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THE USE OF ACOUSTIC INTENSIMETRY TO SIZE AIR LEAKAGE CRACKS.

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SYNOPSIS

Reverberant sound excitation and the sound intensity technique have been used for the measurement of the sound transmission loss of narrow slits in rigid walls. A series of experiments was conducted to determine the transmission loss of slit shaped apertures. The measured transmission loss was in good agreement with existing approximate theories over their accepted ranges of validity. However, the effect of viscosity in small apertures was found to be significant and to vary systematically with the dimensions of the apertures.

As predicted by theory, the dimensions of the apertures determine the magnitudes and resonant frequencies of the sound transmission loss curves. It should thus be possible in principle to size air leakage cracks using the technique described in this paper.

SYMBOLS

A and B are constants which are functions of the crack dimensions width, w, depth, d, and length, l.
K is the product of the wave number of the incident sound, and width, w, of the slit
L is the depth-to-width ratio of the slit (d/w)
e is an end correction.
W_i is the acoustical power incident onto an aperture
W_0 is the acoustical power radiated from the aperture.
τ_c is the transmission coefficient of the aperture.
IL_r is the measured intensity level at a point distance r from the aperture on the receiving side .
SPL_i is the sound pressure level in a reverberant enclosure.

1. INTRODUCTION

Recent work on the design of energy efficient buildings has resulted in considerable attention being paid to energy losses due to air leakage via small constructional cracks. Baker Sharples and Ward [1] have carried out an investigation of air flow through cracks in walls by the method of room pressurisation. Their results show a quadratic relationship between the pressure drop, Δp, across the crack and the air flow rate Q as follows:

$$\Delta p = A\,Q + B\,Q^2 \tag{1}$$

Where A and B in Eq.(1) are constants which are functions of the crack dimensions width, w, depth, d, and length, l.

The following expression for the sound transmission coefficient of a slit shaped aperture has been given by Gomperts and Kihlman[2]:

$$\tau_s = \frac{mK\cos^2(Ke)}{2n^2\{\frac{\sin^2K(L+2e)}{\cos^2(Ke)} + \frac{K^2}{2n^2}[1+\cos K(L+2e)\cos KL]\}} \quad (2)$$

where K is the product of the wave number of the incident sound, and width, w, of the slit, L is the depth-to-width ratio of the slit (d/w) and e is an end correction.

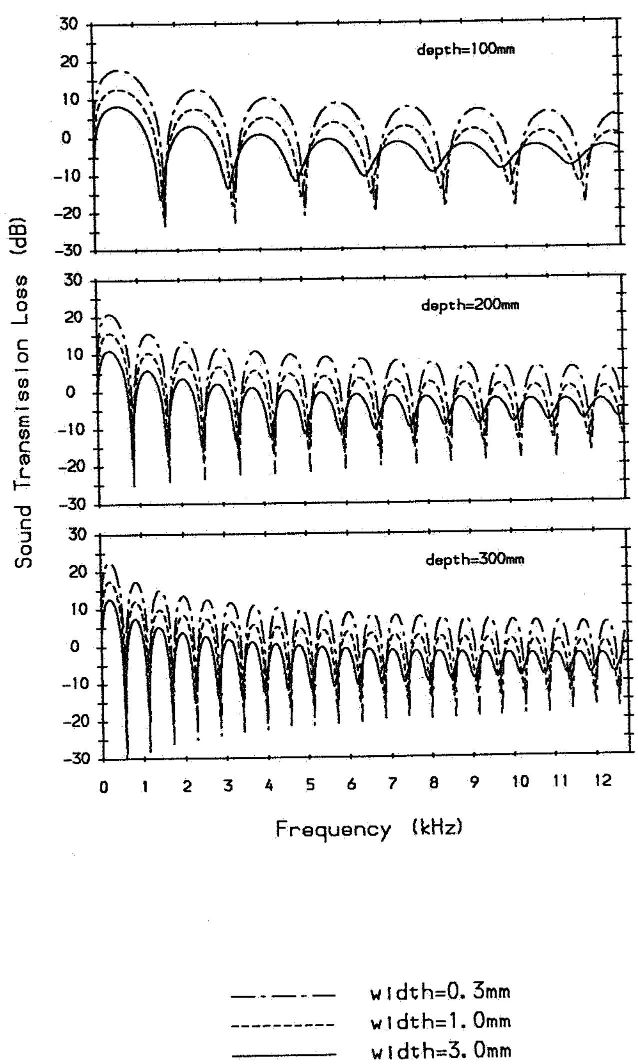

Fig.1 Predicted Transmission Loss Curves

Figure (1) shows predicted transmission loss characteristics for a number of different slits obtained from application of Equation (1). The dependance of these characteristics on slit dimensions is marked. Since the same parameters determine the air leakage characteristics, it suggests that measurement of the sound transmission loss of small cracks might be an effective indirect method of determining the air leakage characteristics of building elements.

