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MEASUREMENT OF AN INSERTION LOSS OF OPEN SCREENS BY AN IMPULSE TECHNIQUE

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1. INTRODUCTION

There is currently no standard method of measurement for open screens, commonly seen in the form of acoustic louvres. Recent work at the University of Liverpool has involved measurements of such screens to ISO 140[1,2]. A survey of over forty manufacturers showed that at present this method was probably the most widely used in assessing louvre performance. Other methods used include BS 4718[3] and in-situ measurements where the noise levels are measured before and after installation. The standard ISO 140 has been shown not to be practical for the measurement of such elements with low sound transmission loss[2,4]. Elements which offer less than 15dB transmission loss cause sound energy feed-back into the source room from the receiver room.

Engineers must be cautious in their selection of acoustic devices based on performance data obtained by these methods, some of which are unsuitable. It is for this reason that the industry, through the Acoustics Committee of the Heating, Ventilating and Air Conditioning Manufacturers Association (HEVAC), are in the process of developing a test procedure for acoustic louvres. The procedure involves generating a diffuse sound field in a reverberant room with a 1m square aperture in one wall. The external sound pressure is measured and averaged for nine positions; 15° apart, on a 3m radius, and at least 1.5m above ground level. The static insertion loss is given by the difference in the averaged sound pressure level with and without the louvre in position. Any directionality is checked by rotating the louvre through 90° and repeating the measurements. Unfortunately the method still requires special facilities, a reverberant room on a free field site or a reverberant to anechoic transmission suite.

An impulse response method has been investigated at Liverpool which offers the advantage of requiring little or no special facilities. It is also practically portable. The method has shown itself to be very versatile in the field of acoustics, with applications in the measurement of sound transmission loss[5,6,7,8], absorption[9], end correction of open pipes[6], concert hall acoustics[10], the characteristics of mufflers[11], transmission of sound at structural junctions[12], and noise control barriers[13].

A description is given of the use of the impulse method for solid panels and open screens. In addition results for profiled panels typically, found as factory cladding, will be presented. It is worth noting that at this conference, eleven years ago, a session was devoted to impulse techniques in acoustics, and results supported those of Raes[5] in that dynamic transmission losses of partitions may give more valuable information on performance and diagnosis of failure, than static transmission losses.

2. STANDARD MEASUREMENTS

The open screens tested are detailed in Figure 1. They consisted of a number of single panels termed pickets in a single row. The Measurements were carried out in accordance with ISO 140[1] in the University transmission loss suite. Details of these facilities and discussion of the effect of energy feedback into the source room can be found in other works [2].

Figure 2 shows the reverberant room transmission loss for two single picket screens, one with 0.2m wide x 0.1m deep panels at 50mm air spacing, and the other with 0.1m x 0.1m panels at the same spacing. The transmission loss given by these screens is small and frequency invariant over the frequency range 100Hz-10KHz. The first screen gave an average transmission loss of 6dB with typical variation of +/-2dB, and the second 4.5dB with +/-1.5dB. Measured transmission losses of this order are likely to be in error since there is energy feedback into the source room from the receiver room.

The corrected transmission loss equation[2] is given as;

$$TL = 10\log_{10}\left(10^{(L_1-L_2)/10} - 1\right) + 10\log_{10}\left(\frac{S}{A_2}\right) \qquad (1)$$

Where : L_1 and L_2 are the source and receiver room sound pressure levels.
S is the specimen test area.
A_2 is the receiver room total absorption.

Results of the correction are indicated in Figure 3, showing the reduction in the screen transmission loss.

3. IMPULSE MEASUREMENT METHOD

This method is briefly described here. For a more detailed description see Gibbs[14]. A typical equipment set up is shown in Figure 4. A short duration pulsed output from the loudspeaker is sensed by the microphone. Windowing of the signal allows the direct component to be captured. Fast Fourier Transformation of this component provides the anechoic frequency response. The measurement is performed with and without the test specimen in position between the loudspeaker and the microphone, resulting in the time histories shown in figure 5(a) and (b). The insertion loss of the panel is simply the level difference between the two spectra.

The precursor signal indicated in Figure 5(c) is the result of a forced bending wave, generated by the incident airborne sound, which propagates freely after reflection at the edges of the test specimen. The effect of the precursor can be reduced by spatial averaging, but with a sufficient sized isotropic plate these unwanted signals were not large enough to mask the direct component. Thus by windowing out these effects the infinite panel response is obtained. Comparisons of these measurements with simple theory are promising, and mass-law characteristics and coincidence are clearly seen[8,12,14]. However, validation of the method for open screens was necessary before measurements could proceed.

4. VALIDATION OF THE METHOD

From the literature search the most relevant work includes that on thnadners[15], slow waveguides[16], and picket or slit type barriers[17,18]. The purpose of the thnadners was to diffract the sound upwards creating an acoustic shadow, that of the slow waveguides was to produce destructive interference between the sound field diffracted over the barrier with that passing through the waveguide. The common relation is the use of Fresnel diffraction theory for the theoretical model.

