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THE TRANSMISSION LOSS OF SIMPLE AND COMPLEX APERTURES IN RIGID WALLS

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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 construction cracks. Work carried out by Baker, Sharples and Ward[1] has demonstrated a quadratic relationship between the pressure drop, p, across the crack and the air flow rate Q as follows:

$$p = A\,Q + B\,Q^2 \qquad (1)$$

Where A and B in Eq.(1) are constants which are functions of the crack dimensions width, w, depth, d, and length, l. If, therefore, the width, depth and length of a leakage crack can be determined then this information can be applied to the relationship of Baker et al to give an estimate of crack leakage characteristics.

The sound transmission loss of slits and holes has been studied theoretically by a number of workers. The following expression for the sound transmission coefficient of a slit shaped aperture has been given by Gomperts[2] :

$$\tau_a = \frac{mK\cos^2(Ke)}{2n^2\left(\dfrac{\sin^2 K(L+2e)}{\cos^2(Ke)} + \dfrac{K^2}{2n^2}\,[1+\cos K(L+2e)\cos KL]\right)} \qquad (2)$$

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.

Figure (1) shows the predicted variation of transmission loss with crack depth and width for a range of different crack sizes.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.

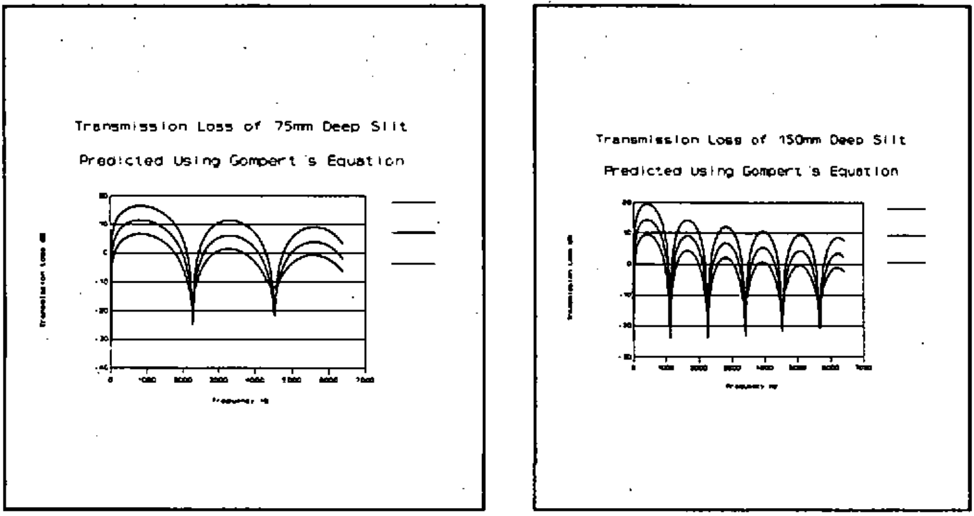

Figure 1 Predicted Transmission Loss

The basis of the proposed technique for acoustic crack sizing was to generate a high noise level in a room and to perform a nearfield scan of the outside wall using a sound intensity probe. It has been shown that this technique is capable of allowing the acoustic power radiated by various elements of a composite wall to be separately measured. The acoustic energy radiated by a crack will be much greater than that radiated by the surrounding wall. The nearfield scan would thus both locate a leakage crack and determine the acoustic power that it radiates to the outside. From the measured internal sound pressure level it is possible to determine the sound intensity incident on the crack. The transmission loss of the crack can be determined as a function of frequency by subtracting the transmitted intensity level from the incident intensity level.

2. VALIDATION OF THEORETICAL MODELS

The first stage of this work involved a series of experiments to test the validity of the existing theoretical models for predicting the transmission loss of small apertures.

A number of fabricated cracks of known geometry and air flow performance were available from the earlier pressurisation work of

Baker et al. These calibrated cracks formed the test pieces for the experimental measurements on simple cracks.

The use of sound intensity measurement techniques have a number of advantages over other methods when dealing with sound transmission by very small apertures. If reverberant field excitation is employed in the experiment then only two acoustic parameters, sound pressure level in the source room and sound intensity level on the receiving side, need to be measured. Because intensimetry 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 even though sound energy is also being radiated by the surrounding structure. 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 various theories are to be detected.

