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MEASUREMENT OF FLANKING TRANSMISSION BETWEEN DWELLINGS

T A Carman and L C Fothergill

Building Research Establishment, Watford, WD2 7JR

INTRODUCTION

Sound transmission between rooms can be by the direct path through the party wall or floor and by indirect paths, for example through the inner leaf of an external wall. Flanking transmission is the term given to sound transmission by any indirect path.

When planning remedial treatment to solve a sound insulation problem, it is important to know which sound path is dominant and so a technique is required for measuring the sound radiated from each surface of a room in order to compare the relative importance of different paths.

The simplest way of measuring the sound power radiated by a surface is the accelerometer method. Vibration transducers are used to measure the acceleration of the surfaces of the receiving room when a loudspeaker is operating in an adjacent source room. The sound power radiated by each surface is estimated from the mean acceleration of the surface. This method is unsuitable for lightweight structures and so an alternative method is being developed by BRE in which the sound power radiated by each surface of the receiving room is calculated from intensity measurements made by sampling over the surfaces. In the present paper the basis of the accelerometer and intensity methods and their advantages and disadvantages will be discussed, and results obtained using the sound intensity method presented.

ACCELEROMETER METHOD

An accelerometer is attached at many different positions on each surface of the receiving room and the root mean square acceleration of each surface is calculated. The sound power (W) radiated by a surface of area A is given by:

$$W = \rho\ c\ u^2\ A\sigma \qquad (1)$$

where ρ is the density of air,
  c is the velocity of sound in air,
  u is the root mean square velocity of the surface
and σ is the radiation coefficient of the surface.

The major shortcoming of this method is that the radiation coefficient, σ, depends not only on the material of which the radiating structure is made, but also on physical conditions including the method of excitation of the structure. At frequencies well above the critical frequency the radiation coefficient may be assumed to be unity but below the critical frequency its value is not usually known. For commonly used materials such as plasterboard and common constructions such as leaves of 100 mm blockwork, a substantial part of the frequency range of importance is below the critical frequency and the method is not very accurate.

A practical drawback of the accelerometer method is the need to attach the accelerometer to the surface being investigated, which could damage paintwork or wall decorations.

SOUND INTENSITY METHOD

Sound intensity is a vector quantity representing, at a point, the rate of flow of acoustic energy through unit area. The sound power (W) radiated by a surface of area A is given by:

$$W = \int_A I_r \, dA \tag{2}$$

where I_r is the mean sound intensity in direction r, normal to the surface, calculated from intensity measurements made by sampling over the surface. The measurements can be made using a probe, comprising two microphones, A and B, mounted face to face, separated by a plastic spacer of known length, Δr. For a medium without mean flow, the intensity can be expressed as:

$$I_r = \overline{p.\ v_r} \tag{3}$$

where p is the instantaneous sound pressure,
v_r is the instantaneous particle velocity in direction r
and the bar represents time averaging.

The particle velocity can be calculated from the pressure gradient:

$$v_r = \frac{-1}{\rho} \int \frac{\partial p}{\partial r} \, dt \tag{4}$$

In this method an approximation for the pressure gradient at the midpoint of the probe is made from the pressure measurements from the two microphones and the sound pressure, p, is taken as the mean of the two pressure measurements, giving:

$$I_r = \overline{\frac{-(P_A + P_B)}{2\rho} \int \frac{P_B - P_A}{\Delta r} \, dt} \tag{5}$$

The two microphones are connected to an analyser which evaluates this equation in octave or third-octave frequency bands and calculates the sound pressure level(L_p) and sound intensity level (L_I) in decibels for each band,

where $L_p = 10 \log_{10} \left(\frac{p}{p_o}\right)^2$ dB and $L_I = 10 \log_{10} \left(\frac{I}{I_o}\right)$ dB (6)

p is the measured pressure
p_o is the reference pressure
= 20 μPa

I is the measured intensity
I_o is the reference intensity
$= \frac{p_o}{\rho c} = 1$ pW/m²

The radiated sound power level (L_w) of a surface of area A is given by:

$$L_w = L_I + 10 \log_{10} A$$

ERRORS IN THE INTENSITY METHOD

Intensity measurements made using this system are subject to known errors which limit the frequency range over which the system can be used. Where possible the errors were calculated theoretically and tests were carried out to determine the experimental procedure and conditions which were required to reduce all errors to an acceptable level.

