Proceedings of the Institute of Acoustics

IN-SITU SOUND INSULATION TESTING USING IMPULSE RESPONSE ANALYSIS

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1. INTRODUCTION

There are a number of papers that deal with simplified or 'quick' test methods for airborne sound insulation testing, but not all of these proposed techniques are easily be adapted to the testing of partially completed constructions. The impulse response technique is not new to the field of acoustics and applications to sound insulation date back to 1955[1]. This paper gives a short review on sound insulation testing using impulse response analysis techniques and considers its potential for testing partially completed sections of a construction. The method has the advantage of allowing the contribution of sound energy through a partition wall to be isolated from that due to flanking, hence, a partly constructed section of wall could be tested as a form of 'quality assurance procedure'. Failures due to insufficient mass, bridging or air gaps might then be identified and corrected before the construction proceeds. If the partially completed section is an external wall or cladding, then impulse response analysis methods could be considered, but obtaining a good signal to noise level can prove difficult.

2. PREVIOUS RESEARCH

Raes[1] introduced the terms 'space insulation' and 'time insulation' and the latter is the principle of the impulse response analysis method. In the standard method of measurement[2] the space around the test element is insulated such that flanking transmission is negligible in terms of the energy transmitted directly through the test element. In time insulation a direct component travelling through the test element is isolated from those components which travel around the element. Louden[3] was the first to use a single-pulse source and performed Fourier analysis on photographed traces of an oscilloscope to yield normal incidence transmission losses for a lightweight panel. The method has been used to measure normal and oblique incidence transmission loss of thin panels and walls[4,5], yielding measurements that agree well with theory. Gibbs and Balilah[5] have demonstrated that the method has the potential for diagnosis of acoustic failure in walls due to cracks. In general, however, measurements of low transmission loss has been more successful than those of high transmission loss and most recent research has therefore focussed on impulse response analysis of solid and open forms of screen[6,7].

3. EXPERIMENTAL METHOD

The impulse response method requires the separation and capture of a direct short duration signal from subsequent scattered, diffracted, and reflected components to allow Fast Fourier Transformation. The captured time signal is transformed to the frequency domain giving the power spectrum. The power spectra with and without the element in position are then used to obtain the transmission loss directly. In this way the transmission or other characteristics of the system under test are assessed independently of the surrounding acoustical conditions. As most acoustical systems are linear and time-invariant, impulse response theory can be applied to obtain the system frequency response, which will completely describe the transmission characteristics of that system.

The typical measurement system is shown in Figure 1. The sound source is a 120mm aluminium cone moving coil loud speaker fitted into the end of a tube of 1.0m length to avoid back radiation from the cone masking the forward radiated component. The pulse signal generator produces a variable rectangular pulse (100μs-4ms) the width of which is selected to give sufficient signal to noise over the frequency range of interest.

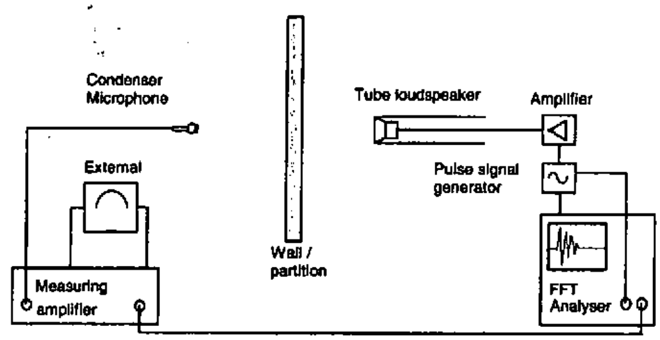
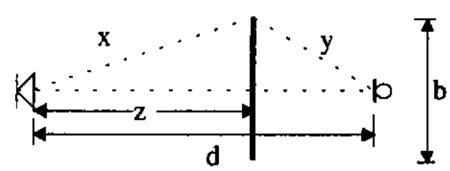


Figure 1. Impulse Response Analysis Instrumentation

The best signal can be obtained using a loudspeaker that has a good frequency response, high efficiency, and a short transient response. Signal capture and frequency transformation was facilitated by means of a portable FFT analyser, triggered directly by the signal generator, and signal-to-noise was improved by averaging in the time domain. The signal time history at the microphone due to a short duration pulsed output from the loudspeaker where a reflecting surface is in close proximity is shown in Figure 2(a). Correct time windowing of the direct component will eliminate the effect of the reflection and subsequent frequency analysis will yield the anechoic frequency response. If a freestanding panel intersects the line between loudspeaker and microphone then an attenuated direct component results with subsequent larger diffracted and reflected components as shown in Figure 2(b). If only the direct component is windowed and its spectrum compared with the spectrum without the panel in position, then the level difference gives the *effective* transmission loss of the panel; the effects of source and receiver frequency and directional characteristics and those of distance and air absorption are eliminated. The amplification through the receiving circuit must be taken into account in the level difference.

