A TWO-MICROPHONE TECHNIQUE FOR MEASURING ACOUSTIC IMPEDANCE IN THE FREE FIELD: EFFECTS OF SAMPLE AREA AND MEASUREMENT ERRORS.

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1 INTRODUCTION

It is necessary to have data on the acoustical absorption of various surfaces, for example to accurately predict the sound field in an enclosure. This data includes the variation of absorption with angle of sound incidence. To enable such data to be obtained, a free field method has been developed to obtain detailed information on the acoustic impedance of a surface. The absorption coefficient may be obtained from the impedance.

The method uses a broad band noise source, two microphones, and a twin channel analyser. One brief measurement gives data over a wide band of frequencies. In this paper we are concerned with the effect on the measured result of; the gain and phase mismatch between the two instrumentation channels, the accuracy of measuring the distance of the microphones from the sample, but in particular the diffraction of sound waves from the edges of the sample.

A number of sound absorbing layers based on glasswool have been measured. Measurements have also been made on soft grassland. In all cases, the results have agreed well with accepted theory. Successful measurements have been made in the frequency range from 80 to 6000Hz. However, so as to highlight the features of interest, in this paper results are shown in the range from 200 to 2200Hz.

2 The Method

Figure 1 shows the measurement setup. The source is a height H above the sample. The sound is incident at an angle θ. The microphone positions are defined by the top microphone height x, and the microphone separation s. A typical measurement setup is H=1.6m, x=65mm, s=50mm and θ=60degrees.

The pressure at any point above the surface can be predicted assuming a point source and an infinite locally reacting plane [1]. By predicting the pressure at two positions, the transfer function between two microphone positions is calculated. But the transfer function and the positions of the microphones are measured in the experiment. The only unknown in the sound field predictions is the impedance of the surface. So the impedance of the surface is found from the sound field predictions using a simple iteration technique. An equivalent technique is described by Champoux [2], along with a review of the basic methods.

3 Measurement Accuracy

The measurement accuracy is determined by three factors:

i) the gain and phase mismatch between the two instrumentation channels

ii) the accuracy of measuring the experimental geometry

iii) and the diffraction of sound waves from the edges of the sample, which is related to sample area.

Each of these factors will now be discussed.

3.1 Gain and Phase Mismatch

The gain and phase mismatch between the two instrumentation channels are corrected for using a calibration measurement. A microphone switching technique in an impedance tube is used, as described by Chung and Blaser [3]. The calibration measurement is made for each experimental setup.

The significance of the gain and phase mismatch between the two microphone channel instrumentation systems is illustrated by figure 3. In the figure, two impedance curves have been calculated from the same measurement. The first curve was calculated with the calibration applied, and the second curve without. The effect is seen to be most significant at the lower frequencies, when the difference between the pressures at the microphones is very small. The low frequency limit of the measurement is the frequency at which the transfer function tends towards unity.

Figure 3 also illustrates a range of higher frequencies for which the measurement is not valid. In this case with a microphone separation of 75mm, the range is from about 1800 to 2200Hz. When an integer number of half wavelengths exists between the microphones, the pressures at the microphone surfaces are again very similar, and again the transfer function tends to unity. The result is a small band of frequencies at which the calculated impedance is inaccurate. Experiments have shown that at frequencies above 2200Hz., the method becomes accurate again.

3.2 The Experimental Geometry.

The experimental geometry is used to calculate the impedance from the transfer function. The dimensions of interest are;

i) the top microphone height, ii) the microphone separation, iii) the source height, and iv) the angle of sound incidence.

Each of these can be measured with an accuracy which can be determined. These parameters are concerned with the precision of the experimental set-up.

Due to measurement errors, the actual impedance of a sample will lie within a known band of values. The error due to each parameter was found by a computer simulation. The results indicate that the technique is most sensitive to errors in the measured parameters in the following order. Microphone separation, top microphone height, angle of sound incidence, and source to surface height. This ranking indicates that greatest effort should be made in determining the microphone positions, rather than in positioning the sound source. These conclusions support the findings of a different kind of numerical by Champoux [4].

Typical measuring accuracies are, source height 1.6 $\pm$ 0.05m, top microphone height 65 $\pm$ 0.1mm, microphone separation 50 $\pm$ 0.02mm, and angle of sound incidence 60 $\pm$1.2 degrees. Further analysis using the computer simulation shows the relative importance of the uncertainties associated with each measurement error to be as follows; angle of sound incidence, source to surface height, microphone separation, and top microphone height. This ranking indicates that the measurement errors quoted above are small for microphone positions.

