Proceedings of The Institute of Acoustics

MEASURING THE ABSORPTION CHARACTERISTICS OF CLADDING MATERIALS WITH REGARD TO DETERMINING FACTORY SOUND FIELDS

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INTRODUCTION

Acoustical Characteristics of Disproportionate Rooms

There exist a whole range of rooms in which statistically diffuse sound fields do not exist, e.g. factories, corridors and open plan offices. The lack of diffusion implies that the simple equations derived by Sabine cannot be expected to produce accurate predictions of the acoustical characteristics of these rooms. Several researchers, notably Baines[1] and Hodgson[2], have outlined the features responsible for the acoustics of such spaces, these are: the room shape, the surface absorption and the acoustical scattering effect of the contents. For predicting factory sound fields knowledge of the effect of all these factors is required. This paper concentrates on one of them, namely the surface absorption of factory cladding materials.

Baines[1] has also pointed out that for a non-diffuse sound field, the diffuse field absorption coefficient may not be relevant. Furthermore, he has indicated that the variation of absorption with incidence angle is pronounced for arrays of panels such as cladding constructions. Consequently, in considering the absorption of cladding, the variation of absorption with incidence angle is an important characteristic.

PREVIOUS STUDIES

Results from Theoretical Studies of Factory Claddings

Theoretical models such as those by Beranek and Work[3], and Mulholland, Price and Parbrook[4], have been developed to investigate sound transmission through panels. To investigate sound absorption by panels and in particular factory cladding, Baines[1] initially considered infinite plate models but found that they were unable to predict sufficient absorption compared with measured results. Subsequently, he tried modelling factory cladding as an array of finite plates and found better agreement between predicted and measured absorption; a drawback was the long computation times involved.

Of particular importance, Baines points out, is that finite plate models of double-skin constructions indicate that at low frequencies most of the sound absorption is due to the vibration of the inner skin. Also, concludes Baines, finite and infinite plate absorption models indicate that the absorption coefficient will depend strongly on the angle of incidence. Experimental work by Bolton[5] has tended to support these conclusions.

Practical Difficulties of Measuring Absorption Characteristics of Factory Claddings

Factory roofs and to a certain extent walls are often constructed by the use of a finite array of panels. Consequently, as reported by Guy et al[6], when measuring the acoustical behaviour of a sample of such a construction the results are affected by:

i) the size, and
ii) the mounting of the sample.

Hence the size and mounting of the sample under test should be as close as possible to a panel in-situ. Also we have the situation in a factory that the sound field is non-diffuse. So we also note

iii) the sound field in which the absorption measurement is made.

Other factors to consider are;

iv) for a finite sample, edge effects[7] and
v) for oblique incidence, the ground effect[8].

It has been shown that the effect of the so called ground wave for local reactors is negligible for small angles of incidence. However, by considering the image-source model for a factory as shown in figure 1, it is evident that for large source-receiver distances, the angle of incidence tends towards grazing. Under these conditions the ground wave becomes significant. Consequently, if we consider the sample under test, we can expect errors in the measured impedance as the angle of incidence increases towards grazing and the ground wave becomes more prominent. An investigation into correcting for the ground wave at large angles of incidence is under way. The idea is to compare measurement results with the prediction of a reliable model, e.g. using the Weyl-Van der Pol formula.

EXPERIMENTAL TECHNIQUES TO MEASURE ABSORPTION CHARACTERISTICS

In order to examine the acoustical behaviour of claddings used in the construction of factories, an investigation was made into the different methods commonly used in the experimental determination of absorption characteristics of different materials. The main techniques identified were as follows:-

i) Impedance tube measurements
ii) Reverberation room measurements
iii) Impulse techniques
iv) Two microphone probe techniques.