There have been a number of previous attempts to employ acoustic techniques to locate cracks and determine their leakage characteristics. For example, Sonoda and Peterson[3] and Ringger and Hartmann[4] both used simple techniques based upon one third octave analysis of sound pressure level which were unsuccessful because they lacked both frequency resolution and sensitivity. In this paper we show how the use of a technique based upon acoustic intensimetry using a two channel Fast Fourier Transform analyser overcomes the problems associated with the earlier work.

2.THE MEASUREMENT OF TRANSMISSION LOSS

Three measurement techniques have been developed for the measurement of sound transmission loss through walls. These are sound pressure measurements which need two reverberant rooms, impulse techniques which use a short duration signal for excitation and avoid the need for reverberant chambers all together, and the sound intensity technique which requires one reverberant room to provide a diffuse exciting sound field.

In the present work the sound intensity technique was selected for the measurement of the sound transmission loss of slit shaped cracks in a rigid wall. The use of sound intensity measurement techniques for the measurement of transmission loss of partitions has been developed since the early 1980's. For example, Crocker, Raju and Forssen[5] used it to measure the sound transmission loss of panels, Minten, Cops and Wijnants[6] have reported work on the application of sound intensity to the measurement of the sound transmission of walls and Mey and Guy[7] have used it for measurement of transmission characteristics of panels.

The technique has a number of advantages over the other methods when dealing with sound transmission by very small apertures. If reverberant field excitation is employed in the experiment then only two parameters, sound pressure level in the source room and sound intensity level on the receiving side, need to be measured. Because it provides a direct measurement of sound energy propagated, there is no need to use a reverberant chamber on the receiving side. This greatly simplifies the measurement procedure and makes it possible to measure the transmission loss of small holes and narrow slits. Further, the use of an intensity measuring system based upon a two channel FFT Analyser enables the frequency characteristics of the transmission loss to be determined with a high degree of resolution. This is essential of the resonance effects predicted by the theory of Gomperts and Kihlman are to be detected.

3. THE EXPERIMENT

The slits, which were all 500mm in length, were made using two parallel steel bars. The width of each slit was set using end spacers of known thickness and different depths of slit were obtained by employing different sizes of steel bars. Fifteen different sizes of slit were employed for these measurements.

A diffuse sound field on the source side was employed in order to simplify measurement of the sound-energy transmission . The diffusion of sound was obtained by having the walls of an enclosure containing the sound source non parallel and highly and uniformly reflective and by the use of two high-power loudspeakers and 20kHz broad-band white noise as the signal source which reduced the possibility of exciting strong individual enclosure resonances or standing waves.

For good insulation the walls of the reverberant enclosure, which had an internal volume of $3.3m^3$, were of cavity construction with mineral wool between two layers of dense chipboard. The top surface of the enclosure consisted of layers of dense 18mm thick chipboard.

The sound pressure level in the source room was measured using a standard Bruel and Kjær a quarter inch condenser microphone (B&K 4135) mounted on the end of a pipe which passed through three holes made in two walls of the enclosure. In order to provide a good acoustic seal, 'O' rings were used in the aperture through which the pipe was inserted. It was thus possible by sliding the pipe along through the different apertures to measure the sound pressure level at a number of different positions in the enclosure. The spectra of microphone were obtained using one channel of a B&K Type 2032 Dual Channel Analyser and then transferred by a standard GPIB-IEEE card to a microcomputer for recording and analysis.

The measured sound pressure level SPL_i in the source room was averaged 500 times by the analyser at each position before the data was recorded in order to eliminate random error and improve the signal-noise-ratio. At least nine positions were taken for sound pressure level measurement in the source room to obtain a uniform averaged sound pressure level. The recorded data indicated that there was very little difference between the measured sound pressure levels at the measurement points over the entire frequency range. This demonstrates that the sound field created in the source enclosure was very diffuse.