3.3 The Effect of Sample Area.

Figure 2 shows various sample areas used in experiments to investigate the effect of the diffraction of sound waves from the edges of the sample. Figures 4,5,6 & 7 show the real and imaginary parts of the normalised impedance calculated from investigations using various samples, areas, and angles of sound incidence. In the graphs, the real part of the impedance is positive, slightly thicker curve, while the imaginary part of the impedance is the nagative curve. The samples were based on a glasswool with a specific flow resistance of $35kNs/m^4$.

Figure 4 shows the results for various areas with an angle of sound incidence of 60 degrees. Figure 5 shows the results for various areas with normally incident sound, using glasswool samples with a hard backing. At normal incidence the measured impedance is seen to be more sensitive to the sample area than for oblique incidence sound. The measurements shown in figures 4 and 5 were made with a microphone separation of 75mm, which gives a acceptable frequency range of 150 to 2200Hz., as discussed above. Figure 6 shows the results for areas of 5x5 units and 3x3 units of glasswool samples with an air backing, using normally incident sound. The measurements in figure 6 were made with a microphone separation of 125mm, which gives an acceptable frequency range of 90 to 1300Hz.

These graphs show that the measured impedance is different for each sample area. The frequencies below which the results differ from those of the largest area measured, the 5x5 units, are seen to be about 1000Hz for the 1x1 unit, and about 400Hz. for the 3x3 units. These frequencies correspond to two wavelengths of approximately 0.3m and 0.9m, which is the distance between the probe and the sample edge in each case. This indicates that the differences in measured impedance are due to diffraction from the edges of the sample area.

Figure 7 shows the impedance measured for a fixed sample area of 5x5 units, with angle of sound incidence of 0, 45, and 60 degrees. The impedance curves are seen to become smoother as the angle of incidence increases. Considering the behaviour for lower frequencies, with normally incident sound the diffraction effects from all the sample edges are the same at the position of the probe above the centre of the square sample. At oblique incidence however, the diffraction effects from each side are different, so no build up of edge effects occurs. The smoother behaviour at higher frequencies is due to the different path length differences of the direct and reflected paths at oblique incidence. The transfer function does not tend to unity, as it does in the normal incidence case.

3.4 Other sources of Error.

Some other factors of interest are;

i) the angle of the probe,

ii) the directivity of the source,

iii) the accuracy of the transfer function,

iv) diffraction due to microphone holders and pre-amps, and

v) precise location of the point at which the microphone measures the pressure.

These factors are not considered in this paper.

4 Discussion

Systematic errors have been found to determine the low frequency limit of the measurement. At low frequencies;-

i) the pressures at the microphone surfaces are very similar, and the transfer function tends to unity.

ii) the distance from the source to the centre of the sample becomes significant, as at small distances the source no longer acts as a point source.

iii) the dimensions of the room become significant, as the low frequencies become attenuated when the smallest dimension of the room is less than two wavelengths.

iv) the area of the sample becomes important, due to diffraction from the sample edges.

Similarly, at higher frequencies when the microphone separation equals $n\lambda/2$, where n is an integer and λ the wavelength, the pressures at the microphone surfaces are very similar, and again the transfer function tends to unity. This situation is less significant at oblique angles of sound incidence, due to the different path lengths of the direct and reflected signals.

Although the impedances in the frequency range 200 to 400Hz. in figures 4,5 and 6 appear to vary widely for different sample areas, these results have been found to be highly repeatable. This indicates that the difference in measured impedance is due to diffraction from the edges of the sample area. While investigations to relate the source height to the edge effects have proved inconclusive, the results presented in this paper indicate that in order to neglect edge effects, the minimum dimension from the probe to the sample edge should be greater than twice the wavelength in air of the lowest frequency of interest.

Research is underway to reduce the edge effects of a square sample through the use of a directional sound source. The two-microphone technique has been used to characterize a nominally locally reacting, non-plane surface. On the other hand, unresolved topics include; the theoretical description of the acoustic field above a finite locally reacting impedance plane in the free field, and the acoustical characterization of non-locally reacting materials, using the above technique.

5 Summary

A free field method to obtain detailed information on the acoustic impedance of a surface, using broad band noise and a two-microphone transfer function technique was discussed. Of particular importance were the effects on the measured result of measurement and systematic errors. Results were shown in the frequency range 200 to 2200Hz., so as to highlight the features of interest including; the diffraction of sound waves from the edges of the sample, measurement errors due to the accuracy of measuring the experimental geometry, and systematic errors due to the tendency of the measured transfer function to unity. An important result is that the measured impedance curves are seen to become smoother as the angle of incidence increases.