A brief description of each method is given below. Equally these techniques could be categorized as by Heap[9] as follows;

i) Surface methods
ii) Transmission line methods
iii) Transfer function methods

Surface methods measure the surface pressure p, and the normal particle velocity u_n of the material. The impedance is then given by the ratio p/u_n. Transmission line methods rely upon measurement of the interference pattern set up in front of the sample. For the transfer function method, for an input x(t) to the system with a response h(t) and an output y(t), then if the Fourier transforms are X(f), Y(f) and H(f) respectively then;

$$y(t) = x(t) * h(t)$$

so

$$Y(f) = X(f) \cdot H(f)$$

Hence

$$H(f) = \frac{Y(f)}{X(f)}$$

H(f) is called the complex transfer function, and is equal to the complex reflection coefficient.

The Impedance Tube Method

The impedance tube methods have a number of advantages such as not requiring a large quiet space, and requiring only small test samples. There are three different types of tube method:

i) Standing wave ratio, the standard impedance tube method,
ii) Random excitation, as used by Seybert[10], and
iii) wave-tube impulse, as used by Ding Yong-Sheng[11].

The standing wave ratio method can be tedious, and although random excitation and impulse methods can overcome the time consumption and single frequency limitations of the standing wave ratio method, difficulties occur when higher vibrational modes are excited in the tube.

With reference to the measurement of the absorption characteristics of factory claddings, the main drawbacks of the impedance tube techniques are:

i) the use of a small test sample, and
ii) the mounting of the sample in the tube.

As mentioned previously, the size and boundary conditions of the sample will critically affect the behaviour of the material. If a large impedance tube, for example the 7m x .5m x .5m duct available at Salford, were to be used, the mounting conditions would determine the behaviour of the sample particularly in the frequency range of interest, namely 50 to 500Hz.

On the other hand, in order to take advantage of the impedance tube in the investigation it was suggested that the sample, dimensions 0.5m x 0.5m, be mounted in the tube so that its behaviour would be as part of an infinite sample, for example like a speaker cone. Thus, the vibration induced in the test sample would travel out from the panel, into the mounting, where it would be quickly attenuated but not reflected, hence simulating the behaviour of a wave in an infinite sample. However, the difficulties of mounting a sample of corrugated metal inside a solid masonry tunnel, in a way that can be repeated precisely and consistently are substantial. In addition, as this method would only provide information for normally incident sound for a sample of fixed dimensions, investigation along these lines was discontinued.

With regard to previous experimental work on the acoustical behaviour of factory claddings performed in impedance tubes, for example by Friberg[12], the measurements were generally taken using very small samples so that the results cannot be said to be representative of the whole surface, and can only be taken as an indication of the relative absorption for the constructions tested. However, the question then arises as to the validity of comparing measurements taken on locally reacting samples of an extended reacting material.

Reverberation Room Method

The reverberation room method measures the random incidence absorption coefficient of the test material. For cladding, the sample is mounted in an opening in the reverberation chamber beyond which there is an anechoic chamber thus providing a free-field backing.

ABSORPTION CHARACTERISTICS OF CLADDING

There are a number of well documented problems regarding the use of reverberant room methods. Work by Guy et al[6], concerned with experimental results for transmission loss of panels, reports that a significant role is played by the panel area on the measured results. The boundary conditions also strongly influence the acoustical characteristics. Furthermore, the parameter measured is the random incidence absorption coefficient which may not be relevant in factories where angular dependence of absorption is very important.

Nevertheless, reverberation room measurements are valuable because they use a standardised test procedure and produce results which form a datum against which other measurement methods can be compared.

Impulse Methods

The main advantages of the impulse technique are;

i) the measurement may be taken in-situ, and
ii) it can be used for all angles of incidence.

A typical impulse measurement technique to determine the absorption of factory roofs is described by Orlowski[13]. The procedure involved radiating a short sound pulse $S_i(t)$ from a loudspeaker, in this case a half cycle of a sine wave at an equivalent frequency of 200Hz. The resultant impulse response $S_o(t)$ is monitored with a microphone placed at various distances from the source, corresponding to different angles of sound incidence with the roof. The recorded signal is electronically gated to isolate the reflection from the roof. The transformed respective spectra $S_i(f)$ and $S_o(f)$ then give the magnitude of the reflection factor of the test sample by

$$| R(f) | = \frac{| S_o(f) |}{| S_i(f) |}$$

The phase of the reflection coefficient is more difficult to determine as it is not possible to distinguish between a phase shift due to time delay and one due to the surface. The major limitations however are:

i) Signal to noise ratio, and
ii) Pulse overlap.

