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SOUND INTENSITY MEASUREMENT OF TRANSMISSION LOSS

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1. Introduction

The standard reverberation room suite measurement of airborne transmission loss (TL) of a partition, embodied in ISO Standard 140, is based upon the following model. The sound intensity incident upon the partition is assumed to be related to the restricted spatial averaged mean square pressure in the source room by the diffuse field expression $I_i = \langle\overline{p_1^2}\rangle/4\rho c$. The transmitted power is assumed to be related to the restricted averaged mean square pressure in the receiving room by $W_t = \langle\overline{p_2^2}\rangle a/4\rho c$, where a is the receiving room absorption which is normally derived from reverberation time measurements. These assumptions lead to the relationships

$$\langle\overline{p_2^2}\rangle/\langle\overline{p_1^2}\rangle = \tau S/a \qquad (1)$$

and

$$TL = \overline{L_1} - \overline{L_2} + 10 \log_{10}(S/a) \quad dB, \qquad (2)$$

where S is the partition surface area.

There are many practical situations to which this model and resulting equations do not apply; they include the following:

(1) Sound transmission between spaces in which diffuse fields do not exist, for reasons of small volume, narrow frequency band excitation, very non-uniform distribution of absorption, or because the actual incident field is essentially non-diffuse;

(2) Systems in which sound energy is transmitted from a source region by flanking paths in addition to the direct path through the partition;

(3) Sound transmission through a partition in the presence of excessive background noise created by uncontrollable sources unconnected with the primary source under consideration.

Even where the test conditions are fairly good, there remain sources of uncertainty in the determination of TL associated with the experimental determination of the space averaged mean square pressures and the receiving room absorption. In addition, the standard method does not indicate the relative contributions to total sound transmission of the various regions of non-uniform partitions. This paper presents the results of some experiments which have been made in a small scale transmission suite as a preliminary investigation into the possibility of using intensity measurements to overcome some of the difficulties outlined above.

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2. Measurement Principle

The total acoustic power transmitted through a partition can be determined by measuring the distribution of intensity normal to the surface over the partition, and then integrating, or summing, the intensity field. The procedure has been reported by Crocker et al. [1] and McGary [2]. There remains the problem of estimating the incident intensity, since the nett intensities on the two sides of a lossless partition are necessarily equal. If the incident field is generated in a large reverberant space, and has a reasonably large frequency bandwidth, it may be assumed that the incident field is diffuse, and that the incident intensity level is related to the room average sound pressure level (evaluated at positions sufficiently removed from the walls and the source(s) by

$$L_I = \overline{L_p} - 6 \quad dB.$$

The accuracy of this estimate has been investigated by Crocker et al. [1] by removal of the partition and measurement of the intensity directed through the aperture so presented. In the case cited, the receiving room was formed by a large laboratory space which contained the source room within it, so that the receiving room sound energy density was much less than that in the source room. This procedure would clearly not be valid if the partition had occupied a large proportion of a wall dividing two highly reverberant spaces since the nett intensity in an ideally diffuse field is zero.

3. Experimental Investigations

For reasons of ease of making intensity surveys and changes of partition, the experiments were performed in a small transmission suite used for teaching purposes. The volume of source and receiving rooms were approximately 14 m^3 each, and the aperture in the dividing wall measured 640 mm x 640 mm. The average room reverberation times were 1.2 seconds and the Schroeder large room frequency, $f = 2000\ (T/V)^{\frac{1}{2}}$, is approximately 580 Hz. Numerous student experiments had suggested that the results of 'standard' TL measurements in the suite were unreliable below about 400 Hz because low frequency values considerably in excess of the mass law were consistently recorded.

