SOURCE DIRECTIVITY AND SOUND INTERFERENCE PATTERNS IN THE PREDICTION OF NOISE LEVELS IN FACTORY SPACES.

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1. INTRODUCTION

1.1 A simple model for the prediction of sound distribution in factory spaces has been developed to predict the intensity (I_T) at a receiver point by an equation of the form:

$$I_T = \sum_{m=1}^{M} \left(\frac{I_m}{r_m^p} \right) + C$$

where M is the total number of sound sources (machines), I_m is the average sound intensity due to source m at a distance of one metre, r_m is the distance from source m to the receiver point. The index p is chosen to provide the best fit to the sound propagation (SP) curve, see figure 1. The space is divided into three contiguous areas and an SP curve generated which consists of three straight lines: one for the nearfield, one for intermediate distances and one for the "far" field (see figure 1). The values of C are chosen to ensure continuity between the various stages of the SP curve.

1.2 The validation of this model (1) in an empty factory space indicated that while farfield predictions were excellent significant discrepancies could exist between predicted and measured sound levels in the nearfield. These differences often constituted the major errors and could be up to 4 or 5 dB.

2. SOURCE DIRECTIVITY

2.1 To reduce, or eliminate, these errors it was decided to investigate what additional parameters needed to be included in the model to improve prediction performance. The first, and most obvious, to be considered was the effects of source directivity. The sound power of the source (Bruel and Kjaer type 4224) included in the model was obtained from measurements of sound pressure level made at six prescribed points around the source (see figure 2).

To retain the essential simplicity of the original procedure it was decided that directivity would be estimated from these six measurements alone. The directivity index measured in this coarse manner gave better results when included in the model than detailed measurements made under anechoic conditions.

2.2 Measurements made 1.5 m above the floor and 1.0 m from the speaker in the reverberant conditions of a factory space gave the directivity pattern shown in figure 3.

2.3 Figure 4(a) shows the differences between predicted and measured sound levels at 1.5 m above the floor in the nearfield of the source. When source directivity (Q) is included in the model the differences are as shown in figure 4(b). It can be seen that there is significant improvement in the agreement but some discrepancies remain.

2.4 It should be noted that source directivity is likely to be a significant factor only in the nearfield and therefore including it into the model is expected to be important for nearfield prediction only. For factory spaces where measurements were made at as many as one hundred points uniformly distributed throughout the space the overall mean error remains virtually unchanged.

3. INTERFERENCE EFFECTS

3.1 It has been known for some time that interference can take place between direct and reflected acoustic waves. In such situations the total sound field at a point may theoretically vary from 0 to 6 dB above that due to the direct field alone. Several workers have found evidence of acoustical interference patterns in real situations (see, for example, 2).

3.2 In a factory with a flat concrete floor one would expect to find acoustical interference patterns in those areas where there is an unobstructed view of a (small) source. We have tested this hypothesis in the laboratory and one large factory. The Bruel and Kjaer 4224 sound source radiated wide band noise and an Ono Sokki CF-350 portable dual channel FFT analyser gave a narrow band analysis of the sound field at specific points in the nearfield. The microphone was placed at heights of 0.6, 0.7 and 0.95 m at 1, 2 and 3 m from the source.

3.3 Analysis showed that the interference pattern was primarily determined by the combination of the direct wave and the first reflection from the floor. Waves reflected from the ceiling or walls have a sufficiently reduced amplitude when arriving at the given measurement positions to not contribute significantly to the frequency at which maxima and minima occur (after all that is what is meant by nearfield).

3.4 Figure 5 shows the measured and predicted SPLs as a function of frequency for the microphone at a height of 0.6 m and a distance of 2 m from the source. The agreement is good (both at this position and at the others specified above) if the acoustic source on the speaker is taken to be 5 cm below the geometric centre. Probably because the floors present in the experiments were smooth concrete it was possible to assume 100% reflection of the sound rays and zero phase change on reflection without significant loss of accuracy, though these assumptions do lead to some errors at the higher frequencies.

3.5 The shape of the interference pattern will be the same for all points in the nearfield: constructive interference at the lowest frequencies followed by a minimum whose frequency is determined largely by source-receiver positions, followed by a series of interference peaks and troughs (see figure 5). However, if the waves reflected from walls and ceiling are included in the total field they impose a scatter (sometimes of several dB) on the interference pattern obtained from summing the direct and first reflection from the floor. Such fine detail is not included in figure 5 below as the detailed response of the loudspeaker has a more dramatic effect.