A Bruel and Kjær sound intensity probe (B&K 3520) was employed with the Analyser to measure the sound intensity radiated from the aperture. The measurement of sound intensity was carried out in a room in which absorptive material was applied to decrease the reverberant field level. The data were averaged 350 times at each point by the analyser before the record was transmitted to the computer. Eight measurement positions were employed along the slit in order to obtain an averaged sound intensity level.

4.THE MEASURED TRANSMISSION LOSS OF SLIT SHAPED APERTURES

The acoustical power, W_i, incident onto an aperture is equal to the product of incident intensity I_i and the area of the aperture i.e.

$$W_i = I_i wl \tag{3}$$

The acoustical power, W_0, radiated from the aperture will be

$$W_0 = I_i wl\tau_c \tag{4}$$

where τ_c is the transmission coefficient of the aperture.

Assuming hemi-cylindrical radiation from the slit, the intensity at a point a distance r is

$$I_r = \frac{\text{power}}{\text{area}} = \frac{W_0}{\pi rl} = \frac{I_i w\tau_c}{\pi r} \tag{5}$$

Using the relationship between sound pressure level, SPL_i, and sound intensity level, in a reverberant enclosure yields the expression

$$TL_s = -10\log\tau_s = SPL_i - IL_r - 6 + 10\log(\frac{w}{\pi r}) \tag{6}$$

Where IL_r is the measured intensity level at a point distance r from the aperture on the receiving side .

Figures (2-3) show some examples of experimental results for slit shaped apertures compared with the predicted values of transmission loss obtained using the Gomperts-Kihlman expression. Three depths (50.8mm, 76.2mm and 152.4mm) and five widths(1mm, 1.5mm 3mm, 6mm and 10mm) of slit were employed giving fifteen different aperture configurations. The measured data indicated that good agreement exists between the experimental results and the approximate theory for the wide and short slits.