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I would like to thank Prof.T.Erik Vigran, not just for his software, designs, and setting up the experimental set-up. But also for supervision, labouring, and friendship. Thanks to Dr.Ian Hempstock for helpful comments on the text. This work is sponsored by the SERC.

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[4] Y.Champoux and A.L'Esperance 1988 Journal of the Acoustic Society of America 84,(1)30-38. Numerical Evaluation of errors associated with the measurement of acoustic impedance in a free field using two microphones and a spectrum analyser.

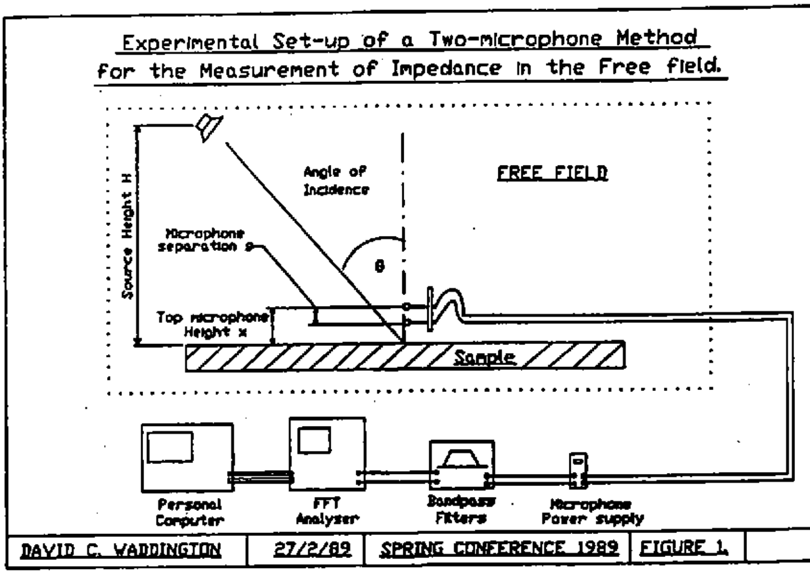
Experimental Set-up of a Two-microphone Method
for the Measurement of Impedance in the Free field.
Angle of Incidence
FREE FIELD
Source Height H
Microphone separation s
θ
Top microphone Height x
Sample
Personal Computer
FFT Analyser
Bandpass Filters
Microphone Power supply
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FIGURE 1.

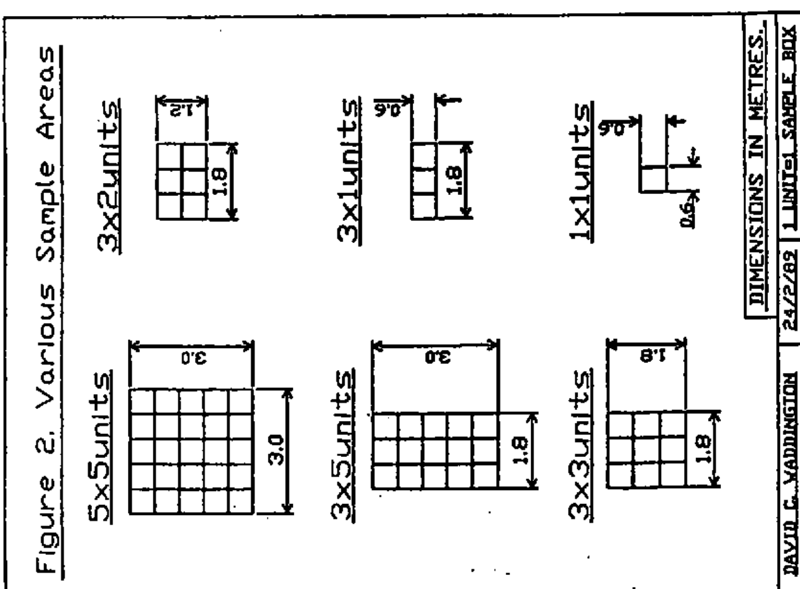
Figure 2. Various Sample Areas
5x5units
3.0
3.0
3x5units
3.0
1.8
3x3units
1.8
1.8
3x2units
1.2
1.8
3x1units
0.6
1.8
1x1units
0.6
0.6
DIMENSIONS IN METRES.
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1 UNIT= SAMPLE BOX

