASUREMENT

ABSTRACT:
Acoustical parameters of porous materials give the necessary and important information for noise control engineers. Profound knowledge their physical characteristics enable an effective sound absorber material design. The theory of sound-absorbing materials has progressed considerably during the last decade. A noise control engineer with serious interest in sound absorbing technology is advised to study all this parameters.
Noise control engineers frequently face problems of design sound absorbing materials that provide the desirable sound absorption coefficient that minimizes the size and cost, does not introduce any environmental hazards, and stands up to hostile environments. The designers of those absorbers must know how to choose the proper material, its geometry and the protective facing. Porous sound-absorbing materials are utilized in almost every areas of noise control engineering. This paper deals with the acoustical parameters of porous materials and their measurement.

KEYWORDS:
porosity, flow resistivity, tortuosity, measurement

INTRODUCTION

A small part of the acoustical parameters used to describe the visco-inertial and thermal behavior of acoustical porous materials are directly measurable. This is the case for the open porosity, the static air flow resistivity and the high frequency limit of the dynamic tortuosity.

OPEN POROSITY

The open porosity, term commonly reduced to "porosity", refers to the ratio of the fluid volume occupied by the continuous fluid phase to the total volume of porous material. For acoustical materials, its range of values is approximately [0.70 0.99]. The schematic representation of an acoustical porous medium is shown on figure 1. The fluid phase, in white, is made up of a network of connected pores. The closed pores are considered to be a part of the solid phase, in grey. [9].

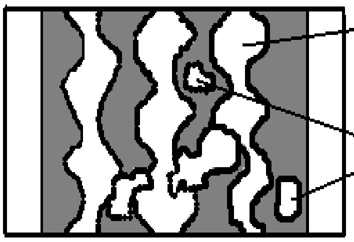

Figure 1. Schematic representation of an acoustical porous medium [9]

Open porosity measurement

The porosity can be directly measured and there are several methods to do so [2].

The gravimetric measurement of porosity requires the weighing of a known volume of dry material. Shot can be separated from fiber by a centrifuge process. The dry weight can be used together with the sample volume to calculate the bulk density ρ_B. Subsequently an assumed solid density is used to calculate the porosity h from [7]:

$$h = 1 - \frac{\rho_A}{\rho_B} \quad (1)$$

where: h - is the porosity, ρ_A- is the solid density [kg.m^{-3}], ρ_B - is the bulk density [kg.m^{-3}].

A gravimetric method may be used with some consolidate granular materials is to saturate the sample with water and deduce the porosity from the relative weights of the saturated and unsaturated samples. Mercury has been used as the pore-filling fluid in some applications, but for many materials the introduction of liquids affects the pores.

The dry method of porosity determination has been developed by Champoux et al.[3] is based on the measurements of the change in pressure within a sample container subject to a small known change in volume. The lid of the container is a plunger, which is driven by a precise micrometer. The pressure inside the chamber is monitored by a sensitive pressure transducer and an air reservoir connected to the *container through a valve serves to isolate the system from fluctuations in atmospheric pressure. The system has been estimated to deliver values of porosity accurate to within 2%. This method measures the porosity of connected air-filled pores. However the gravimetric methods do not differentiate between sealed pores and connected pores. The open porosity measurement apparatus is shown on figure 2.*

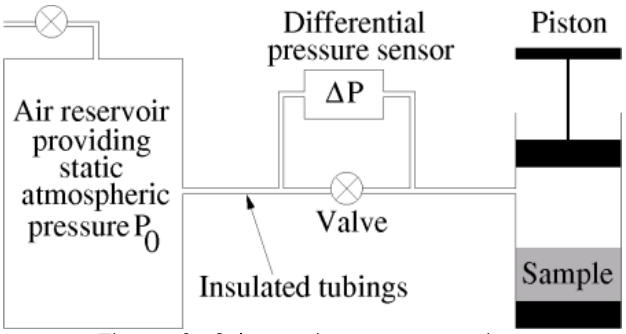

Figure 2. Schematic representations of the open porosity measurement apparatus presented by L. Beranek [9]

An acoustical (ultrasonic) impulse method for measuring porosity using the impulse reflected at the first interface of a slab of air-saturated porous material has been proposed and has been shown to give good results for plastic foams.

