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ACOUSTIC PROTECTION OF OPEN SCREENS

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1 INTRODUCTION

Earlier work [1] considered the sound reduction index (SRI) of open forms of screen such as acoustic louvres, used where there is a requirement for acoustic control together with natural ventilation. Recent work [2] investigated a method of measurement of this type of screen, with results of a survey suggesting that the standard ISO 140 [3] recommendation was probably the most widely used for assessing louvre performance in the U.K. at present. However, use of this standard has been shown to be impractical for such elements with low sound transmission loss, as the receiving room reverberation time measurement will be influenced by energy flow between rooms during decay measurements [4]. The standard method and an alternative impulse method are reviewed herein, and a simple engineering comparison between the two is considered for open screens.

2 ISO 140 RECOMMENDATION

The facilities at Liverpool University provide a reverberation transmission suite the dimensions of which satisfy ISO 140 with the exception of the aperture area, (refer to table 1). The modal overlap, M, in table 1 was assigned a value of unity [5,6]. The repeatability of six consecutive insertion loss measurements were in accordance with part two of ISO 140 [1].

Coupling of the two rooms through the test specimen will be significant when the transmission loss is small, typically less than 15dB. The standard equation [3] is thus modified to give [7]

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

where L_1 and L_2 are the source and receiver room sound pressure levels respectively, S is the specimen test area and A is the receiver room total absorption. Where the difference between the room sound pressure levels is 3 dB or less the correction can not be considered accurate [8] and results can be negative [1]. A level difference greater than 9.5 dB gives corrections less than 0.5 dB so that the effective range of application is 3 - 9.5 dB.

At low frequencies open screens can fall below this range and strong coupling between the rooms results in longer reverberation times and incorrect estimates of 1/A [4], leading to greater than true transmission losses. Adjustment of the absorption in the source room may be used to suppress coupling and improve results but unfortunately may have adverse effects on the room diffusivity.

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An alternative method of Bies and Davies [5], uses the determination of level differences in both directions and of the absorption in both rooms, however, it is iterative and requires substantial computation time. Despite these uncertainties in absolute measurements in the low frequency range the facilities gave good repeatability. Small changes in the screen configuration yielded consistent (albeit small) changes in insertion loss with no cross-over. However it is still clear that the results of the ISO 140 method at lower frequencies must be treated with some caution when measuring open screens such as acoustic louvres.

In the U.K. the problem has been recognised by the Acoustics Committee of HEVAC [2], who have issued a recommended test procedure [9] for the measurement of static insertion loss of acoustic louvres. The procedure involves generating a diffuse sound field in a reverberant room which has a 1 m square aperture in one wall. The external sound pressure at the louvre is measured and averaged for nine positions; at angles 15^0 apart, on a 3 m radius from the louvre centre, and at least 1.5 m 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. Directionality can be checked by rotating the louvre through 90^0 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.

3 IMPULSE RESPONSE METHOD

An impulse response method offers the advantage of requiring little or no special facilities and is practically portable. A short duration pulse from the loudspeaker, designed to give a large separation between the forward radiated pulse and the back radiation from the cone, is captured by the microphone. The signal is passed through an attenuator and band-pass filter as required, then digitised by the Fast Fourier Transform (FFT) analyser. A time history of the signal is displayed on the FFT screen showing the direct signal separated in time from subsequent delayed, reflected and scattered components. The measurement is performed first in free space then with the test panel in position between the loudspeaker and the microphone. The diffracted components and later room reflections are windowed out allowing the direct component to be isolated and Fourier transformation of this part of the signal provides the anechoic frequency response. The insertion loss of the panel is simply the level difference between the two frequency spectra.

The method has been used for transmission loss of panels indicating clearly coincidence and mass law [10]. However the main mechanism for open screens is that of diffraction. Validation of the impulse method was made using measurements and prediction for single aluminium and chipboard panels. This work was reported in a previous paper [2] and involved the capture of both the direct and diffracted components. The effect of the direct component is negligible compared to that of the diffracted component however, where required, it can be isolated to give the (infinite) panel insertion loss.

The contribution of the diffracted component was predicted from Fresnel-Kirchhoff diffraction theory [11]. The sound field behind an infinite screen containing an aperture illuminated by a point source is replaced by its compliment, an absorbing screen in free space using Babinet's principle [12]. This results in the following equation, explained in more detail elsewhere [2,13]

[2] Heating, Ventilating and Air Conditioning Manufacturers Association

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

$$- \frac{A}{4\pi}\iint_{screen} \sqrt{\tau}\, e^{j\phi}\left(\frac{e^{jk(r_s+r_r)}}{r_s\, r_r}\left[\left(jk - \frac{1}{r_s}\right)\cos\theta_s + \left(jk - \frac{1}{r_r}\right)\cos\theta_r\right]\right) d_s \qquad (2)$$

where P(R) is is the sound field at a point R, τ is the sound transmission coefficient. ϕ is the phase shift between incident and reflected sound waves, given by

$$\phi = \tan^{-1}\left(\frac{\omega m\ \cos\theta}{2\rho c}\right) \qquad (3)$$

The remaining terms are indicated in figure 1. The result for a 3 mm thick aluminium panel 1.95 m x 1.22 m with a 2.5 m source to receiver spacing is shown in Figure 2, together with theoretical prediction, using equation 2. The agreement is good but shows increased discrepancy at higher frequencies where there is a greater phase shift due to an increase in the ratio of panel depth to wavelength.

