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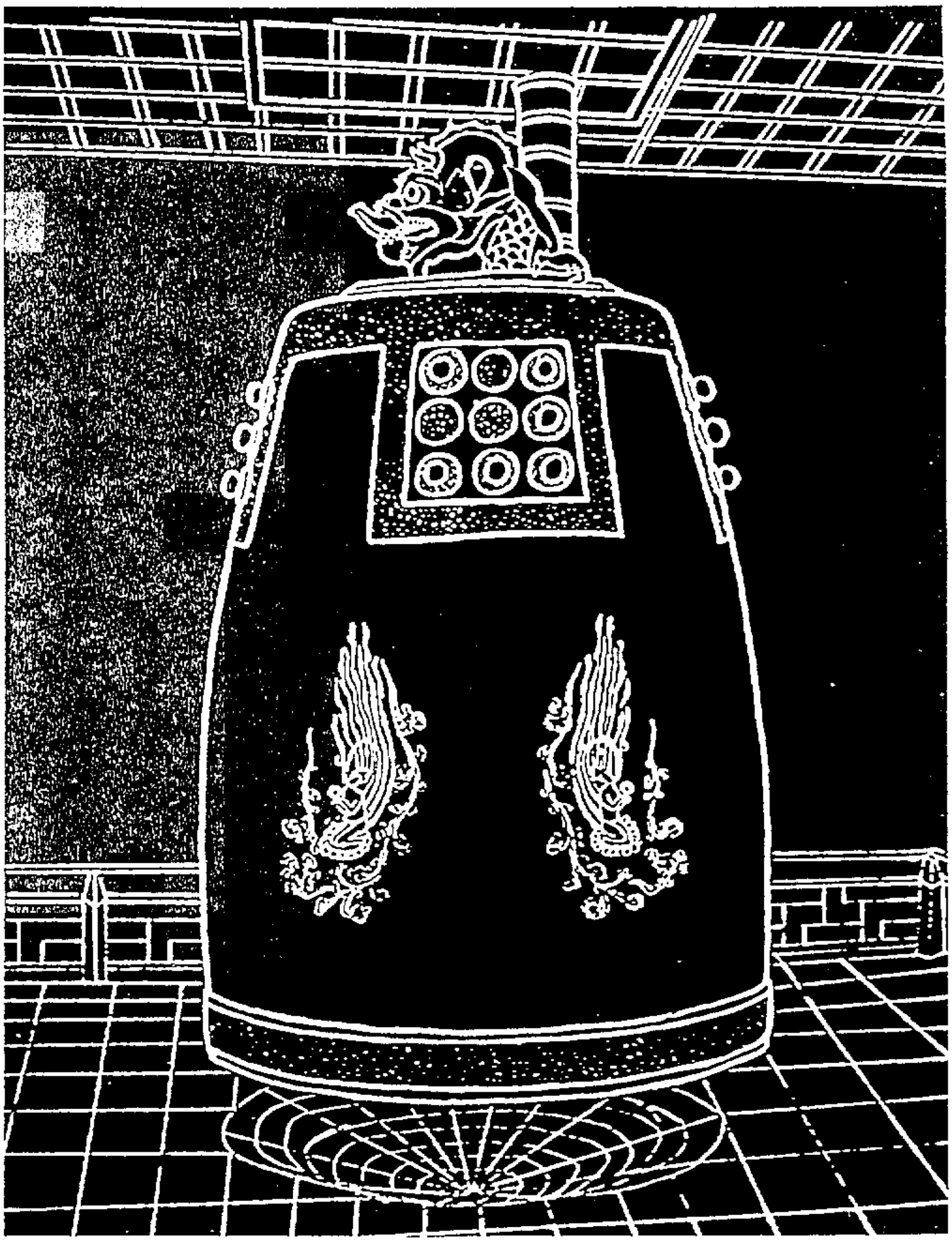

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A SIMPLE TRANSFER FUNCTION TECHNIQUE FOR IMPEDANCE TUBE MEASUREMENTS

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ABSTRACT This paper describes an original improvement to the standard two-microphone technique of measuring the sound absorption coefficient of materials. It is shown that a classical apparatus intended for pure tone measurements can be easily rearranged in order to fit the requirements of the new procedure. The input signal can be any kind of wide band noise, possibly pre-filtered. Two microphone are used at the same time: a fixed one (reference microphone) and a moving probe-tube microphone. Using the probe the sound field inside the tube is sampled in seven points, carefully spaced; this results in seven transfer functions from the probe to the reference microphone and in many other transfer functions from one probe location to another. The sound absorption coefficient can be computed from any of them; therefore a suitable algorithm can average for every frequency the best results discarding the problematic ones. The selection is performed by analysing the coherence associated with every measurement.