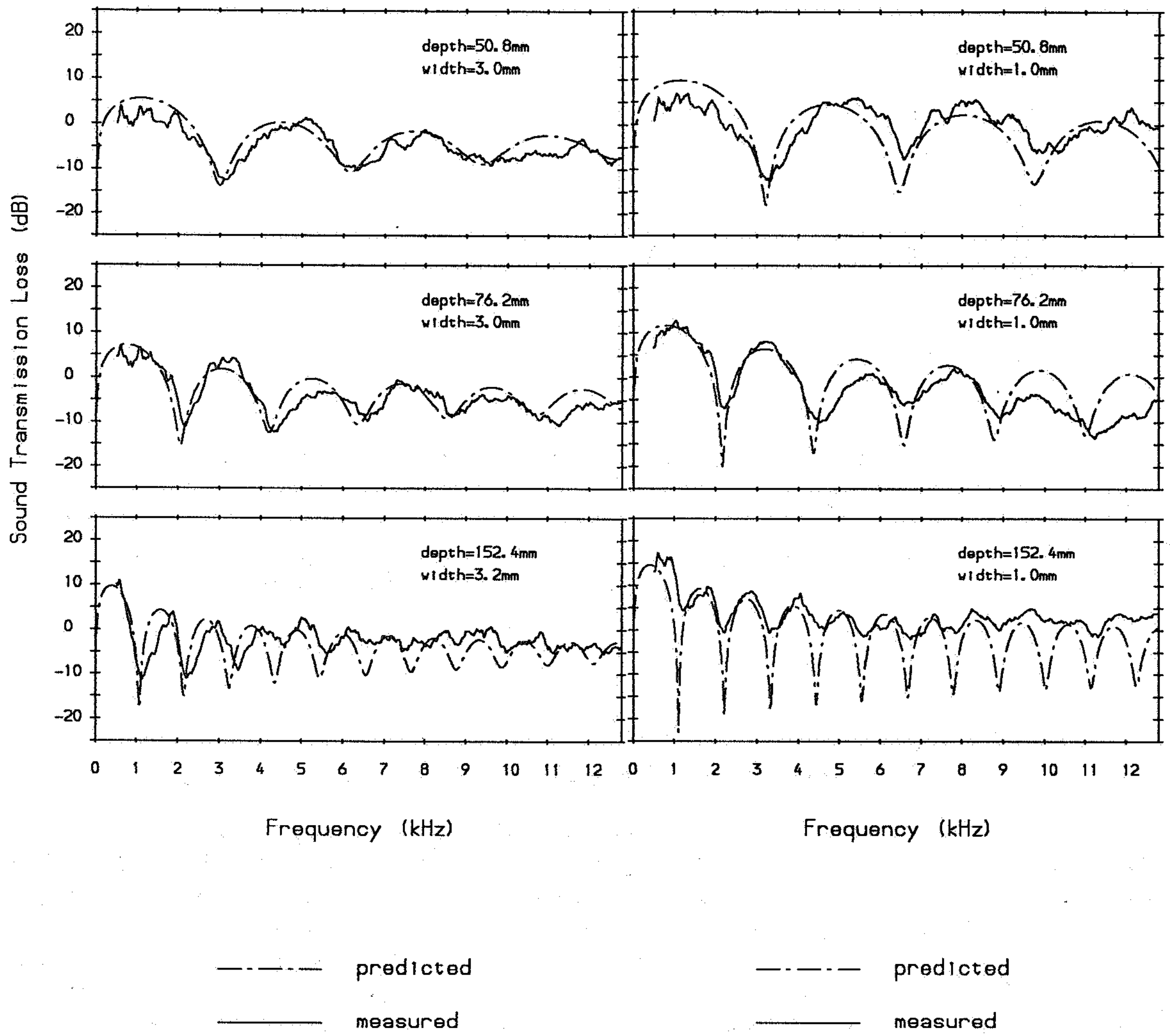

Fig.2 Transmission Loss of 3mm wide cracks.

Fig.3 Transmission Loss of 1mm wide cracks.

Two systematic trends were found from an examination of the measured transmission loss characteristics. The first is that, for a given depth, the difference between measured and theoretical values of transmission loss at the fundamental resonant frequencies become greater as the width of the aperture decreases and for a given width, the difference increases as the depth of the slit increases. This difference is plotted against the ratio of slit depth-to-width in Figure 4. It can be seen that the difference between the measured transmission loss and the theoretical value is a function of the ratio of slit depth to width.

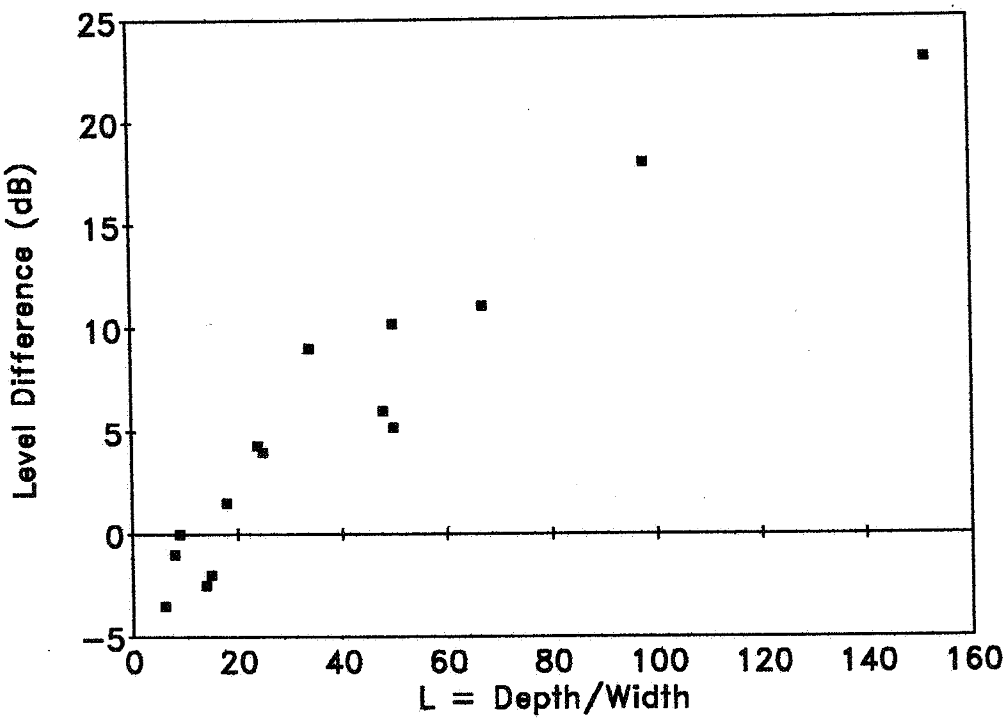

Fig.4 Difference between predicted and measured minimum transmission loss.