Sampling error

Sampling error is an error to which both the accelerometer method and intensity method are subject, accuracy being limited by the number of samples taken. A Brüel and Kjaer intensity analysing system type 3360 was used to measure the mean intensity radiated by a thin cellular plastic panel of area 4.5 m² and critical frequency 2000 Hz, mounted in a wall separating two reverberent rooms. A loudspeaker was operated in the source room and absorbent material was placed in the receiving room to reduce the reverberent field. Intensity level measurements were made at 63 positions for the frequency range 50 Hz to 4000 Hz. The mean sound intensity level was estimated from the 63 measurements and then from only 9 measurements and there was very good agreement between the two results both above and below the critical frequency of the panel. The 95% confidence limits increased from ±0.6 dB for 63 positions to ±2 dB for 9 positions, showing that measurements should be made at a minimum of 9 positions. Further tests have shown that a minimum of 2 measurements, each averaged over at least 16 seconds, should be made at each position.

Proximity error

Thomson has shown [1] that measurement accuracy is a function of $\Delta r/r$, where Δr is the microphone separation and r is the distance between the radiating surface and the midpoint of the microphones. Error calculations have been carried out for monopole, dipole and lateral quadrupole sources and, by considering the most complex of these sources: a lateral quadrupole, a range of $r > 2\Delta r$ is obtained for a maximum inaccuracy of ±1.5 dB.

To find the upper limit for r, intensity measurements were made with the probe at increasing distances from the panel up to 400 mm, using microphone spacings of 12 mm, 25 mm and 50 mm. In all three cases there was good agreement between measurements made within 200 mm of the surface, but measurements at greater distances showed deviations from the rest. 200 mm was therefore taken as the upper limit of r.

Approximation error and error due to phase mismatch

Use of the intensity system at high frequencies is limited by an error introduced by the approximation for the pressure gradient, and at low frequencies by an error due to phase mismatch between the microphone channels. In general a sound field is too complicated to calculate these errors, but calculations may be made for ideal sound fields to give an indication of the frequency range for a given microphone separation.

For a plane wave propagating parallel to the axis joining the microphones, it can be shown [2] that the ratio of the measured intensity (I_m) to the true intensity (I_t), with a phase mismatch of $\emptyset$ between two microphone channels, is given by:

$$\frac{I_m}{I_t} = \frac{\sin(k\Delta r \pm \emptyset)}{k\Delta r} \qquad (8)$$

where $k = 2\Pi/\text{wavelength}$

The error in a sound intensity measurement, $L_E = L_{I_m} - L_{I_t}$ (9)

Hence from equations (6), (8) and (9), the approximation error is given by:-

$$L_E = 10 \log_{10} \frac{\sin (k\Delta r \pm \emptyset)}{k\Delta r} \qquad (10)$$

Fig 1 shows the approximation error with a phase mismatch of 0.3° (the maximum phase mismatch for the system being used) for three microphone separations. From this the theoretical frequency range for a given error can be obtained.

To determine the useful frequency range of the system experimentally, the system was used in an anechoic chamber to measure the sound pressure level and sound intensity level 2 m from a loudspeaker in a small cabinet. The sound field in the central part of the anechoic chamber was a close approximation to that from a point source in the frequency range considered, and so the values of the sound intensity level and sound pressure level in any frequency band should have been numerically equal. The useful frequency range was taken to be the range over which the intensity level measurements differed from the pressure level measurements by less than 1.5 dB. This experimentally obtained frequency range is compared in Table 1 with the theoretical frequency range for an error of ≤ 1.5 dB, obtained from Fig 1, for three microphone separations.

Table 1. Comparison of experimental frequency range and theoretical frequency range for an approximation error of ≤ 1.5 dB.