3.6 Inclusion of interference patterns in the model is only justified in those rare circumstances where there is an unobstructed view of the source. Such an inclusion refines the reflection effects and predicts an increase in measured levels at points where constructive interference occurs, and so may be important when measurements are made in, say, octave bands.

4. FINAL COMMENTS

4.1 Further validation of the new version of the model incorporating source directivity as determined by measurement on the shop floor has been carried out using data collected in three very different empty spaces. 97.3% of all the predicted values were within 2 dB of the measured sound pressure levels.

4.2 The next stage of the work will be to extend the model to fitted factory spaces and to establish a data base of sound propagation curves to enable predictions to be made in new factories.

REFERENCES

1. C.J. Jones. "A computer model for the prediction of noise levels in factories". Progress report for transfer from MPhil to PhD, South Bank Polytechnic, London, June 1989.

2. J. Roberts, A. Kacelnik and M. Hunter. "Sound Interference Patterns in Animal Acoustic Communication". IoEE Tech Memo 66, South Bank Polytechnic, London, May 1979.

Figure 1. Sound propagation curve for a typical empty factory space.

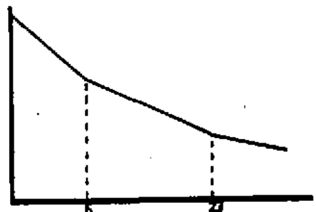
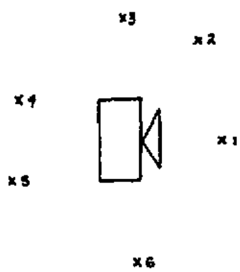
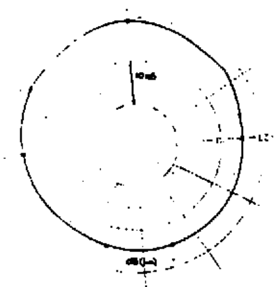


Figure 2. Plan view of sound source showing the six measurement positions.



All measurement positions 1 m from edge of source at a height of 1.5 m.

Figure 3. Directivity pattern of the B&K sound source.



Based on measurements made at the six prescribed points when the source was located in an empty factory space.

Figure 4. Errors between predicted and measured SPLs.

Error (dB) = predicted - measured

3.4	2.4	-2.0 + source
2.5	2.0	1.9
1.7	2.0	1.9

4 m square grid.

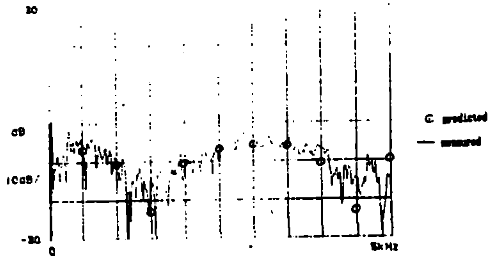
(a) Directivity NOT included in the model.

1.9	0.2	-0.7 + source
1.0	0.4	0.4
0.1	0.5	0.4

4 m square grid.

(b) Directivity included in the model.

Figure 5. Measured and predicted sound interference patterns.



microphone position 2 m from source 0.6 m above floor.

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THE IN-SITU SOUND INSULATION PROPERTIES OF CLADDING SYSTEMS EMPLOYED IN FACTORY BUILDINGS

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1. INTRODUCTION

It has been established by many researchers that the sound field in a factory building having a disproportionate shape (i.e. having one dimension considerably larger than the others) is not classically reverberant [1].

Unlike the case of the proportionate room where, within a certain distance from the source, a reverberant field level is established which does not change with increased distance from the source, the noise level in a disproportionate room exhibits a steady decrease with increasing distance from the source. Figure 1 shows the difference in the two sound fields (after Hodgson [1]).

The transmission loss of factory cladding panels, however, is usually measured in transmission suites where the exciting sound field is classically reverberant. In this situation the transmission characteristics of the panel are determined by forced transmission below the critical frequency and by resonant transmission above the critical frequency. Forced transmission results from the spatial matching of stationary waves of the source room sound field with mode shapes of the test panel [2]. These mode shapes are thus forced to vibrate at a frequency which is higher than their natural frequency. Above the critical frequency resonant transmission takes place because of a flow of energy between resonant modes in the source room and the panel.