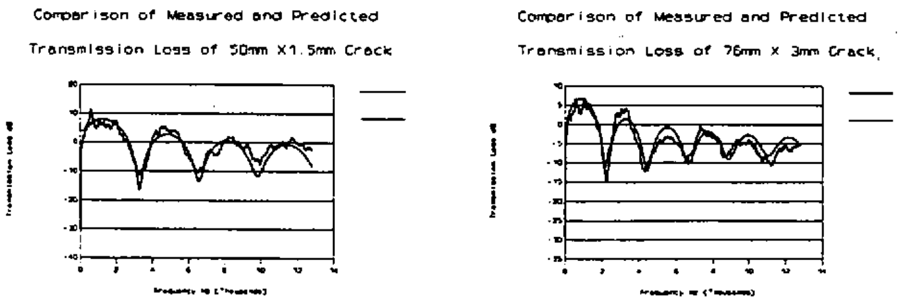

Figure 2 Comparison of Predicted and Measured Transmission Loss Characteristics

Figure 2 shows some examples of experimental results for slit shaped apertures compared with the predicted values of transmission loss obtained using the Gomperts-Kihlman expression.

The measured data indicated that good agreement exists between the experimental results and the theory for the wide and short slits but the agreement was less good for the long and narrow slits. 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 3. 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.

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.

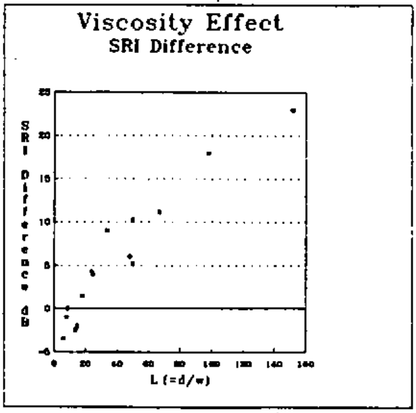

Figure 3 The Effect of Viscosity

3. CRACK LOCATION

It was found relatively easy to locate cracks using either a nearfield intensity or sound pressure scan. The null search method, in which microphones are employed in the "side by side" configuration with their diaphragms parallel to the surface containing the crack, proved to be particularly efficient at locating the position of an aperture. (See Fig.4). This technique could be used to determine the length of a crack to a high degree of accuracy (of the order of 2mm). Unfortunately, as can be seen from an examination of the data obtained from transverse scans, the resolution is too poor for the crack width to be determined in this way. A number of other techniques were investigated including a very near field sound pressure scan using a probe microphone but it proved impossible to achieve the required resolution.

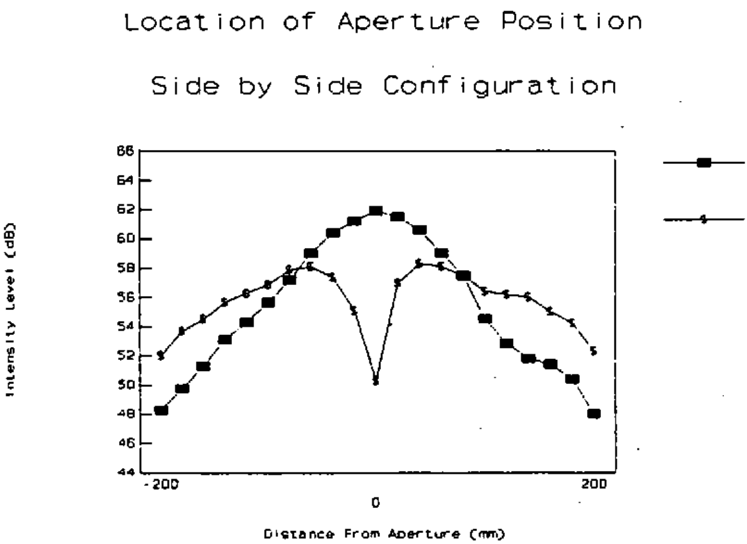

Figure 4 Crack Location Using Nearfield Scan

4. 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 to a high degree of accuracy from a nearfield intensity scan of the wall.

In order to determine the depth 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 in principle by performing a Fourier Transform on the transmission loss characteristics. However,this approach was found to be unsuitable for practical use. The reason is that the time resolution is the inverse of the bandwidth of the transmission loss curve. For example, if the bandwidth is 10,000 Hz then the time resolution is 0.1 msec. If this resolution is expressed in terms of distance then, as the velocity of sound is approximately 340 m/s, the spatial resolution is 34 mm. A bandwidth of 10,000 Hz is about the maximum that can be used for intensity work at the present time and so the spatial resolution that is achievable using this method is not adequate for the sizes of cracks likely to be encountered in building construction.