4.1 Optical diffraction theory

The model for prediction uses Huygen's principle taken from optical diffraction theory[19,20], which states that each point on a wavefront becomes the source of a so-called secondary wave. Kirchhoff's mathematical formulation yields values which in most cases give good agreement with the results of experiment.

Consider an aperture in an infinite baffle where r_s and r_r are the distances from the source and receiver to the element area d_s on the aperture, both at an angle θ_s and θ_r to the normal (Figure 6). r_o is the distance between source and receiver. If the aperture is illuminated by a point source then the pressure at the receiving point is given by;

$$P(d_s) = \frac{Ae^{(jkr_s)}}{r_s} \qquad (2)$$

The sound field at the receiving point with an intervening screen is given by;

$$P(R) = \frac{-A}{4\pi} \iint_{\text{Aperture}} \frac{e^{jk(r_s+r_r)}}{r_s\, r_r} \left[\left(jk - \frac{1}{r_s}\right)\cos\theta_s + \left(jk - \frac{1}{r_r}\right)\cos\theta_r \right] d_s \qquad (3)$$

This applies for an aperture in an absorbing screen. Adopting Babinets principle[19] we can consider an absorbing screen in free space of the same size and shape as the aperture, giving ;

$$P(R) = \frac{Ae^{jkr_o}}{r_o} + \frac{A}{4\pi} \iint_{\text{screen}} \frac{e^{jk(r_s+r_r)}}{r_s\, r_r} \left[\left(jk - \frac{1}{r_s}\right)\cos\theta_s + \left(jk - \frac{1}{r_r}\right)\cos\theta_r \right] d_s \qquad (4)$$

Here the first term is the sound field at the receiver in the absence of any screen.

4.2 Mass-layer theory

At frequencies where the wavelengths are much greater than the dimension of the aperture the air in the aperture begins to act as an inert mass per unit area[18]. The screens then react as a thin membrane with an equivalent mass per unit area, m given as;

$$m = \frac{\rho}{\sigma}(l_o + 2\Delta l) \qquad (5)$$

ρ is the air density, σ is the ratio of the open area to the period (i.e:gap/gap + picket width), l_o is the gap depth, and $2\Delta l$ is the gap end correction. Values for the end correction are given by Cremer and Müller[21]. The surface mass density is finite so some transmission of sound energy through the screen causes an increase in sound pressure at the receiver and the following term is added to equation (4)[17];

$$\frac{-A}{4\pi}\iint_{screen} \sqrt{\tau}\, e^{j\phi}\left(\frac{e^{jk(r_s+r_r)}}{r_s\, r_r}\left[\left(jk - \frac{1}{r_s}\right)\cos\theta_s + \left(jk - \frac{1}{r_r}\right)\cos\theta_r\right]\right) d_s \qquad (6)$$

Where :

$$\tau_0 = \left[1 + \left(\frac{\omega m\cos\theta}{2\rho c}\right)^2\right]^{-1} \qquad (7) \qquad\qquad \phi = \tan^{-1}\left(\frac{\omega m\cos\theta}{2\rho c}\right) \qquad (8)$$

and m is the surface mass density, θ is the angle of incidence, c is the speed of sound in air, and ϕ is the phase shift between incident and reflected sound waves.

5. SINGLE LEAF PANELS

To ensure the method is valid for this application measurements were first carried out on a single panel. Figures 7(a) and (b) show the results for a 10mm thick chipboard panel 0.825x0.675m using a 1.5m source to receiver spacing, and a 3mm thick aluminium panel 1.955x1.22m with a 2.5m source to receiver spacing. Theoretical prediction is also indicated and the agreement good but the discrepancy is greater at higher frequencies where there is an increasing phase shift caused by the panel depth. This becomes more obvious as the wavelength approaches the depth of the panel.

When measuring the diffraction around the panel the result of including the direct component has negligible effect. However, although small it can be isolated to find the panel insertion loss.

6 OPEN SCREENS

It is relatively easy to omit the direct component for single panels. However open screens can be considered as a line of thin panels where the direct and diffracted components arrive at the microphone at almost the same time. It is not possible therefore to distinguish the components separately. Thus the time history represents a series of diffracted signals decaying in amplitude as the sound path through each successive opening becomes longer, as shown in Figure 4(c). This causes no problem as the transmission through the solid panels is negligible compared to that through the open areas.

The open screens were placed within a baffle, acting as the wall area of a facade. For these measurements this baffle ensured correct windowing after the last diffracted component through the furthest spacing between the panels. The time history for this situation is shown in Figure 4(c).

Results for two open screens measured are presented in Figure 8. The same screens were measured according to ISO 140. Figure 8(a) shows the 0.2m wide x 0.1m deep panels at 50mm air spacing, and 8(b) the 0.1m x 0.1m panels at 50mm spacing.