1. INTRODUCTION

Acoustic properties of little samples of material are usually measured using the standing wave tube. The classical pure-tones method is more and more replaced by the two-microphone random-excitation technique introduced by Seybert and Ross [1] and further developed by Chung and Blaser [2]. Fahy [3] introduced a modified technique in order to use a standard apparatus with a single moving microphone and Chu [4] studied it in detail. The best of those methods can be implemented in a quick, easy to use technique without elaborate calibration procedures.

2. APPARATUS AND TEST PROCEDURE

Fig. 1 shows a schematic diagram of the apparatus used in this investigation. It is based on a classical B&K type 4002 device, on which a B&K type 4135 1/8" microphone (plus a B&K type 2630 amplifier) is mounted close to the sample holder an flush to the tube wall. Signal generation and analysis are performed using an Ono Sokky CF 360 FFT analyser. Further computations are done with a PC linked to the analyser. In order to measure up to 5 kHz, two standard steel tubes are used:

1) a 100 mm diameter, 980 mm long tube with a lower cut-off frequency of 90 Hz and an upper cut-off frequency of 1800 Hz;

2) a 30 mm diameter, 300 mm long tube with a lower cut-off frequency of 800 Hz and an upper cut-off frequency of 6500 Hz.

In principle, the input signal can be any kind of broadband random noise, possibly pre-filtered in order to avoid higher modes. In this study the white noise supplied by the analyser was used, because it is simpler than the periodic pseudorandom sequence suggested by Chu [4]

Moving the probe, the sound field inside the tube can be sampled in N points, carefully spaced; this results in N transfer functions between the probe and the reference microphone (the latter is labelled $N = 0$): $H_{01}(f)$, $H_{02}(f)$, ..., $H_{0N}(f)$. From these, $N(N - 1)$ transfer functions between any two different probe positions can be computed:

$$H_{ij}(f) = \frac{H_{0j}(f)}{H_{0i}(f)} \qquad (i,\ j = 1,\ 2,\ \ldots,\ N) \tag{1}$$

possibly only for the incident or for the reflected part of the sound pressure wave: $H_{ij,I}(f)$, $H_{ij,R}(f)$.

Hence, the normal incidence complex reflection factor at the probe positions can be computed according to Chung and Blaser [2]:

$$R_{n,i}(f) = \frac{H_{ij}(f) - H_{ijI}(f)}{H_{ijR}(f) - H_{ij}(f)} \tag{2}$$

Then, the normal incidence complex reflection factor on the surface of the test material, which is at a distance d_i from the i-th probe microphone location, is [2]:

$$R_n(f) = R_{n,i}(f)\, e^{2jkd_i} \tag{3}$$

Known $R_n(f)$, the normal incidence normalized impedance $\zeta_n(f)$ and the normal incidence sound absorption coefficient $\alpha_n(f)$ can be readily obtained:

$$\zeta_n(f) = \frac{1 + R_n(f)}{1 - R_n(f)} \tag{4}$$

$$\alpha_n(f) = 1 - |R_n(f)|^2 \tag{5}$$

At each probe location, measurements are simultaneously performed on the entire frequency range of interest. For every distance between two measurement positions, s_{ij}, the transfer function can be determined up to a frequency f_m [2]:

$$f_m \leq \frac{c}{2s_{ij}} \tag{6}$$

c being the speed of sound. Therefore, each transfer function $H_{ij}(f)$ is computed by eq. (1) only up to f_m.

Calibration is not needed, because sequentially using the same microphone (the probe) and cancelling the reference microphone effects by eq. (1), any systematic error related to the microphone chains is in principle eliminated.