Other difficulties are;

iii) Ringing,
iv) edge effects, and
v) ground effect.

Suggestions to improve the signal to noise ratio include the use of tone bursts rather than pulses, and the use of signal averaging, where repeated occurrences of the pulse are summed, together with the noise. Since the noise is uncorrelated, its mean value tends to zero, leaving a clean version of the pulse. This technique also overcomes the problem of ringing, where the panel reacts abnormally due to the action of a large impulse.

In order for the impulse technique to work, the incident and reflected pulses must be separable. Now, at grazing incidence the path difference is small, and the pulses may overlap. In this case the pulses must be deconvoluted, for example using Cepstral techniques as described by Bolton and Gold[14].

Concerning the use of impulse techniques for a panel absorber, resonances are excited, resulting in a reflected pulse of greater length than the incident pulse, with the decaying reflected pulse introducing noise into the system, and consequently increasing inaccuracies. Also, as the surface is hard, the incident and reflected pulses tend to be very similar, which results in the reflection coefficient being difficult to extract from the impulse data. Merhaut[15] points out that the acoustical behaviour of some samples may be different for a short transient signal than for a stationary one, and although the impulse technique has been under investigation for a number of years, and has been used successfully to measure ground impedances, results for the behaviour of panels which compare favourably with those taken by other methods are difficult to obtain.

Two-microphone Probe Measurements

A two-microphone probe has been used by Legouis and Nicolas[16] to measure the normal specific impedance of porous materials at low frequencies, employing a phase gradient method. The method consists of measuring the phase gradient as a function of distance along a normal to the material. The apparatus has been used for low frequency ground impedance measurements down to 30Hz. The method requires a minimum of instrumentation, sometimes limited to a simple phase meter, provided the instrument is precise enough to measure the small differences in phase between the microphones.

Daigle and Stinson[17] describe a very similar technique, stressing the effects of extraneous reflections, and the importance of making the measurements in the absence of such reflections. This is a major restriction to the technique, so far as the measurement of the absorption characteristics of factory claddings is concerned.

Work by Allard and Aknine[18] illustrates the use of the two-microphone probe in an impedance tube, presenting a method much faster and easier to implement than the classical standing wave ratio method. Also, further work by Allard et al[19] on the use of a two-microphone probe for free field measurements has been reported. Here the sample is placed in an anechoic room and the probe is placed close to the surface of the sample. The probe measures the complex pressure and velocity at the surface of the sample resulting from radiation by a loudspeaker set at a distance of 4m along the axis of the sample. Figure 2 illustates the situation. Results for impedance were obtained but only for frequencies above 700Hz. This is because of the finite dimensions of the sample and the consequently non-plane acoustic field in front of the sample.

An investigation of the application of this technique to the measurement of the complex impedance of a plasterboard sample suspended in an anechoic chamber was recently undertaken. Initially the Nortronics intensity probe and type 830 signal analyser were employed but this equipment only provides the RMS values of p and u_n. Consequently, only the magnitude of the characteristic impedance at the surface of the sample could be measured. Subsequent experiments are using a matched pair of capacitor microphones and a dual channel signal analyser.

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SUMMARY AND CONCLUSIONS

The absorption characteristics of cladding materials have an important effect on the sound field in factory buildings. Furthermore, because of the disproportionate shape of these buildings and the consequent lack of diffusion in the sound field, the variation of absorption with incidence angle is an important parameter.

Theoretical and experimental studies on the absorption characteristics of factory cladding materials, in particular those of Bolton and Baines, have indicated that the absorption is strongly dependent on the angle of sound incidence.

Measurement of the sound absorption of cladding at oblique incidence involves overcoming a number of problems such as edge effects and the ground effect.