7. CONCLUDING REMARKS

An impulse response technique has been investigated by application to solid and open screens which are not amenable to measurement by standard methods. Mass-law and coincidence characteristics of solid panels are indicated and the consideration of the diffracted component yields results which agree with Kirchhoff theory.

The mass-layer and optical theories are combined for the case of open screens. Mass-layer prediction gives good agreement with impulse measurement at low frequencies and the optical model prediction gives good agreement at high frequencies. The method requires no specialist acoustic facilities and measurement systems can be portable.

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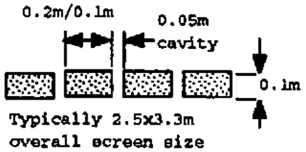

Figure 1 Typical detail of open screen

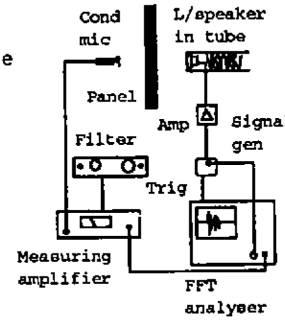

Figure 4 Impulse measurement

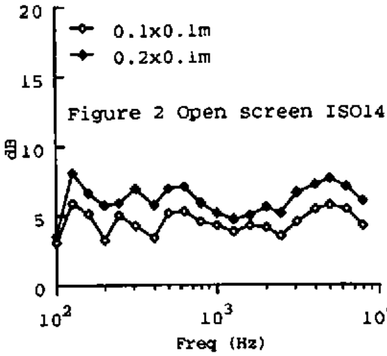

Figure 2 Open screen ISO140

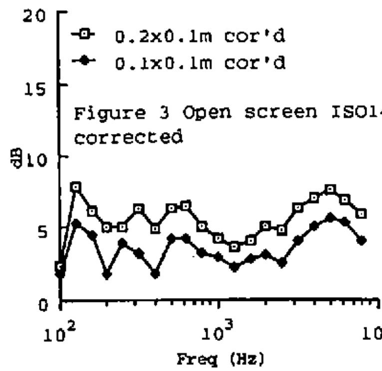

Figure 3 Open screen ISO140 corrected

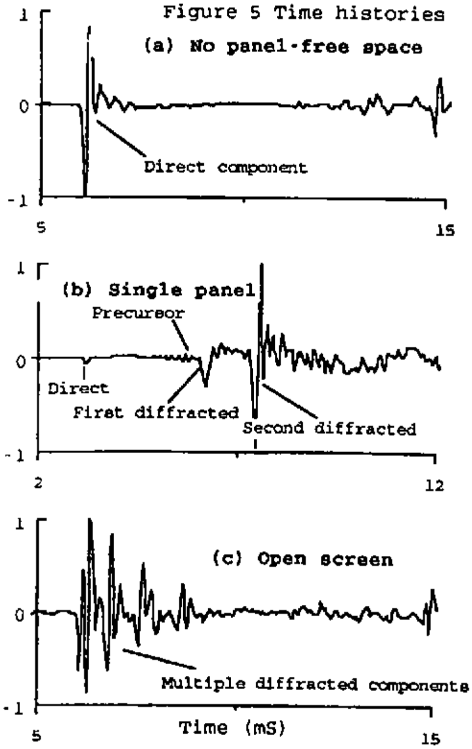

Figure 5 Time histories

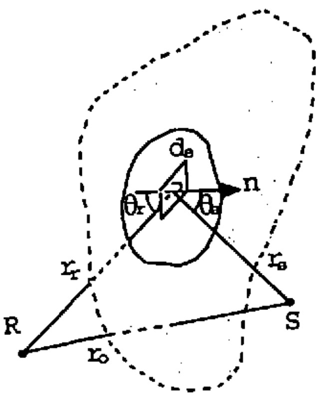

Figure 6 Diffraction geometry

Figure 7 Single panel results

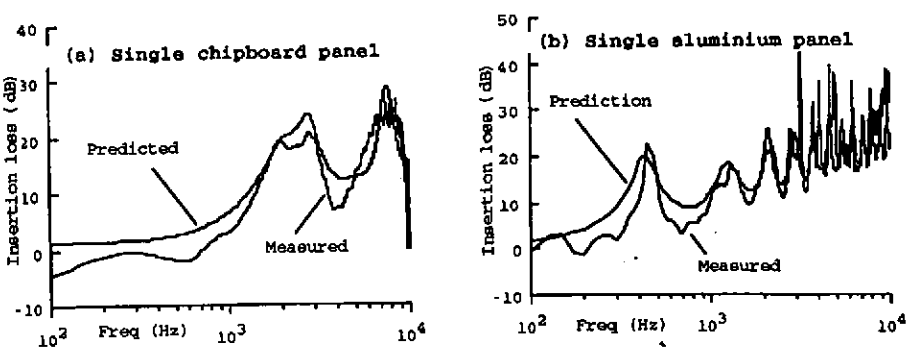

Figure 8 Open screen results