To help set the time window upon the desired part of the signal correctly, the arrival of each signal can be predicted from the relative positions of source, receiver, partition, reflecting surfaces and partition size and then compared to the time history. Figure 5 demonstrates the relationship between the geometrical arrangement and maximum allowable direct signal duration. t is the time in seconds and c is the speed of sound in air.



$$t \le \left[(x+y) - d\right]/c$$

Figure 3. Source, receiver and panel geometry

4. MEASUREMENT OF SINGLE HOMOGENOUS PANELS

Measurements can be obtained for normal and oblique angles of incidence and it is possible to average over a number of angles to obtain an angle-average impulse response measurement. This has been shown for open forms of screen with transmission losses around 20dB and averaging over angles from 0^0 to 75^0, giving quite good results[7]. Figure 4 shows the impulse response time histories for various angles of incidence using a single aluminium panel. Using time-of-flight prediction a direct wave signal would be expected at 3ms, corresponding to the reference signal at 1m source-receiver spacing, Figure 4(a-c). At higher angles of incidence there appears a pre-direct component which precedes the direct signal seen in Figures 4(d-f). This is termed the 'precursor' wave, because it is a supercritical wave that travels in the panel as a bending wave with a velocity greater than that of sound in air. These pre-direct components provide the coincidence information for the panel.

Figure 5 and Figure 6 indicate the measured transmission loss at normal incidence and at an angle of incidence of 75^0 respectively. Normal incidence measurements have been compared with mass law theory demonstrating good agreement and giving the expected gradient of 6dB per octave increase in frequency. The deviation from mass law at high frequencies is due to the upper frequency limits of the measurement system. Oblique incidence results are compared with known theory[8] expressed here as

$$\mathrm{TL} = 10\ \mathrm{Log}_{10}\left\{\left[1 + \eta\left(\frac{\omega\rho_s}{2\ \rho_o\ c}\cos\theta\right)\left(\frac{\mathrm{B}\omega^2}{\rho_s c^4}\sin^4\theta\right)\right]^2 + \left[\left(\frac{\omega\rho_s}{2\ \rho_o c}\cos\theta\right)\left(1 - \frac{\mathrm{B}\omega^2}{\rho_s c^4}\sin^4\theta\right)\right]^2\right\} \quad (1)$$

where ρ_s is the panel surface density and the damping is represented by the structural loss factor, η, and B is the bending stiffness per unit width. The coincidence dip at 75° compared well with the predicted frequency of 4325Hz, but was noticeably reduced. In all cases it was found that the predicted transmission loss at coincidence from Eqn. 1 was an underestimation of that measured. This, together with the shift in coincidence at some angles of incidence might be expected since in reality the spreading incident sound waves will strike the panel over a range of angles[6].

Edge reflected components can also be seen in the time history in Figure 4, between the direct and diffracted components at all angles of incidence and with increased amplitude as angles of incidence increase. These are the result of free bending waves generated at the edges of the partition, which then reflect, travelling back across the centre and registering in the time history. For measurement of the infinite panel response these edge reflections must be excluded from the time window. The arrival of the edge reflected component depends upon the bending wave velocity such that at high frequencies or with dense, thick walls the edge reflected component will arrive early and cannot be separated out of the time history. Spatial averaging of the signal can be used to reduce this component. The source-receiver vector, source-panel distance and angle with the panel is maintained, whilst the point of intersection of the vector and the panel is varied. The arrival time and phase of the edge reflected signals vary and are attenuated on averaging while the direct signal component is reinforced.

Gibbs and Balilah[5] have already demonstrated this for masonry walls. Figure 7(a) shows the direct component, precursor and diffracted components of a transmitted signal through 120 mm plastered brickwork at normal incidence. The radiated sound due to edge reflections arrives at the microphone position before the diffracted component and before the direct component is completed. Spatial averaging reduces the unwanted fluctuations to a lesser level, as shown in Figure 7(b), by averaging over just eight positions. The resultant agreement between measurement and theory is seen in Figure 8 in one third octave bands and is fair. An adequate reduction in edge reflections and reasonable signal-to-noise could only be achieved with thinner walls and was not possible for thick walls such as 220 mm plastered brickwork.