STATIC AIR FLOW RESISTIVITY

The static air flow resistivity, term commonly reduced to "resistivity", is one of the two most known parameters, with the open porosity, used to describe the acoustical behavior of porous materials. It characterizes, partly, the visco-inertial effects at low frequencies. Sound is vibrations in the air, so it is easy to imagine that sound cannot easily propagate through materials which air can hardly pass through [10]. In other word, flow resistivity can represent the difficulties of the propagation of sound (air-borne sound) in the gap in porous materials. A material such as iron and rubber etc. which air cannot pass through easily does not propagate the air-borne sound but propagate only the structure-borne sound (vibration). The models by Delany-Bazley [4] and Delany-Bazley-Miki [6] use only this parameter to describe the behavior of fibrous acoustical materials.

For bulk -, blanket -, or board-type porous materials the flow resistivity R_1 is defined as specific flow resistance per unit thickness [7]:

$$R_1 = \frac{R_f}{\Delta x} \quad [N.s.m^{-4}] \text{ or } [Pa.s.m^{-2}] \qquad (2)$$

where:
R_f - is the airflow resistance $[N.s.m^{-3}]$ or $[Pa.s.m^{-1}]$,
Δx- is the thickness of the layer [m].

The flow resistivity is a measure of the resistance per unit thickness inside the material experienced when a steady flow of air moves through the test sample. Flow resistance R_f represents the ratio of the applied pressure gradient to the induced volume flow rate and has unit of pressure divided by velocity. [7]

$$R_f = \frac{\Delta p}{\upsilon} \quad [N.s.m^{-3}] \text{ or } [Pa.s.m^{-1}] \qquad (3)$$

where:
Δp- pressure $[N.m^{-2}]$ or [Pa],
υ - velocity $[m.s^{-1}]$.

If a material has a high flow resistivity it means that it is difficult for air to flow through the surface. For acoustical materials, its range of values is approximately $[10^3\ 10^6]$. [9]

STATIC AIR FLOW RESISTIVITY MEASUREMENT

The resistivity can be directly measured [5]. The measurement of the flow resistance and flow resistivity of porous building materials has been standardized on a compressed-air apparatus [1]. In this measurement the pressure gradient across the sample in a fixed sample holder is monitored together with various flow rates. Compressed air is passed through a series of regulating valves and very narrow opening into chamber E. This creates an area of low pressure immediately in front of the three tubes connected to the rest of the system. Air is drawn from the environment through the sample as a result of the pressure differential. The rate of airflow through the system is controlled by three flowmeters, giving a total measurement range between 8.7 and 0.1 L/min. Normally the flow rate must be kept below 3 L/min to avoid structural damage to the sample. The schematic representation of compressed-air apparatus for laboratory measurement of flow resistance is shown on figure 3. [7]

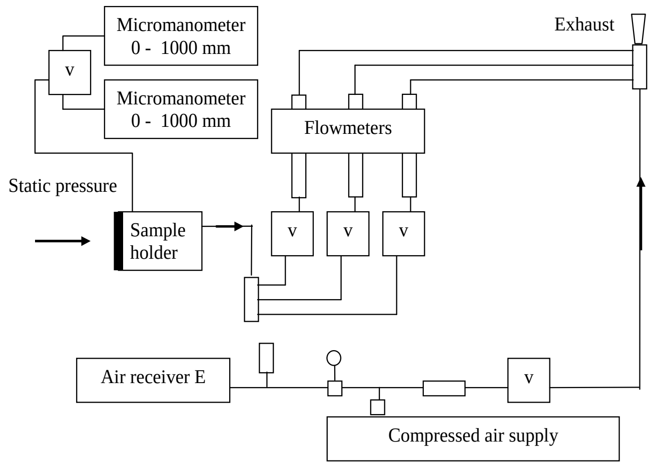

Figure 3 Schematic representation of a compressed-air apparatus for laboratory measurement of flow resistance [7]

A comparative method [8] makes use of a calibrated known resistance placed in series with the test sample. Variable capacitance pressure transducers are used to measure pressure differences across both the test sample and the calibrated resistance. For steady, nonpulsating flow, the ratio of flow resistance equals the ratio of measured pressure differences. The schematic representation of this apparatus is shown on figure 4.