4. SINGLE LEAF OPEN SCREENS

For the solid single panel it proved relatively easy to time window upon the direct component of the transmitted signal, but open screens are a line of narrow panels vertically spaced and the direct and diffracted components arrive at similar times. It is difficult to distinguish the components separately in this case, as the time history gives a series of diffracted signals decaying in amplitude as the sound path through more distant openings become longer. In the low frequency region where the wavelength is much greater than the dimension of the aperture the air plug acts as an inert mass and the equivalent mass per unit area of the open screen is then used. This is known as the mass-layer effect [14].

Results for the single panels and open screens generally agreed with those of Wassilieff [13]. Destructive interference by the sound passing through the gaps with the sound transmission around the barrier, gave improved insertion loss at certain frequencies, but constructive interference at other frequencies caused a reduction in performance.

Figure 3, shows the results of recent measurements for a screen consisting of 0.2 m wide x 0.1 m deep panels at 50 mm air spacing. The transmission loss given by these screens is small and relatively frequency invariant over the frequency range 100 Hz-10 KHz. The agreement of the impulse measurements with mass-layer prediction at low frequencies and optical diffraction theory at the higher frequencies is good. The transition from the mass-layer to the optical model occurs in the region where the picket width is between $\lambda/2$ and $2\lambda/3$.

5 DOUBLE LEAF OPEN SCREENS

A double leaf screen, with staggered vertical openings, has been proposed for increased sound insulation. The impulse method has been shown to give reliable results, consistent with theory, for the simple cases so far studied. Therefore, it was reasonable to expect the results of the double screens to be a good indication of their performance, no matter how complicated the path through the screen as long as the whole signal is captured.

Further, we wished to provide an engineering approach to the problem and a possible method of comparison with ISO 140 measurements, to which many open types of screen have been measured in practice [2]. In order to compare with ISO 140 some angular variation must be assumed or measured. It is clear that the random incidence transmission loss equation [8] can not be applied to the normal incidence results for open screens since it assumes a mass law mechanism only. Indeed for single open screens the normal incidence performance was worse than the oblique incidence insulation; the reverse of the situation for solid panels.

The results of two screens are presented, both using 0.2 m wide x 0.1 m deep panels, and a separation of 0.1 m between each leaf. The separation between the panels shown in figures 4 and 5 is 0.05 m and 0.1 m respectively. Results are presented in one third octave frequency bands. As a first step the average value of the impulse measurements at angles from 0^0 - 75^0 in 15^0 steps was obtained and compared to standard ISO 140 measurements. The screen offering higher insulation, figure 4, shows good agreement between the methods. The screen with a lower insulation, figure 5, gave less than good but still acceptable agreement.

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Table 1 : Dimensions of facilities and ISO 140 requirements

Parameter	Receiver room dimensions	Source room dimensions	ISO 140 requirement
Volume (m^3)	122.00	74.00	50.00
Volume difference (%)	164.00	61.00	min^{m}10.00
Area (m^2)	149.00	109.50	—
Test area (m^2)	3.50	3.50	10.00
Min^m edge length (m)	1.66	1.66	2.30
Cut-off freq (Hz) [M=1]	200.00	250.00	—