Microphone separation	Experimental frequency range	Theoretical frequency range
12 mm	100 - 5000 Hz	80 - 6300 Hz
25 mm	50 - 2500 Hz	40 - 3150 Hz
50 mm	*50 - 1250 Hz	20 - 1600 Hz

*Measurements in anechoic chamber not valid below 50 Hz

There is good agreement between the two sets of frequency ranges. A microphone separation of 25 mm appears to be the most suitable for intensity measurements in buildings as it has a useful frequency range of 50-2500 Hz.

Effect of a reverberent field

A reverberent field affects the accuracy of intensity measurements in two ways. The intensity analysing system measures the resultant intensity radiated by the surface, which is equal to the difference between the radiated and absorbed intensities. This leads to an underestimation of the radiated power and so it is necessary to reduce the reverberent field in the receiving room by placing some highly absorbent material in it.

Another effect of a reverberent field is to increase the error due to phase mismatch. The reactivity index, K, of a sound field is defined as the ratio of the free-field phase difference between two points, $k\Delta r$, to the true phase difference, Φ:

$$K = k\Delta r/\Phi \qquad (11)$$

As the reactivity index increases, the true phase difference becomes smaller and any phase mismatch will be more significant. The reactivity index is usually quoted in logarithmic form:

$$L_K = -10 \log_{10} K \qquad (12)$$

and it can be shown [3] that $L_K = L_I - L_P$ (13)

Hence at any position the reactivity index of the field at any frequency can be calculated from the sound intensity level and sound pressure level.

An investigation into the effect of reactivity on intensity measurements was carried out in a test house at BRE (see Fig 3). The mean sound intensity level and mean sound pressure level were measured over a 225 mm brick wall separating a source room and receiving room, with decreasing amounts of absorbent (acoustic foam blocks) in the receiving room. Fig 2 shows the sound intensity level and reactivity index (calculated from $L_I - L_P$) for five levels of absorbent in the receiving room. For frequencies above 100 Hz it can be seen that when the magnitude of the reactivity is less than 13 dB, the measured intensity levels are, in general, consistant within ±1 dB. As the reactivity increases, and for frequencies below 100 Hz, the measurements become more erratic but generally agree within ±2 dB up to a reactivity of -15 dB. Therefore -15 dB appears to be the maximum acceptable level of reactivity for reliable intensity measurements with this system.

INVESTIGATIONS TO IDENTIFY SOUND TRANSMISSION PATHS USING THE INTENSITY METHOD

The first investigation was to use the intensity method to identify the dominant sound path between two rooms in the BRE test house. The house has two storeys with four similar rooms of 42 m³ on each storey. The external wall is cavity brickwork and the internal walls are a 225 mm brick party wall and 102 mm brick spine walls. The source room and receiving room were on the ground floor, separated by the party wall (see Fig 3). The noise source was a loudspeaker in a large cabinet, driven by a pink-noise generator. Sound intensity level and sound pressure level measurements were made at a minimum of 17 positions over each surface with the midpoint of the probe at 100 mm from the surface.

Fig 4 compares the mean sound power level radiated by each wall in the receiving room, in third octave bands from 63 Hz to 2000 Hz. Points have been omitted for frequency bands where the resultant energy flow was into the surface (giving a negative value for the mean intensity) as the surfaces were not contributing to the radiated sound power at these frequencies. The results for the floor and ceiling have not been included as these surfaces were absorbing sound energy in most frequency bands and radiating energy at only a very low level in the other bands and were consequently making a negligible contribution to the radiated sound power.

It can be seen that the party wall is the dominant radiating surface, the sound power level being greater than that radiated by any other surface in all frequency bands. Above 630 Hz the party wall was the only surface which was radiating at a high enough level to be measured by the analyser, the intensity levels at the other surfaces frequently falling below the lower measuring limit of the analyser. Both the internal and external flanking walls were also radiating sound energy and it can be seen that the external wall, which included a window, was, in general, radiating at a lower level than the internal spine wall. This is probably due to the window breaking up the radiating surface of the wall. The back wall was making very little contribution to the radiated sound power.

The technique has therefore identified the dominant sound path as being the direct path through the party wall, and has also shown the relative importance of the paths through the flanking walls.

