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APPLICATION OF DIGITALLY GENERATED AND PROCESSED TRANSIENTS TO MEASUREMENT OF ACOUSTICAL PROPERTIES OF POROUS MATERIALS

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Introduction

This paper describes the development and use of a compact and convenient piece of apparatus for measuring the complex propagation constant and characteristic acoustic impedance of porous materials. The principles of the method are much as used by Seybert and Ross (1), though here a deterministic signal is used as the excitation rather than the random excitation favoured by Seybert and Ross and such other authors as Chung and Blaser, (2). None of these authors exploit the full potential of the method to obtain parameters that completely describe the porous material (provided that it can be treated as a lossy effective fluid) but confine themselves to measurement of reflection/absorption coefficients.

Theory

(i) Propagation constant

It can be shown (3) that the ratio of the complex acoustic pressure at a distance l_1 in front of a rigid termination p_1, and the complex acoustic pressure at that termination p_0, is equal to the hyperbolic cosine of the product of l_1 and the propagation constant, i.e.

$$p_1/p_o = \cosh(\gamma l_1)$$

where $\gamma = \alpha - jk$ is the propagation constant

Hence measurements at these two points enable γ to be determined.

(ii) Characteristic acoustic impedance

The reflection coefficient at an interface may be shown to be given by

$$R = -\frac{1-(p_1/p_2)\exp(+jk_ol_2)}{1-(p_1/p_2)\exp(-jk_ol_2)}$$

where k_o is the wavenumber in the region in front of the interface, p_1 is the complex pressure at the interface and p_2 is the complex pressure a distance l_2 in front of the interface. Since $R = \frac{Z_{face} - Z_o}{Z_{face} + Z_o}$

where Z_o is the characteristic impedance of the medium in front of the interface and $Z_{face} = Z_c \coth \gamma l_1$, knowledge of γl_1 (from above), and p_1 and p_2 enables Z_c/Z_o, the relative characteristic impedance of the sample, to be determined.

These complex pressures may in principle be measured equally well either by using a continuous sine wave as the input and measuring the amplitude and phase at each position for each frequency, or by inputting a suitable transient signal to the system, capturing the time history of the acoustic pressure at the appropriate positions and then taking the Fourier transform of each of these time histories. This latter method is, given suitable apparatus, much more rapid and convenient to use.

The transient signal used here is a linearly frequency swept sine wave. This has the advantage of a roughly level spectrum throughout its range, and rapid fall-off at either end of the range (4). This latter point is particularly important in work involving plane waves in tubes where it is undesirable that significant amounts of cross-modes are generated.

Experimental Details

Figure 1 is a diagram of the acoustical apparatus. The sample under test is placed directly in front of a rigid plate that blocks one end of a cylindrical tube, at the other end of which is a loudspeaker. The tube discussed here is 12.7 cm in diameter which means that only plane waves can be propagated both in the air in the tube and also in the material provided the frequency used is kept to below around 1_{kHz} (since the speed of sound in a porous material is less than the speed of sound in air, the cut-off frequency for the propagation of cross-modes in the material will be lower; the precise permissible maximum frequency depends therefore on the properties of the particular porous material being tested). Holes are provided in the sidewall of the tube for the insertion of ½-inch microphones: one at the back of the sample immediately in front of the rigid termination; one at the front surface of the sample; and one (or more) in front of the sample.

The electronic arrangement is shown in Figure 2. The A/D and D/A converters are part of the microcomputer used to control the whole experiment. The experiment itself proceeds in the following fashion:

(i) the computer requests the parameters of the swept sine wave to be used (start and finish frequencies and duration of signal) and then works out and stores digital samples which, when fed to the A/D converter will generate the desired signal.

(ii) the signal is output by the computer so that the amplifier gains may be set to obtain the best possible signal/noise.

(iii) with microphone 1 at position 1 and microphone 2 at position 2, the average signal received at these microphones for any desired number of repetitions of the signal is stored; microphone 1 is then moved to position 2 and microphone 2 to position 3 and the process repeated.

(iv) the computer then calculates the appropriate discrete Fourier transforms and hence the propagation constant and characteristic impedance of the sample. Note that use of the same microphone to measure the two pressures required for each calculation eliminates the need for calibrated microphones/amplifiers since onlythe ratios of the pressures are required and not their absolute values.

Results

Figure 3 shows a set of results for 48 kg m^{-3} Fiberoc. The pairs of solid lines represent estimates 5 Hz apart, made using the system described, of (mean + 1 standard deviation) and (mean - 1 standard deviation) derived from ten repetitions of the whole experiment. (including repacking the sample). The random error of the experiment due to causes other than the sample packing is negligible.

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Also shown are the results of similar measurements made at various spot frequencies using a steady state sine wave as the input; the two sets of results can be seen to be almost identical, justifying the use of the transient method.

References

1) A.F.Seybert and D.F.Ross 1977 J.Acoust. Soc. Am. 61 (5), 1362-1370 Experimental determination of acoustic properties using a two-microphone random excitation technique.