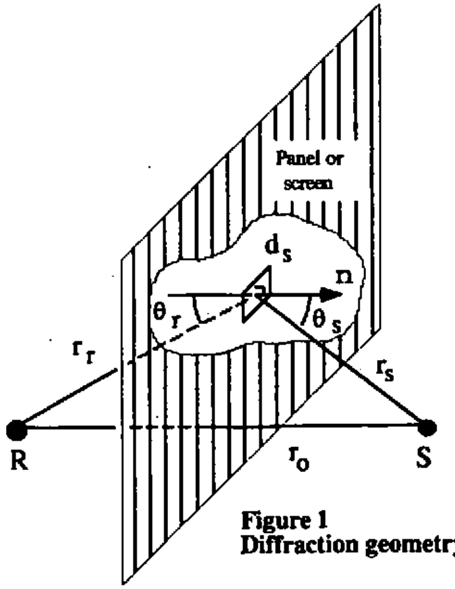

Figure 1
Diffraction geometry

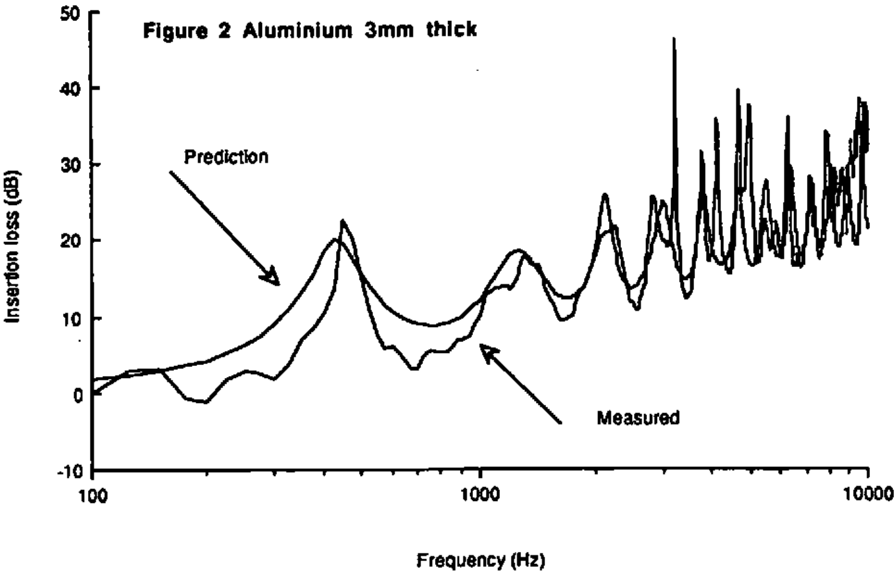
Figure 2 Aluminium 3mm thick
Prediction
Measured
Insertion loss (dB)
Frequency (Hz)
50
40
30
20
10
0
-10
100
1000
10000

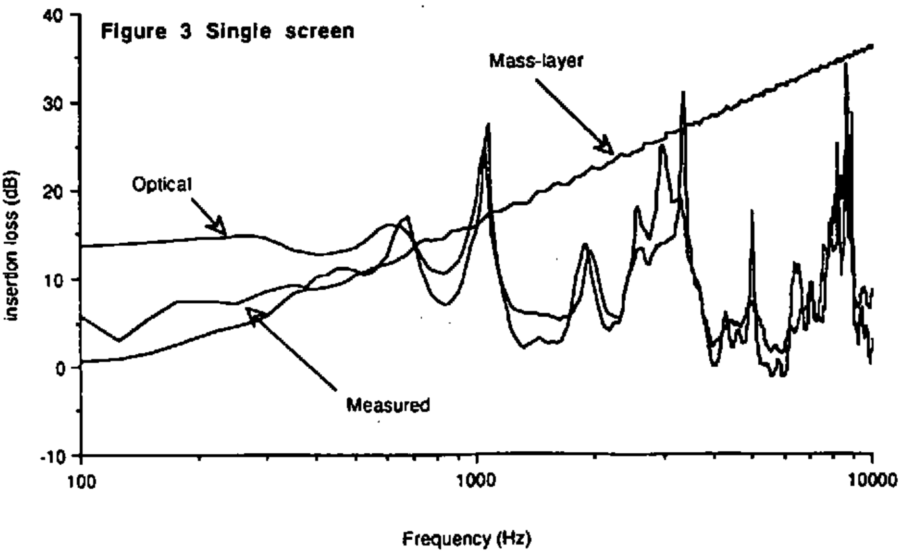
Figure 3 Single screen
Mass-layer
Optical
Measured
insertion loss (dB)
Frequency (Hz)
40
30
20
10
0
-10
100
1000
10000

Figure 4 Double screen with 0.05m spacing

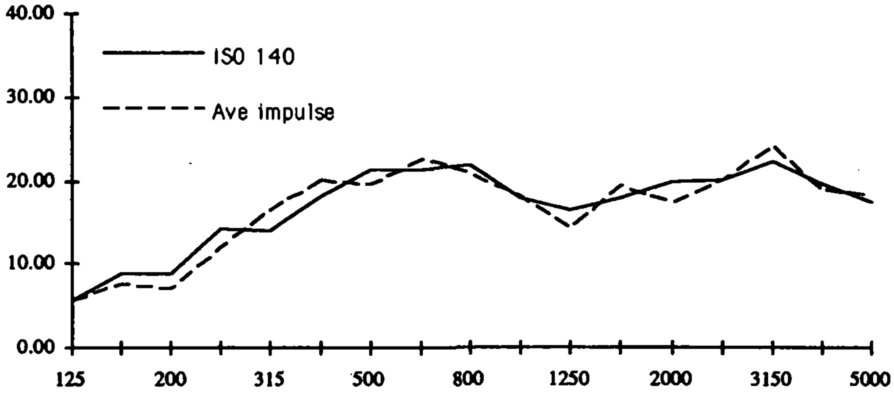

Figure 5 Double screen with 0.1m spacing