The second investigation was to identify the dominant sound path between two rooms in timber-framed flats. The source room was on the first floor and the receiving room was directly below it on the ground floor. The noise source was a Brüel and Kjaer 4224 noise source with an external filter to control the frequency range. Sound intensity and sound pressure level measurements were made over the four wall surfaces (see Fig 5) and the ceiling for two frequency ranges:

63-800 Hz using the 50 mm spacer
and 1000-4000 Hz using the 12 mm spacer

The combined results, shown in Fig 6, identify the ceiling as the dominant radiating surface up to 1000 Hz with wall 4, an internal partition, also radiating strongly at low frequencies. Between 200 Hz and 400 Hz walls 1, 2 and 3 are also contributing to the radiated power. At high frequencies (above 1000 Hz) the external wall with a window (wall 2) is seen to be radiating most strongly.

The direct path through the party floor has therefore been identified as the dominant sound transmission path below 1000 Hz, and a flanking path through the external wall as the dominant path above 1000 Hz.

For both investigations acoustic foam blocks were placed in the receiving room to reduce the reverberent field. The magnitude of the reactivity index was then less than 15 dB in most frequency bands for each surface that was investigated.

CONCLUSION

A technique is needed for measuring the sound power radiated by room surfaces in order to identify the dominant sound path in buildings. The accelerometer technique is well established and simple to use, but is unsuitable for certain common lightweight constructions. It has been shown that the direct measurement of sound intensity can be used successfully to identify dominant sound paths in brick and in timber framed structures. The technique requires high sound levels in the source room and is susceptible to errors in highly reactive fields, but this problem can be overcome by increasing the level of absorbent in the receiving room. Care is necessary in both collecting data and interpreting the results, but the intensity method does enable study of flanking paths where the accelerometer method would be unreliable, and as it does not damage wall decoration it is suitable for use in occupied dwellings. Overall the intensity method offers a valuable alternative to the accelerometer method.

REFERENCES

[1] Thomson, J K. Tree, D R. 'Finite difference approximation errors in acoustic intensity measurements'. Journal of sound and vibration (1981), vol 75, No 2, 229-238.

[2] Gade, S. 'Sound intensity'. Brüel and Kjaer Technical Review No 3, 1982.

[3] Gade, S. 'Validity of intensity measurements in partially diffuse sound field'. Brüel and Kjaer Technical Review, No 4, 1985.

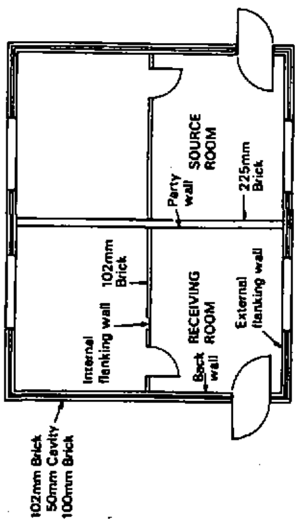

Figure 3 Plan of ground floor of BRE test house

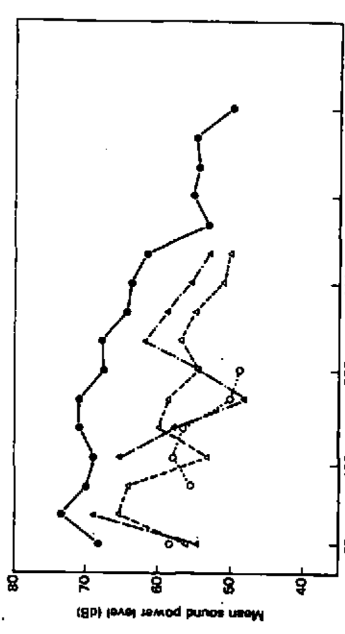

Figure 4 Comparison of the mean sound power levels radiated by the party wall (●—●—●), external flanking wall (△- - -△- - -△), internal flanking wall (▲-·-▲-·-▲) and back wall (○···○···○) of the receiving room of the BRE test house