3.1 Comparison of standard and intensity-based determinations of TL

Standard, albeit small scale, TL measurements were made on a 5 mm thick plywood panel (A) and a 13 mm thick panel of hardboard/honeycomb sandwich construction (B). The critical frequencies were approximately 3600 Hz and 995 Hz respectively. Transmitted intensity measurements were made in octave bands with the I.S.V.R. analogue intensity meter at 81 points distributed uniformly over the panels; the measurement distance was 40 mm. Microphone reversal was occasionally employed to verify the accuracy of the intensity measurements. The 'incident' intensities were estimated by removing the panel and repeating the survey at the plane previously occupied by the panels. These intensities were found not to be measurably altered by the introduction of a large quantity of sound absorbent material into the receiving room. The measured incident intensities were consistent with the average sound pressure levels in the same room with the panel in place: this was not unexpected because the panel area (as an 'open window') was small compared with the total absorption of the source room. TL's were measured in three octave bands only because of the large number of measurement points employed: subsequent experience showed that this number could safely be greatly reduced in routine intensity surveys. The results were as follows:

	Transmission Loss (dB)		
Frequency (Hz)	250	1k	4k
Panel A:			
Standard	16	22	27
Intensity	15	21	24
Panel B:			
Standard	18	25	31
Intensity	18	24	32

The uncertainty associated with these values is difficult to estimate but the maximum likely errors are about ±1·5 dB. The most surprising feature of these results is the agreement between the values at 250 Hz, a frequency in the range where the small size of the rooms and the panel were expected to produce unreliable estimates.

3.2 Transmitted intensity distributions

The distribution of radiated intensity over rectangular panels vibrating in their natural modes has been thoroughly investigated theoretically [3] and confirmed experimentally [4]. It is known that, at frequencies below the critical frequency, panel modes radiate from their corners and edges, and at frequencies above the critical frequency they radiate from the whole surface. Theories of sound transmission explain mass controlled transmission either by attributing radiation primarily to acoustically fast waves forced in the panel by the incident field, or by assuming that natural modes which radiate inefficiently at their natural frequencies, respond and radiate at frequencies well above their natural frequencies, i.e. in a mass controlled manner. Both models would suggest that radiation occurs fairly uniformly over an acoustically excited panel at all frequencies, although radiation at supercritical frequencies would be strongly directional. The possibility of actually measuring the radiated intensity distribution was therefore very intriguing.

There is not room to present the results in detail in this short paper, but in summary it can be stated that, at frequencies well below the critical frequency there was observed to exist a central region of low, and even negative, intensity; at frequencies in the vicinity of the critical frequency the edges of the panels appeared to radiate somewhat more strongly than the central regions; and at frequencies above critical the central region tended to radiate more strongly than the edges. Whether these characteristics are specific to the test arrangement and types of panel is not known and therefore no attempt is made to explain them theoretically.

3.3 Incident intensity measurements

The angular distribution of octave band intensity at the aperture plane was also measured. It was found, somewhat unexpectedly, that the high frequency distribution is no nearer diffuse than the low frequency distribution. However, the 'cut-off' seen at between 60° and 80° does suggest that the explanation of the difference between 'diffuse' and 'field' transmission losses may rightly have been attributed to a deficiency of waves incident at near grazing angles.

4. Discrimination against Flanking Transmission

The intensity transmitted by a panel, together with the local surface L_p was measured with both room doors closed, and then with both doors open. Some results are shown in the table below.

Intensity and Sound Pressure Levels (dB)

O.B. centre frequency (Hz)		250			1k			4k		
Measurement point on panel		a	b	c	a	b	c	a	b	c
doors closed	L_I	66.5	73	69.5	63	63	62	53	53	51
	L_p	75	76	73	72	74	71	58	58	57
doors open	L_I	66.5	73	72	64	63	63	52	*	54
	L_p	78	78	78	81	81	81	69	69	69

*value highly uncertain.

It is seen that intensity levels can in general be measured fairly accurately even where the value of L_p-L_I is as high as 18 dB: however this demands a very high quality intensity measurement system. Of more practical importance is the fact that the sound power transmitted through the panel could be reasonably accurately determined even where the sound power radiated into the room through the much larger open door aperture was measured to exceed it by a factor of as much as 80 (19 dB). Hence it would seem that radiation from surfaces other than that on which intensity is measured should present no problem in practice: in fact the main problem lies in the relatively poor signal to noise ratios experienced with high transmission loss partitions.

References

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