A possible explanation for this phenomenon is the effect of viscosity which was ignored in the derivation of Eq.(2). The theoretical transmission curves related to ideal sound propagation in the aperture without any damping. In fact, energy loss must take place in the propagation of sound waves. This loss is due to viscous effects which tend to degrade the sound energy into heat. The experimental data indicate the attenuation is a function of the ratio of depth-to-width of the aperture.

Another phenomenon which demonstrates the effects of viscosity and friction could be observed from examination of the transmission loss characteristics. The measured magnitude of transmission loss differs systematically from the theoretical predictions. The deeper the depth, the greater the difference. This again demonstrates sound energy loss due to viscous effects in a long narrow opening.

5.DETERMINATION OF CRACK DIMENSIONS

It has been shown above that the measured transmission loss characteristics of simple cracks are in good agreement with the values predicted by application of the Gomperts-Kihlman equation. In order to size air leakage cracks, however, it is necessary to be able to extract the relevant dimensions from measured transmission loss characteristics.

The measurement of crack length is relatively trivial. This parameter can be established reasonably accurately from a nearfield scan of the wall. In order to determine the depth, however, it is necessary to make use of the fact that the transmission loss characteristics are periodic with a period determined approximately by the time taken by sound to travel a distance equal to twice the crack depth. This time can be determined by performing a Fast Fourier Transform on the transmission loss characteristics.

The remaining parameter is the crack width. The most obvious approach to determining the magnitude of this parameter is by means of a simple nearfield scan. However, this method does not have sufficient resolution to determine the widths of the very narrow cracks of interest here. An alternative method has been developed based upon the fact that it is necessary to know w before the transmission loss can be calculated from the measured data.

From Figure (1) it can be seen that the transmission loss curve for a 0.3mm wide slit is "the same" as that of the 1mm wide slit but the maximum values are 10*log(1/0.3) dB higher.

Having found l suppose the transmission loss is predicted assuming w = 1mm and suppose the true value of w is actually 0.3mm then the predicted transmission loss curve will be shifted down relative to its true position by this value.

If the value w=1mm is also used to calculate the measured transmission loss when the true value is actually 0.3mm, then the experimentally determined transmission loss curve will be shifted up by 10*log(1/0.3)dB relative to its correct position .

If the two curves were plotted then the experimental curve would lie 2*log(1/0.3) dB above the theoretical curve.

Expressed more generally, if the predicted and measured transmission loss characteristics are calculated using a value of 1mm for the value of the width then the experimental curve would lie 2*10log(1/w) dB above the theoretical curve where w is the true width measured in mm. Therefore, if the difference between the curves is determined and substituted in the above expression it is possible to obtain a value for w.

If this value of w is then used to determine the measured and predicted transmission loss characteristics they should be very similar apart from the region of resonance (transmission loss minima) where viscosity effects become important. However, a relationship has been found between l/w and D,the difference between the predicted minimum and the experimental minimum. Therefore, as l is known and D can be determined it is possible to obtain confirmation of the value of w determined above.

6. CONCLUSIONS

The sound intensity technique and reverberant sound excitation have been used for the measurement of sound transmission loss through narrow slits in rigid walls. The experimental results obtained in this study are in reasonable agreement with the Gomperts-Kihlman predictions. As predicted by the theory, the dimensions of the apertures determine the magnitudes and resonant frequencies of the sound transmission loss curves. It should thus be possible in principle to size air leakage cracks using the technique described in this paper.

Sound energy losses which were attributed to viscosity were observed in the course of this investigation. These effects were observed with narrow slits. The effect increased as the area of the apertures decreased and the depth of the opening increased. The experimental results indicated that the effect is of such magnitude that it cannot be ignored when deriving expressions for transmission loss coefficient for very small apertures. The curve of Figures 4 suggest the possibility of using the experimental data to determine an approximate relationship between the effects of viscosity and the dimensions of apertures which could be incorporated into any practical technique employed to size air leakage cracks based on acoustic intensimetry.

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