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3) D.R.A. Christie 1976 J.Sound Vib. 46 (3), 347-355. Measurement of the acoustic properties of a sound absorbing material at high temperature.

4) R.H.Reed, A.W.Hall and L.E.Barker 1960 NASA Report TND 508. Analog techniques for measuring the frequency response of linear physical systems excited by frequency sweep inputs.

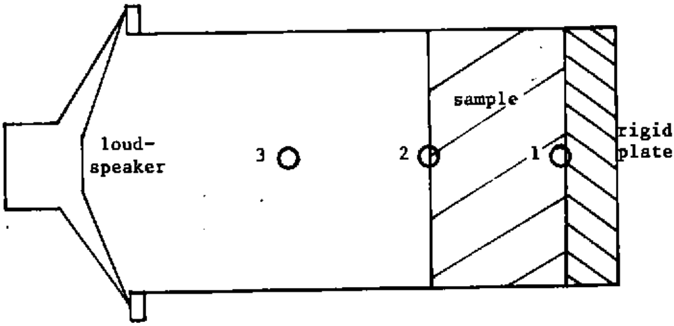

Figure 1

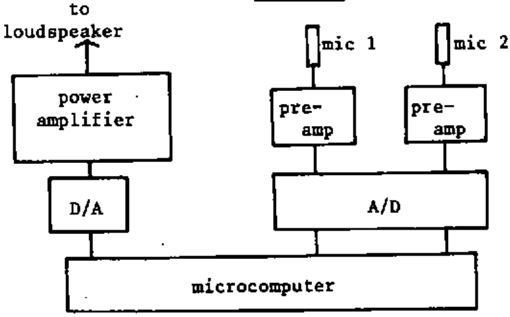

Figure 2

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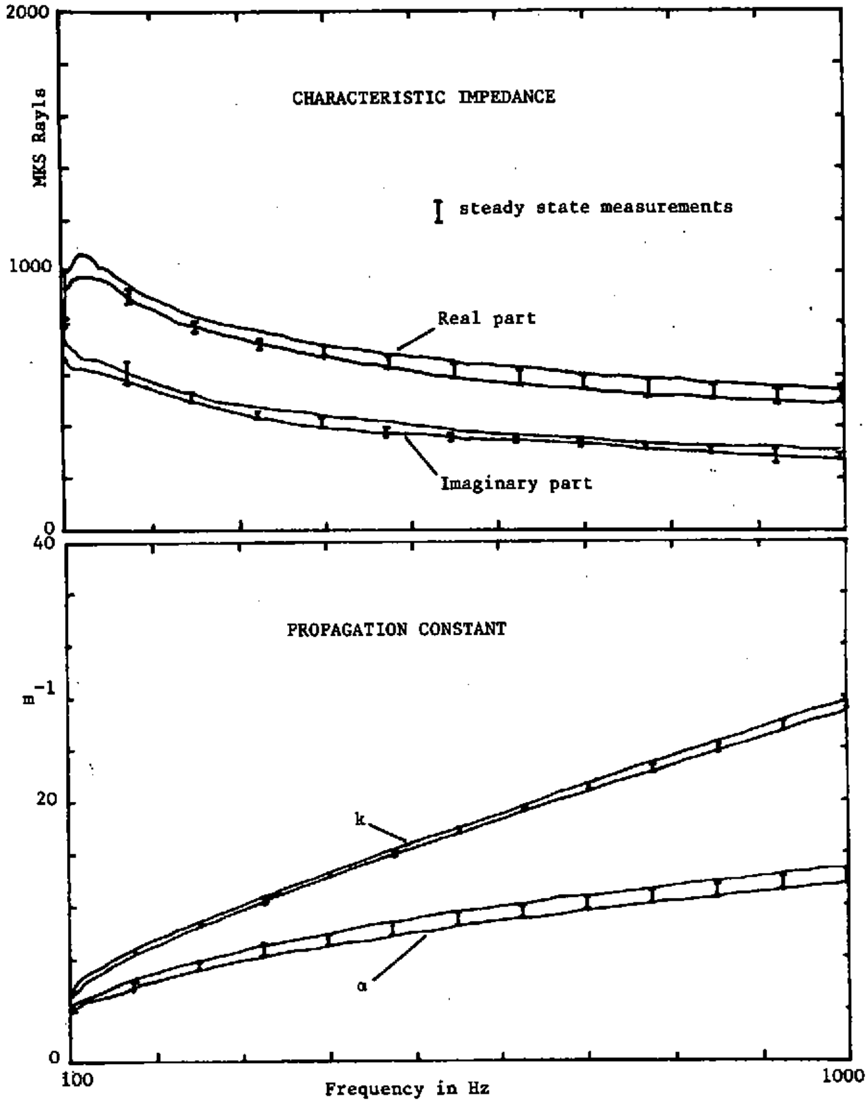

Figure 3