A survey of the different techniques for measuring absorption has been carried out and the conclusions are as follows. The impedance tube method, although well suited to measuring the normal impedance of small locally reacting samples, is not suitable for cladding which acts like a panel absorber and is not locally reacting. The reverberation room method, which gives the random incidence absorption coefficient, is a useful indicator of absorption but is considered inappropriate for use in the prediction of sound fields in disproportionate rooms.

Impulse techniques apparently provide all that is required to measure the acoustical characteristics of factory claddings. The method can be used in situ and can provide data over the whole frequency range of interest and at various angles of incidence. However, practical difficulties are encountered in the isolation of the reflected pulse particularly in the case of a resonant panel. In addition, the accuracy becomes very low if the direct and reflected pulse are of similar magnitude.

The most promising method appears to be the use of a two-microphone probe which can provide information on the impedance with varying angles of sound incidence. The application of this method to absorption measurements on factory claddings is currently being undertaken.

ACKNOWLEDGEMENT

This work, which forms part of a project into the prediction of sound fields in factory buildings is supported by a grant from the Science and Engineering Research Council.

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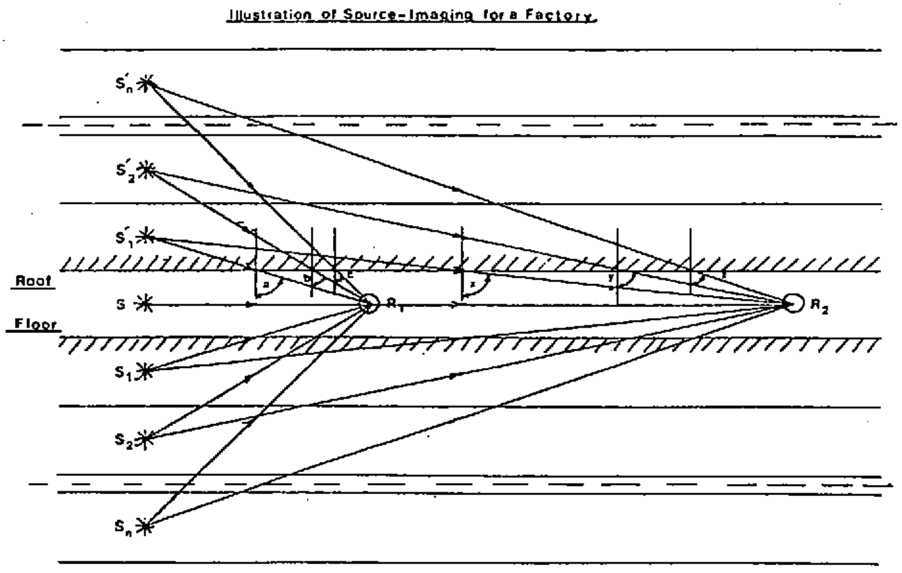

Figure 1

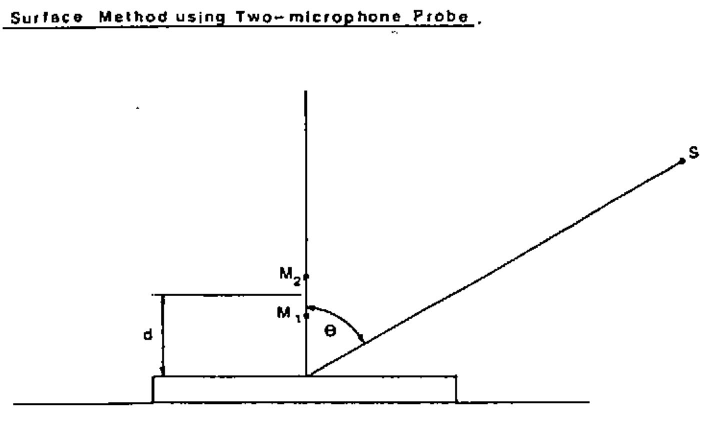

Figure 2

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