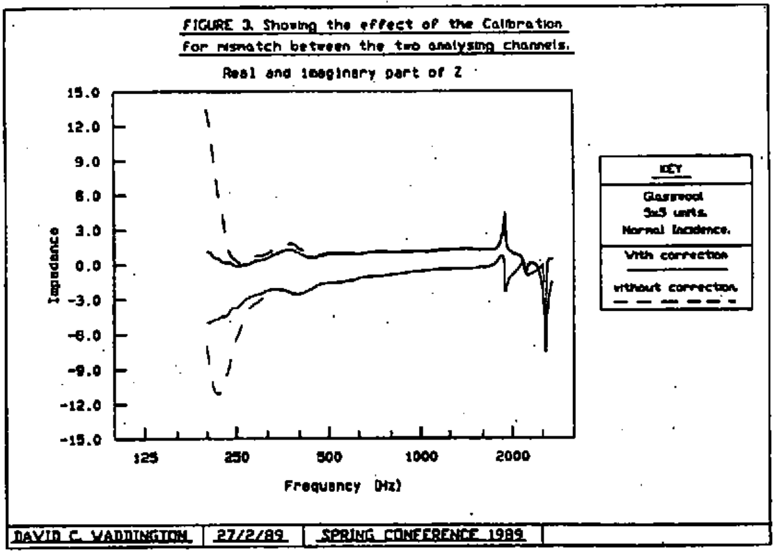
FIGURE 3. Showing the effect of the Calibration
for mismatch between the two analysing channels.
Real and imaginary part of Z
15.0
12.0
9.0
6.0
3.0
0.0
-3.0
-6.0
-9.0
-12.0
-15.0
Impedance
125
250
500
1000
2000
Frequency (Hz)
KEY
Glasswool
5x5 units.
Normal Incidence.
With correction
without correction
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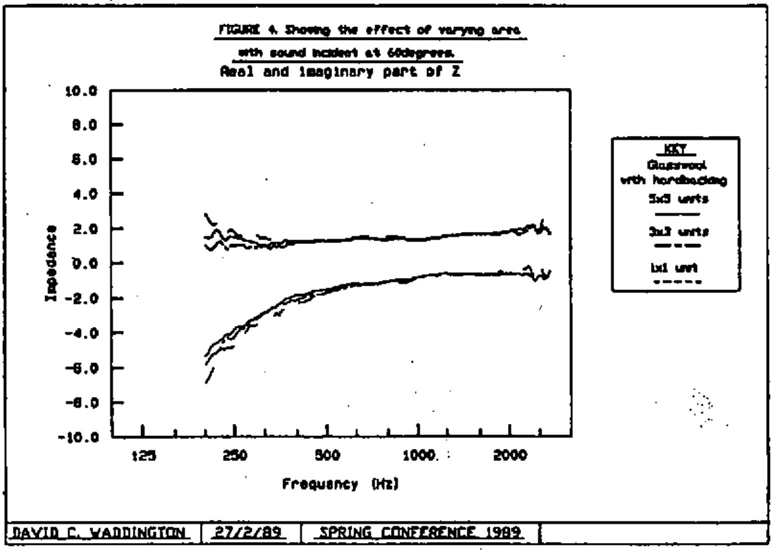
FIGURE 4. Showing the effect of varying area
with sound incident at 60degrees.
Real and imaginary part of Z
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
Impedance
125
250
500
1000
2000
Frequency (Hz)
KEY
Glasswool
with hardbacking
5x5 units
3x3 units
1x1 unit
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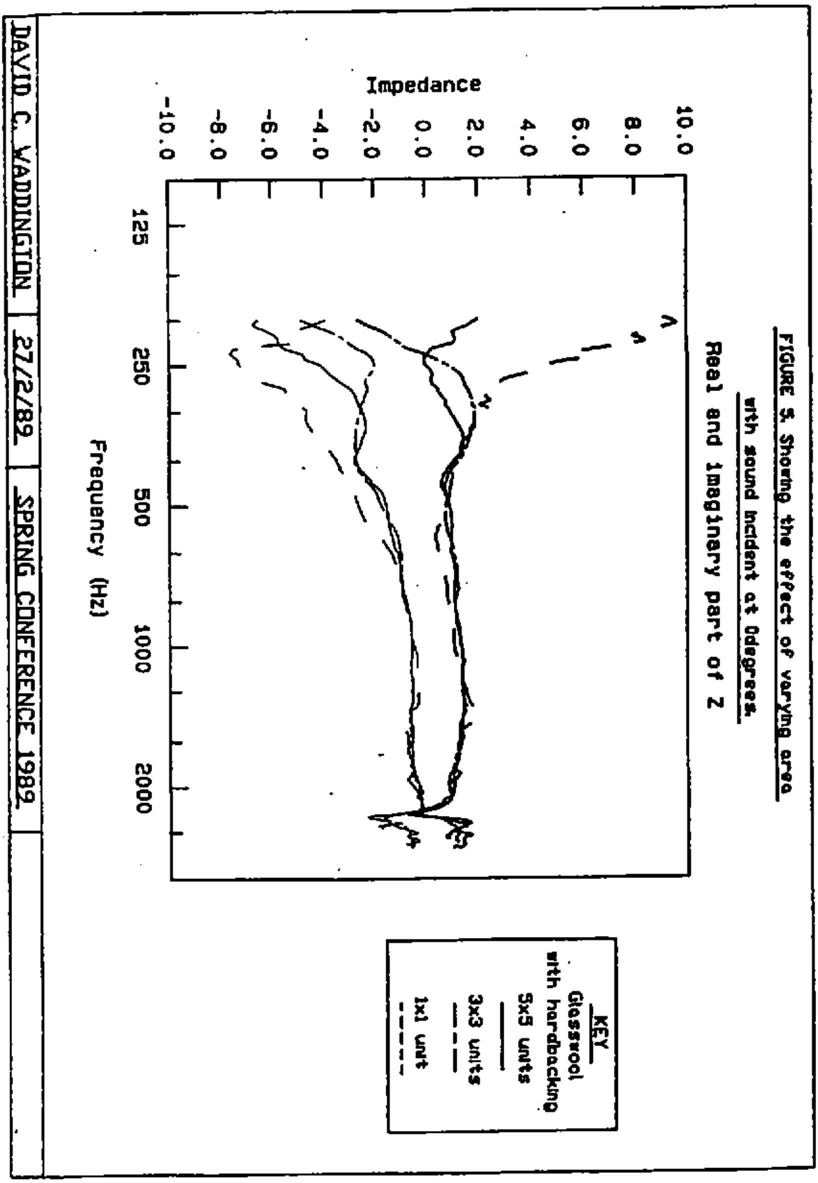