Since the exciting sound field in a disproportionate room differs from that in a proportionate reverberant chamber. The mechanism of sound transmission by a panel employed as cladding for a disproportionate factory will not be the same as in the conventional transmission suite. It is possible, therefore, that transmission loss data obtained by conventional methods is not applicable to the disproportionate factory situation. In this paper the results of a series of experiments are described in which the transmission loss of a panel is measured when subjected to both a classically reverberant sound field and the sound field in a disproportionate room.

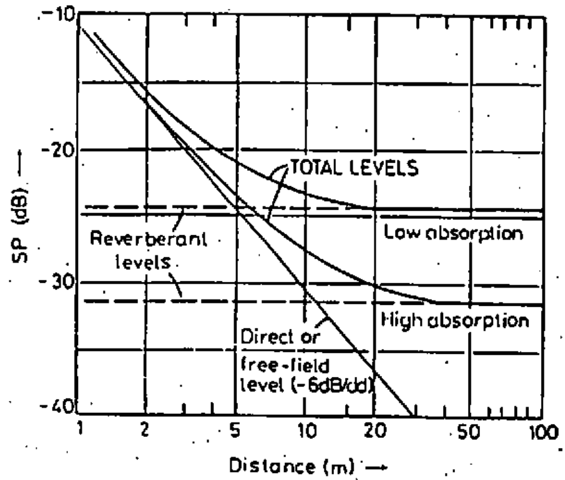

Figure 1a Direct, reverberant and total field SPL predicted using the Sabine theory for a large empty enclosure with low and high absorption