Working in the frequency domain, however, it was possible to determine the resonant frequencies to a high degree of accuracy. A computer program was written to enable the experimenter to move a cursor along a screen display of the measured transmission loss characteristics and to read off the screen the values of the resonant frequencies. In this way the depth of the crack can be determined to within 5%.

The remaining parameter that has to be determined is the crack width. At first glance the most obvious approach to determining the magnitude of this parameter might seem to be by means of a simple nearfield intensity scan. However, as discussed above, this method was found not to 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 the width before the transmission loss can be calculated from the measured data.

The procedure is to assume a value of width, w_a, and to use this with the measured internal sound pressure level and external intensity level to calculate a first approximation to the transmission loss characteristics. The value of the crack depth can then be determined as described above. The transmission loss is then predicted using Gompert's equation with the measured depth and the same assumed value of width. If the assumed value of width employed is correct then the measured and predicted transmission loss characteristics will be identical (apart from around the resonance frequencies). If, however, the assumed value of width is incorrect (as is likely to be the case) then the experimentally determined transmission loss curve will be shifted up by $10*\log(w_a/w)$ dB relative to its correct position and the theoretical curve would be displaced down by $10*\log(w_a/w)$ dB relative to its correct position. If the two curves were plotted then the experimental curve would thus lie $20*\log(w_a/w)$ dB above the theoretical curve. 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 will 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.

5. COMPLEX APERTURES

The work of Baker, Sharples and Ward included measurements of the flow characteristics of complex crack shapes ('L' shaped and 'U' shaped). Since leakage paths of these and other complex shapes will be encountered in building construction it was necessary to to investigate the sound transmission properties of complex cracks.

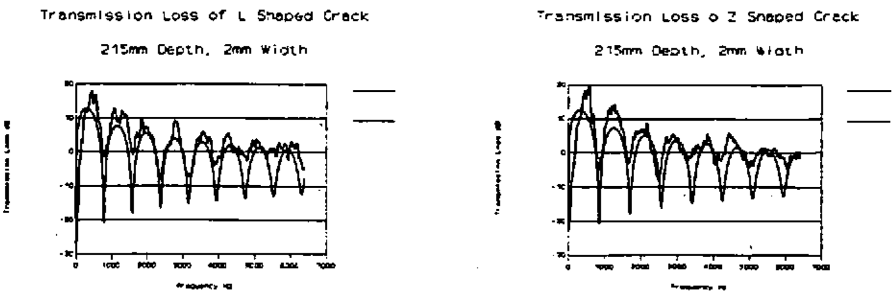

Figure 5 Transmission Loss of Complex Cracks

Figure 5 shows some examples of the measured transmision loss characteristics of L and Z shaped cracks. Also shown is the predicted transmission loss characteristics of a simple crack of equivalent length. It can be seen that the main resonances are determined by the total length of the crack. The shape of the curves, however, differ from those of simple cracks. The peak transmission loss values are higher and the curves are not as smooth. The latter effect is probably due to internal reflection at the bends.

Attempts were made to extract information regarding the dimensions of the components of the cracks by means of applying the Fast Fourier Transform to the measured transmission loss characteristics. In principle this could yield information regarding the time travelled between the bends by sound within the crack. However, the limited bandwidth that could be obtained prevented this technique from being exploited although there were some indications that useful information could be obtained with a larger bandwidth.

It was found that the shape of the transmission loss curve of a complex crack does not depend upon the direction in which the net flow of acoustic energy takes place. This has been verified by measurements on 'L' and 'Z' shaped tubes. Baker et al, however found that the flow characteristics of complex cracks depended on the direction of the air flow.

6. CONCLUSIONS

The technique of acoustic intensimetry has been applied to the measurement of the acoustic transmission loss small cracks similar to those resulting in air leakage from buildings. The measuring system was based upon a two channel Fast Fourier Transform analyser which had the necessary resolution to detect those minima in the transmission loss characteristics of narrow cracks determined by acoustic resonances within the cracks. Algorithms were developed which enabled simple "straight through" cracks to be accurately sized.

The measured transmission loss characteristics of complex cracks were found to differ markedly from those of simple cracks of equivalent length. A method was suggested whereby the technique of acoustic intensimetry could be used to size such complex cracks.

7. REFERENCES

1. P.B. Baker, S. Sharples and I.C. Ward 1987 Building and Environment 22 293-304. Airflow through cracks.
2. M. C. Gomperts 1964 Acustica 14(1), 1-16. The 'sound insulation' of circular and slit-shaped apertures.