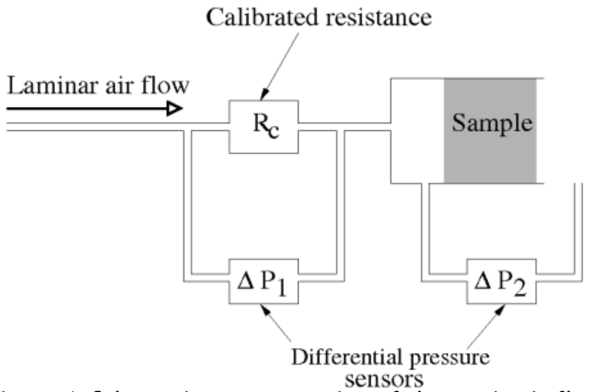

Figure 4. Schematic representation of the static air flow resistivity measurement apparatus presented in [ISO 9053]

TORTUOSITY

The tortuosity or the structural form factor of the material takes into account the curliness of the pores (see figure 5).

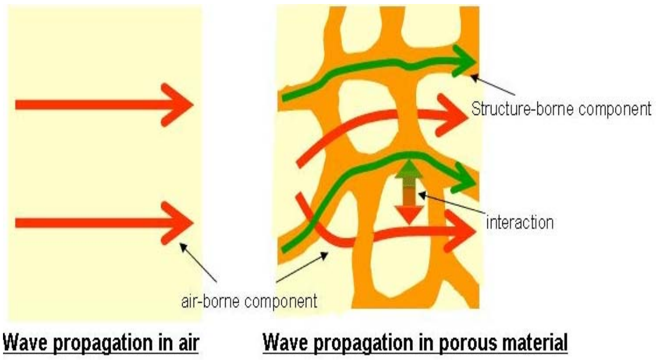

Figure 5. The sound propagation in the air (left) and in a porous material (right)[10]

Tortuosity is responsible for the difference between the speed of sound in air and the speed of sound through a rigid porous material at very high frequencies. Tortuosity is related to the formation factor used to describe the electrical conductivity of a porous solid saturated with conducting fluid. Indeed tortuosity can be measured using an electrical conduction technique in which the electrical resistivity of such a saturated porous sample is compared to the resistivity of the saturating fluid alone. Thus:

$$T = \frac{F}{h} \quad (4)$$

where:
h - is the porosity of the sample,

F - is the formation factor defined by $F = \frac{\sigma_S}{\sigma_f}$ *where* σ_f *and* σ_S *are the electrical conductivities of the fluid and fluid saturated sample, respectively. These in turn are defined by* $\sigma = \frac{GL}{A}$ *where L is the length of the sample, A is the area of the end of the sample, and G is the ratio of the resulting current to the voltage applied across the sample. [7]*

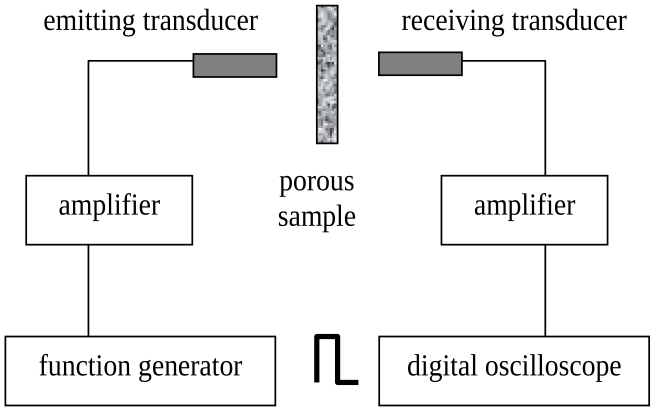

Figure 6. Schematic representation of the tortuosity measurement apparatus [11]

Tortuosity measurement is based on the measurement of formation factor. To measure the formation factor, first a cylindrical sample of the material is saturated with a conducting fluid. Saturation is achieved by draving the fluid through the sample after forming a vacuum above it. Agitation of the sample is also required if the pore sizes are small. A voltage is applied across the saturated sample placed between two similarly shaped electrodes at a known separation. The conductivity of the fluid is measured at similar voltages within a separate fluid-tight unit. The use of separate current and voltage probes assures a good contact between the end of the sample and the electrodes, eliminates problems associated with voltage drop at the current electrodes, and allows the simultaneous measurement of the electrical resistivities of the fluid and the saturated porous material. Tortuosity can be measured by measuring the velocity of sound which is transmitted in the fluid that fills the porous material, in ultrasonic domain. Therefore, the measurement system is composed of sensors for transmitting and receiving ultrasound, power amp and oscilloscope.

CONCLUSION

Acoustical parameters of porous materials give the necessary and important information for noise control engineers. Profound knowledge their physical characteristics enable an effective sound absorber material design. The theory of sound-absorbing materials has progressed considerably during the last decade. A noise control engineer with serious interest in sound absorbing technology is advised to study all this parameters.

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