The signals detected by the microphones can be degraded by extraneous noise in the measurement (for example from outside the tube) or by non-linearities in the system being measured. Therefore, together with the transfer functions $H_{0i}(f)$, the coherence functions $\gamma^2_{0i}(f)$ are measured; hence, the coherence between any two probe locations are computed:

$$\gamma^2_{ij}(f) = \gamma^2_{0i}(f)\gamma^2_{0j}(f) \tag{7}$$

These quantities are used in a simple criterion to assure that, at every frequency, the transfer functions resulting from eq. (1) represent valid data: each $H_{ij}(f)$ is considered correct only if the related coherence $\gamma^2_{ij}(f)$ is greater than a previously fixed threshold g:

$$\gamma^2_{ij}(f) \geq g \qquad (0 \leq g \leq 1) \tag{8}$$

Finally, the values resulting from eqs. (3), (4) and (5) and passing the threshold criterion (8) are further averaged in order to give the final result

3. RESULTS AND DISCUSSION

The outlined procedure can be applied in a standard impedance tube, as the one described in [3], but the introduction of the fixed microphone avoids any reference to the loudspeaker signal and allows the use of homogeneous sound pressure signals.

The computation process resumed in eq. (1) avoids the need of a microphone calibration, like the sensor-switching technique described in [2]; actually, the usage of eq. (1) can be regarded as a repeated application of a sensor-switching procedure.

The N-points sampling ($N \geq 3$) allows the use of an ordinary broadband signal in place of a periodic pseudoramdom sequence [4].

The application of the simple threshold criterion expressed in eq. (8) and the linear averaging of the valid results are easier to implement than the signal enhancement technique reported in [2], and do not require a third microphone. Indeed, it is worth noting that, taking $N \geq 3$, also the signal enhancement technique of Chung and Blaser could be implemented.

Experiments were performed with the apparatus shown in Fig. 1 in order to identify which values of the parameters are best suited for a routine procedure. The upper frequency limit was chosen as 5 kHz. The distance of the reference microphone from the sample surface was fixed as d_0 = 6 mm in both tubes. After several trials, N = 7 probe positions were selected, regularly spaced by Δs = 27 mm in the larger tube and by Δs = 12 mm in the smaller one. These different microphone locations and separations allowed to cover a wide frequency range, see eq. (6). At every probe location, $H_{01}(f)$ and $\gamma^2_{01}(f)$ were computed averaging 16 samples. The coherence acceptance threshold was chosen as g = 0,85.

The procedure is currently in use; Fig. 2 shows an example of measurement performed on a sample of special brick under development. Other examples can be found in [5].

As can be seen, there is an excellent agreement between the pure tone measurements and the transfer function ones near the absorption peak at about 2700 Hz; indeed the real shape of the sound absorption curve and the location of the maximum can be truly identified only looking at the transfer function curve, because the peak doesn't occur at a 1/3 octave band nominal frequency.

On the other hand, there are some discrepancies between the pure tone points and the transfer function curve in the range 800÷1000 Hz; these can be due to the different behaviours of the very thin slits between the sample edge and the holder under different sound fields (with such a material slits are unavoidable, because it is very difficult to cut a circular sample from a brick). Another source of disturbances is connected with the tube vibrations induced by the loudspeaker, to which the reference microphone is very sensitive; these are partly correlated with the signal and therefore cannot be completely eliminated by averaging.

It should be noted that the lower frequency limit for the random noise transfer function method seems actually to be about 200 Hz.

4. CONCLUSION

A classical apparatus for pure tone measurements can be easily rearranged in order to fit the requirements of a simple two-microphone technique of measuring the acoustic properties of materials. The input signal can be any kind of wide band noise, and measurements can be simultaneously performed on the entire frequency range of interest. Using a fixed reference microphone and a moving probe one, several transfer functions can be quickly measured; then a suitable algorithm can average for every frequency the best results discarding the problematic ones. The selection is performed by analysing in a very simple manner the coherence associated with every measurement. The method does not require absolute calibration of the microphone chains. The device seems to be very sensitive to the tube vibrations.