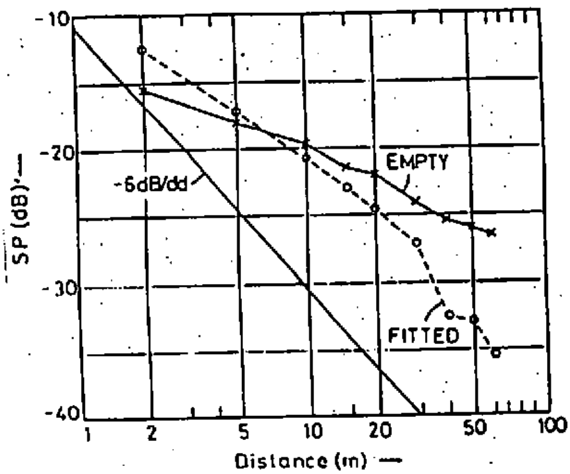

Figure 1b dB(A) SPL measured in a factory when empty and fitted

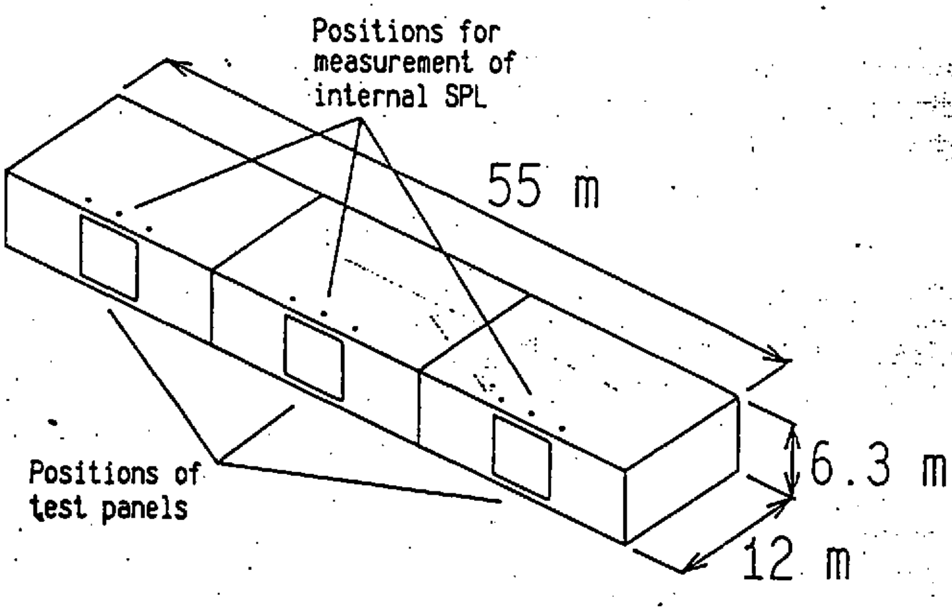

Figure 2 The model factory

2. THE EXPERIMENTAL APPROACH

There are two problems which have to be solved before a comparison can be made of the acoustic insulation properties of a panel subject to different sound fields. The first is that it is not practicable to measure the transmission loss of a full size panel under both truly reverberant excitation and factory field excitation whilst ensuring that boundary conditions remain the same. The second is that it is necessary to be able to measure the acoustic power radiated by the test panel and to be confident that the measurements are not affected by sound radiation from neighbouring panels when the test panel is part of a factory wall.

The solution to the first problem is to make measurements on scale models where a test panel and its mounting system can be easily moved between two different enclosure models. The solution to the second problem is to use the technique of near field intensity to measure the acoustic power transmitted by a specific area of cladding. Crocker, Raju and Forssen [3] have shown this method is capable of determining the transmission of sound by individual elements in a composite partition.

3. THE SCALE MODEL EXPERIMENT

3.1 The Models

Two 1:10 scale models were constructed for measurement of the transmission loss of a single panel. The first was of a proportionate reverberant room of dimensions 6m x 6.5m x 7m full scale and the second was a disproportionate room simulating a factory space of full size dimensions 55m x 12m x 6.3m (see Figure 2). The floor and ceiling of the factory model were treated with an array of diffusing objects. Large objects were used on the floor (simulating machines) and small objects were used for the ceiling (simulating light fittings, roof lights, air handling plant etc.).

3.2 Measured Internal Sound Field of the Factory Model

A characteristic of the sound field in disproportionate rooms is that the sound level due to the operation of a single source away from the immediate location of that source is not independent of distance but falls by approximately 3-4 dB per doubling of distance. Figure 3 shows the measured attenuation versus distance curve of the model factory along the centre line, with the noise source at one end. The distance attenuation characteristics are such that the sound field in the model approximates that obtained from measurements in real factory buildings (see Figure 1).