FIGURE 5. Showing the effect of varying area with sound incident at 0degrees.

FIGURE 6. Showing the effect of varying area with sound incident at 0degrees.

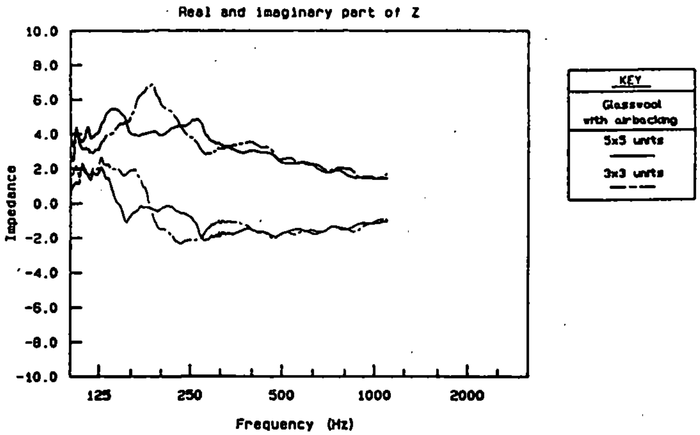

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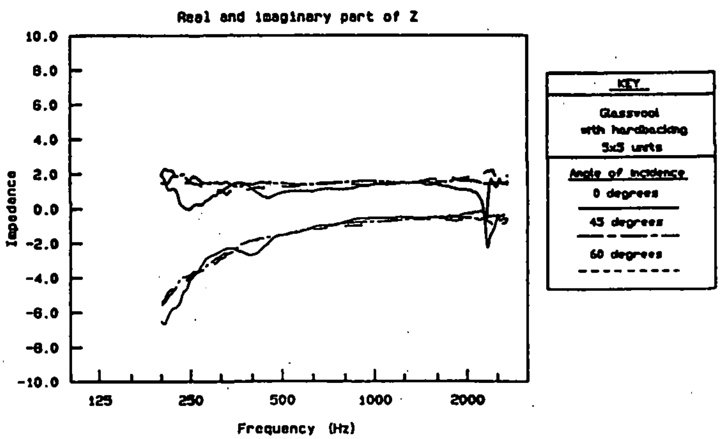
FIGURE 7. Showing the effect of angle of incidence on the measured impedance of a sample.



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