5. MEASUREMENT OF STIFFENED PANELS

An alternative to masonry walls is profiled cladding panels generally constructed from composite materials. The main difference with these wall systems is that they are complex in construction and have inherent stiffening and/or external stiffening such as purlins. The effect of adding external discontinuities (stiffeners) is to create internal as well as edge reflected signals. The infinite panel response is then more difficult to obtain and the question arises as to whether it is desirable to isolate the unstiffened panel response. Indeed, stiffeners and their effects become an integral part of the panel response. With profiled panels there are additional internal discontinuities due to the bends in the profile. The effects of stiffening using impulse response methods was investigated for a simple case and further work is ongoing looking at profiled panels in more detail.

A large thin aluminium panel, 2.235m x 1.78m, was fixed with lengths of 25mm steel U-rail in one direction along the panel (Figure 9) and sealed with superglue. Provided the distance between the stiffeners was wide enough it was still possible to exclude the internally reflected components and obtain the infinite panel response. Where the stiffeners were closely mounted the effects of early reflections were reduced by spatial averaging over sixteen positions, randomly selected, over the surface of the panel. At each position, a reasonable distance away from the free edges, 16 averages were obtained giving a total of 256 averages. The resulting time history is shown in Figure 10. As with the masonry wall in Figure 7, there is some reduction in the edge reflection and a window end was set at 4.68ms providing the insertion loss in Figure 11. The effectiveness of the averaging procedure is evident and is equivalent to windowing out the internally reflected components. The result is shown with the mass law theory line and indicates a close comparison to the simple panel in Figure 5, but with greater differences at higher frequencies.

6. CONCLUDING REMARKS

This paper has reviewed, albeit briefly, the impulse response analysis method and has tried to demonstrate its potential as a future testing method for incomplete sections of a construction in-situ. It should be appreciated that the method offers some promise as an in-situ measurement and not an assessment of in-situ performance. The main conclusions with respect to possible use in the field can be listed as follows.

i. Impulse response methods can be used for the measurement of insertion loss of isotropic panels where Mass-law characteristics and coincidence are clearly indicated. They are, however, only proved for laboratory situations and field measurements need to be undertaken.
ii. There is potential, subject to these field measurements, for using the method upon single-leaf walls and stiffened panels of lower sound insulation where spatial averaging is employed.
iii. The problems of signal-to-noise would need addressing before field measurements of in-situ performance can be seriously undertaken.
iv. The method can be quick and is inexpensive although spatial averaging increases the complexity and reduces its advantages in terms of speed.

Although not demonstrated here, it is possible to relate the laboratory based, normal incidence, impulse response measurement of isotropic panels to a laboratory based random incidence response across a frequency range that includes the coincidence region. If field measurements were to show some success then a similar method relating normal incidence, impulse response to field incidence results would be desirable.

7. REFERENCES

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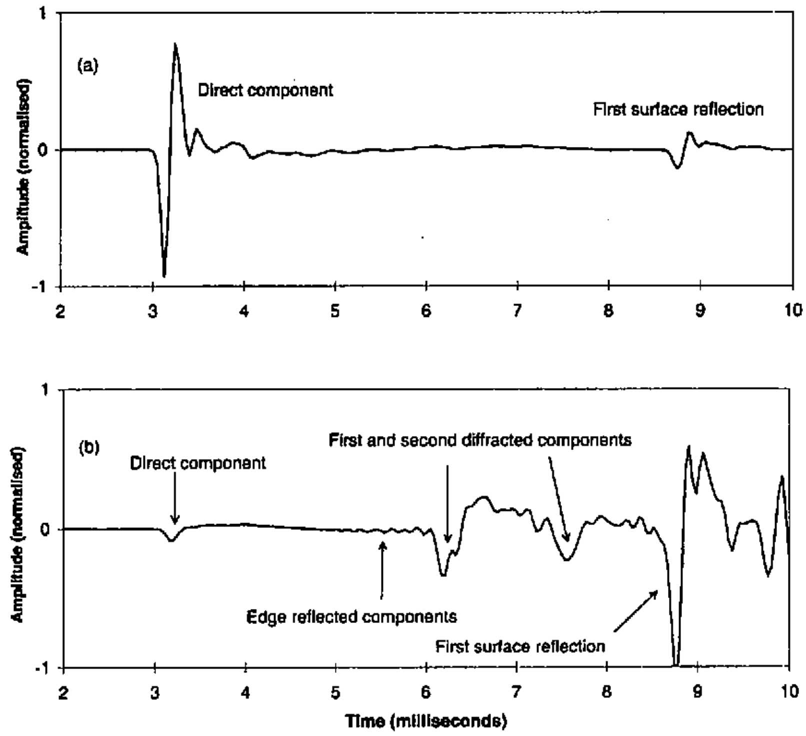


Figure 2. Time histories for (a) reference signal and (b) aluminium panel at 1m source-receiver spacing and normal incidence.