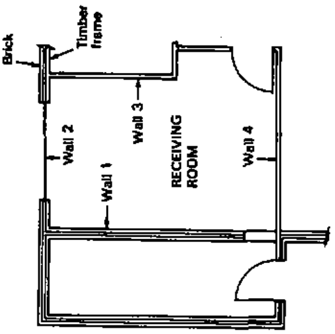

Figure 5 Plan of Receiving Room of timber-framed house

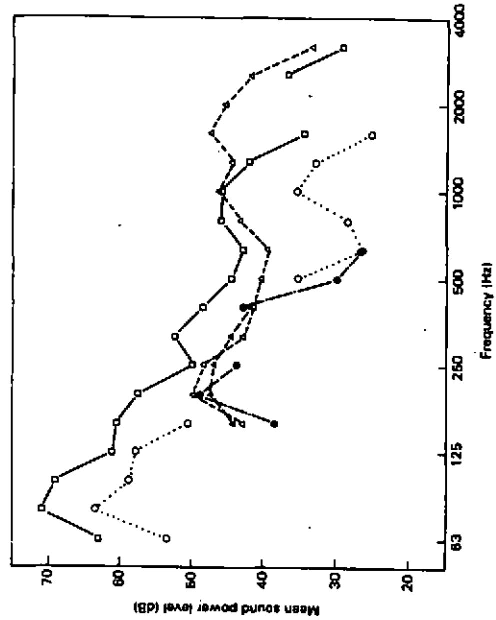

Figure 6 Comparison of the mean sound power levels radiated by Wall 1 (●—●), Wall 2 (△- -△- -△), Wall 3 (▲-·-▲), Wall 4 (○···○···○) and the ceiling (party floor) (□—□—□) of the receiving room in the timber-framed house

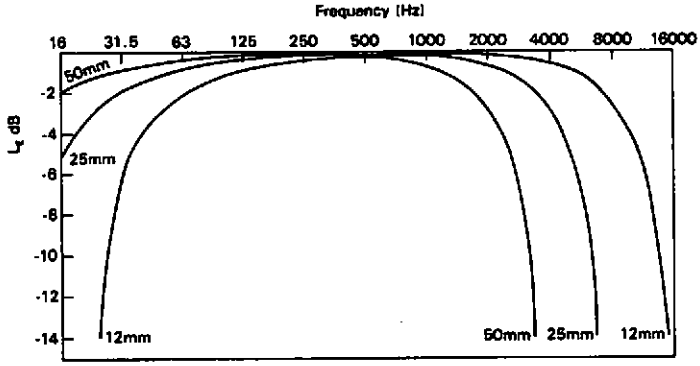

Figure 1 Approximation error, L_ϵ, for microphone separation, Δr, of 12 mm, 25 mm and 50 mm. A phase mismatch of 0.3° is assumed in each case

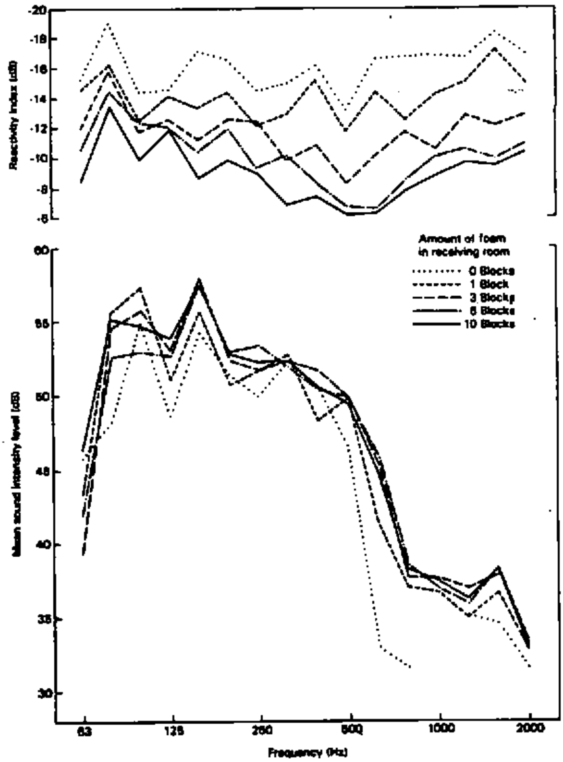

Figure 2 Mean Sound Intensity Level and Reactivity Index at the party wall of the BRE test house with increasing amounts of absorbent in the receiving room