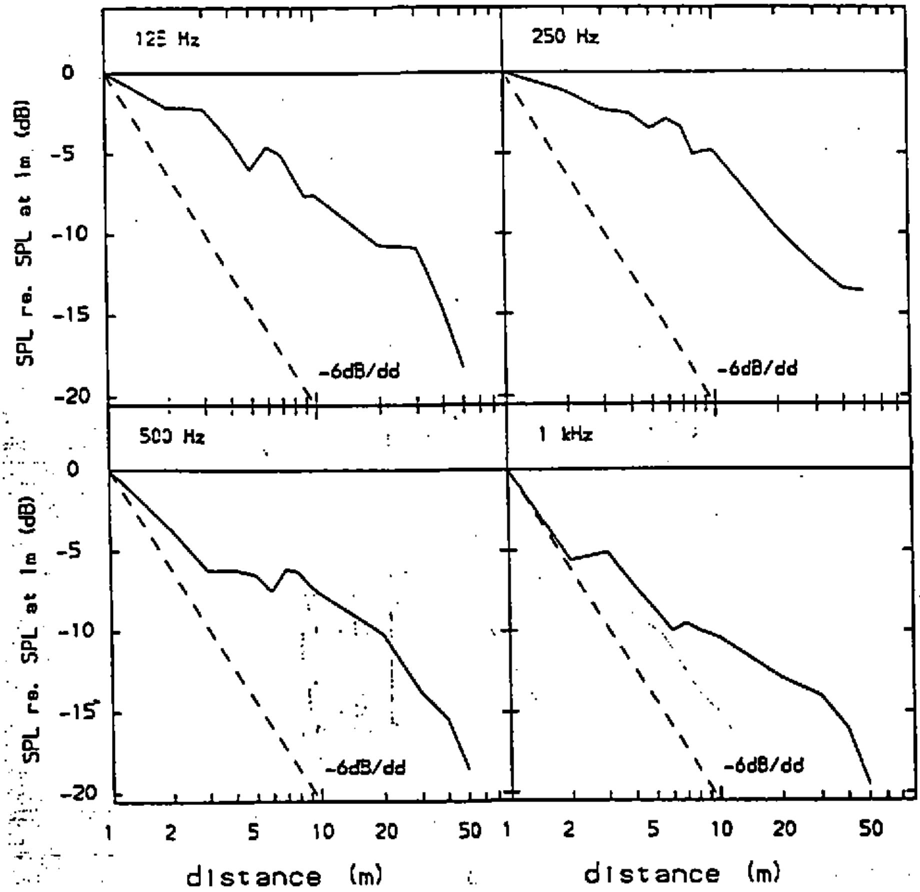

Figure 3 Octave band attenuation versus distance for the model factory

3.3. The Measured Transmission Loss

The sound intensity transmitted by a test panel, which was a sheet of perspex measuring 5m x 5m full scale and of thickness 3mm was first measured using the exciting field in the proportionate room. The critical frequency of this panel is approximately 9200 Hz. The transmission loss was calculated from these results and the measured internal sound pressure level. The test panel was then inserted into the side walls of the model factory and the internal sound pressure level in the vicinity of the panel was measured. The transmitted intensity was again measured using a near field intensity scan and the transmission loss calculated. The test panel was fixed at three positions at various points along the wall (see Figure 2), Figure 4 shows the measured transmission loss of the panel excited by the sound field in the proportionate room compared with that for excitation by the sound field of the disproportionate room.

4. CONCLUSION

The measured values of transmission loss are similar for the case of excitation by a classically reverberant field and the sound field in a disproportionate space. Significant deviations occur for frequencies close to the critical frequency of the test panel. At the present time the reason for this is not understood and work is continuing with the aim of finding an explanation for this effect.

5. REFERENCES

[1] M. HODGSON, 'Factory Sound Fields - Their Characteristics and Prediction,' Acoustics Australia, 13 pp.9-15 (1985).

[2] K.A. MULHOLLAND AND R.H. LYON, 'Sound Insulation at Low Frequencies', J.A.S.A., 54, pp.867-878 (1973).

[3] M.J. CROCKER, P.K. RAJU and BJORN FORSSEN, 'Measurement of the Transmission Loss of Panels by the Direct Determination of Transmitted Acoustic Intensity', Noise Control Engineering, 17 pp.6-11 (1981).

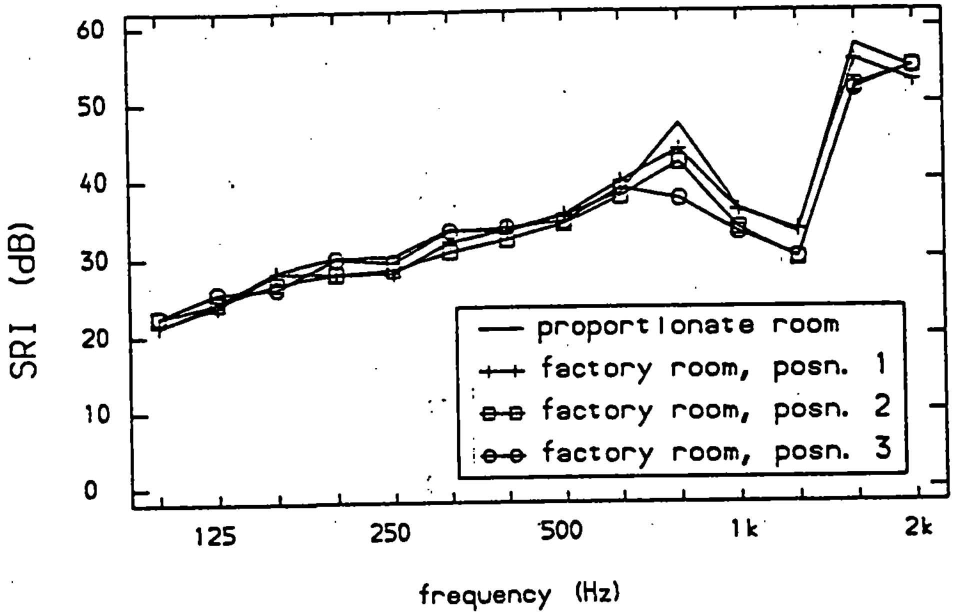

Figure 4 A comparison of the transmission loss of the perspex panel for the proportionate and disproportionate source rooms