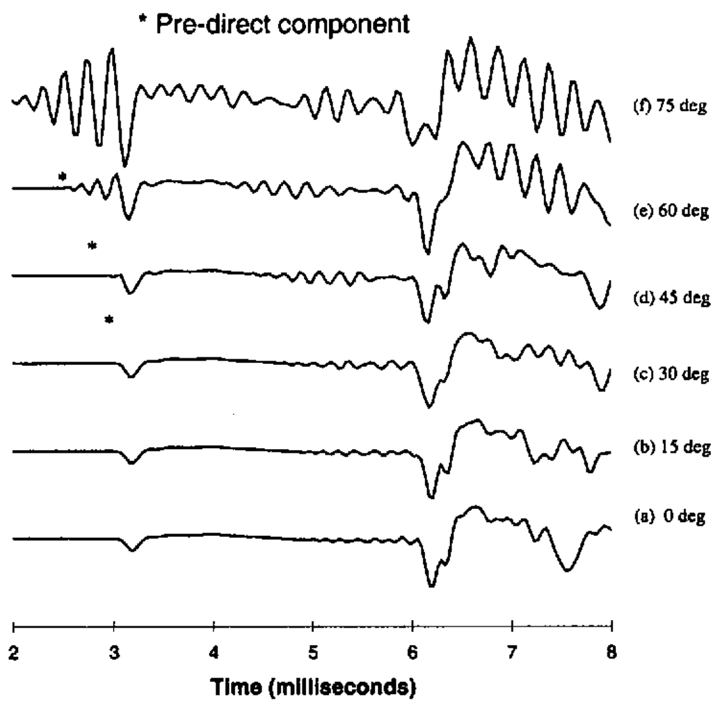


Figure 4. Time histories for aluminium panel (source-panel-receiver spacing of 0.7m-0.3m).

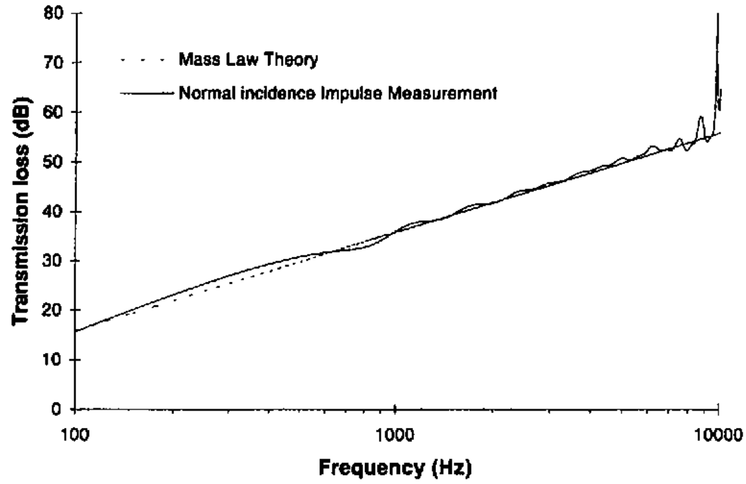


Figure 5. Normal incidence Impulse response measurement on aluminium panel (infinite response).

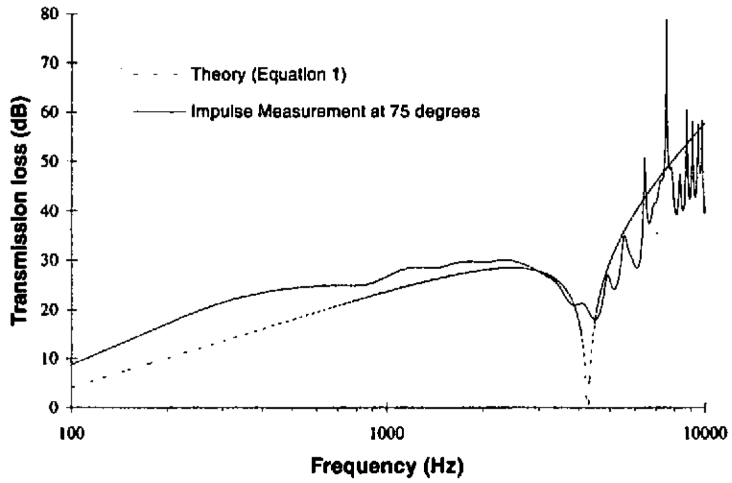
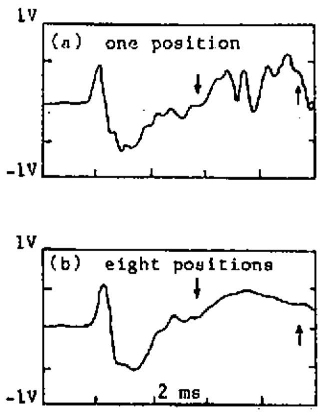