5. ACKNOWLEDGEMENT

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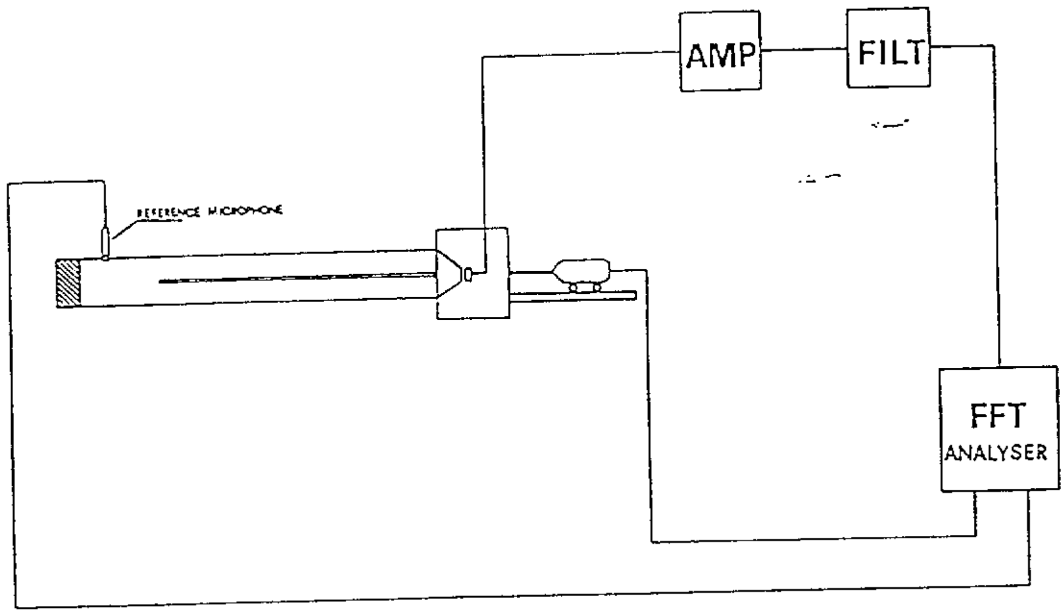

Fig. 1. Schematic diagram of the experimental apparatus.

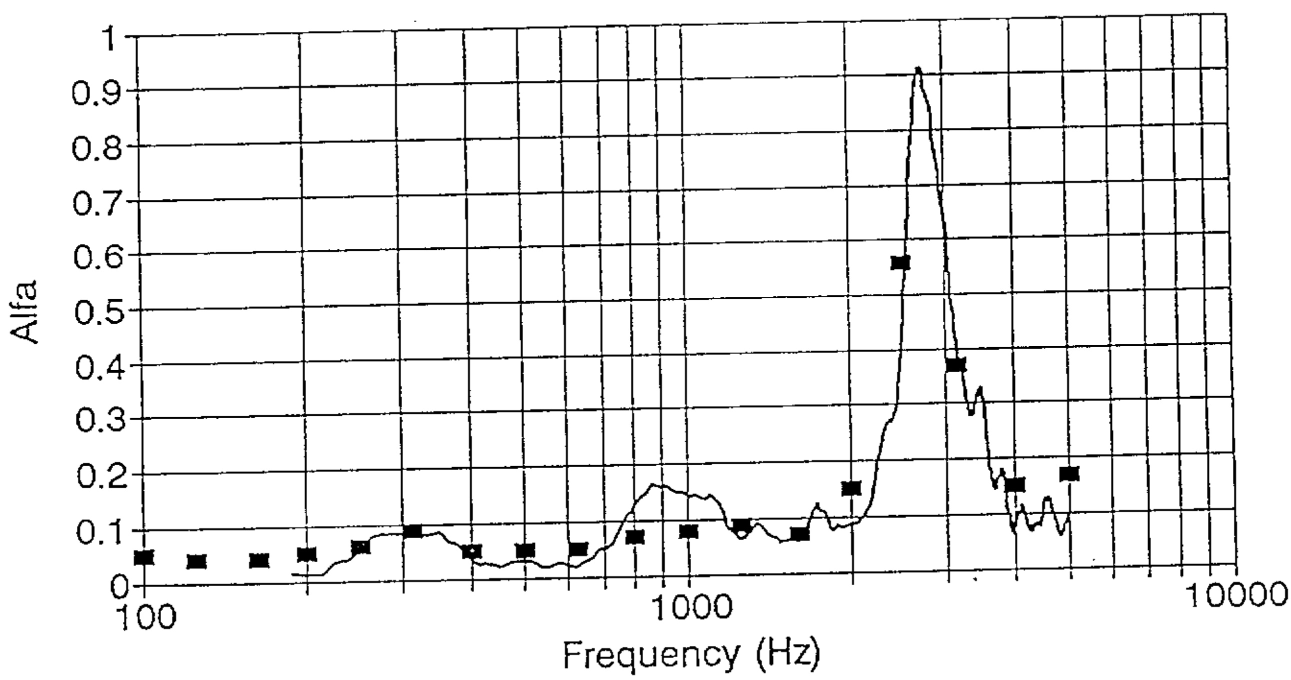

Fig. 2. Sound absorption values at normal incidence for a sample of a special brick with relatively large and low holes. Continuous line: measured with the transfer function method; square: measured with the pure tone method.