Figure 6. Impulse response measurement on aluminium panel at 75 degrees (infinite response)



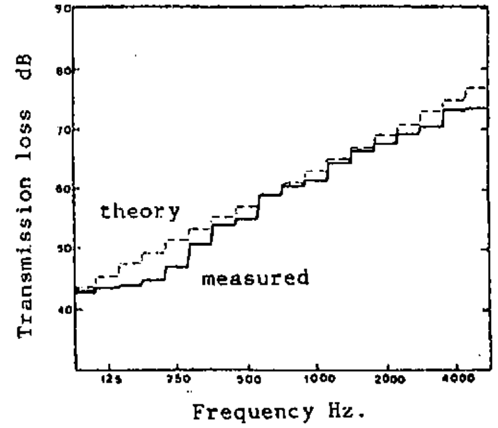


Figure 7. Eliminating edge reflections by spatial averaging (courtesy Ref. 5).

Figure 8. One third octave band measurement of single brickwork wall. (courtesy Ref. 5)

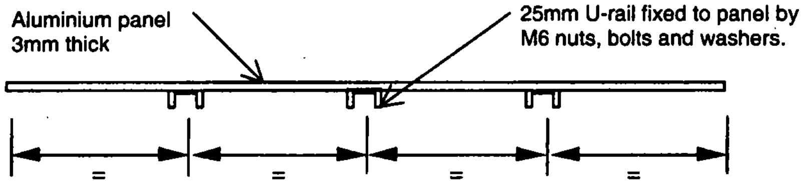


Figure 9. Detail of three stiffeners to single panel

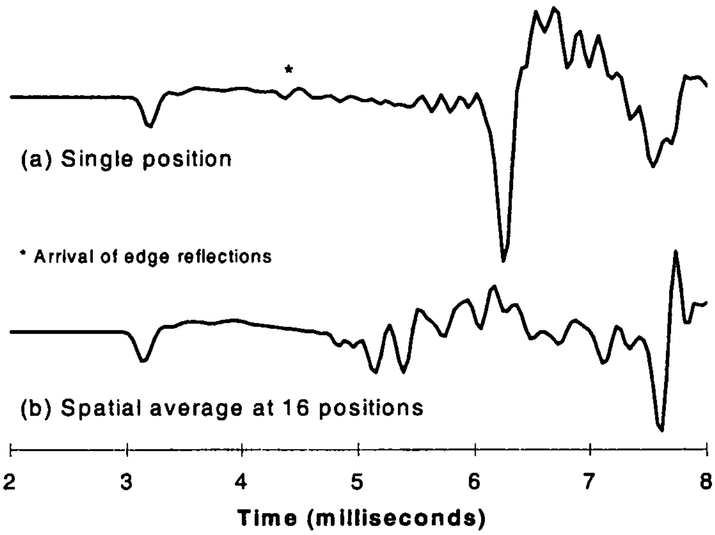


Figure 10. Time histories for aluminium panel with three stiffeners measured at the centre position.

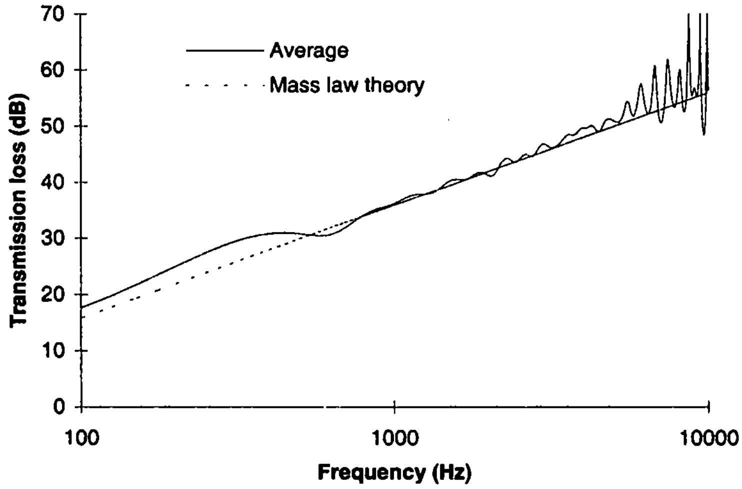


Figure 11. Aluminium panel with three stiffeners, using spatial averaging.