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A COMPARISON OF IMPULSE AND STEADY STATE MEASUREMENT OF SOUND TRANSMISSION THROUGH BUILDINGS

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1. INTRODUCTION

Although the techniques for measuring the transmission of sound through buildings have been refined considerably over the years, the basic objectives have remained the same, namely to measure the distribution of sound level in a range of frequency bands under steady state conditions. No consideration is given to what might be described as the dynamic characteristics of sound transmission, i.e. changes in the temporal characteristics of the signal; the results of steady state tests are assumed to apply equally well to all types of noise irrespective of time signature. In particular, no distinction is made between the transmission of sound from impulse sources and those of constant sound power.

However, in other branches of acoustics it has been felt necessary to modify or extend experimental techniques to take the temporal characteristics of signals into account. The introduction of impulse time constants in sound level meters and the distinction that is now made between the early and late energy in concert hall acoustics reflects the fact that the ear is not a linear energy integrator with respect to time and that a distinction needs to be made between the overall energy received from an impulse signal and the time pattern of energy arrival.

In view of the readiness with which transient signals may now be captured and processed using digital techniques, it is relevant to consider whether measurements of sound transmission through buildings should also be extended to include impulse as well as steady state testing. This subject is a considerable one and would require, amongst other things, a general understanding of how the signals received from sources with different time signatures are processed by the ear when they have been modified by transmission through a building. However, a reasonable measure of agreement does exist that, in the case of one specific type of impulse source - speech, the intelligibility in a given level of background noise is determined by the fraction of energy from each speech sound that arrives within a short time interval following the arrival of the direct sound. The length of this interval is normally taken to be 50msecs.

In the light of this evidence, the paper examines to what extent steady state data is adequate for predicting speech intelligibility in buildings and whether there is a need to supplement it by measurements of the transient response of the transmission paths.

2. THEORETICAL BACKGROUND

The impulse response of a time invariant linear system completely describes the transmission channel and allows both the time and frequency character-

istics of a situation to be obtained from a single measurement. In the time domain, the relationship between the input and output signals $x(t)$, $y(t)$ respectively is given by:

$$y(t) = \int_{-\infty}^{\infty} x(\tau) \cdot h(t-\tau) d\tau$$

where $h(t)$ is the impulse response. In the frequency domain, this equation becomes:

$$Y(\omega) = H(\omega) \cdot X(\omega)$$

where $X(\omega)$, $Y(\omega)$ and $H(\omega)$ are the Fourier transforms of $x(t)$, $y(t)$ and $h(t)$ respectively. $H(\omega)$ is the transfer function of the transmission path and is the characteristic that is measured in a steady state analysis.

Additionally, the time domain information can be integrated to yield the 'energy history' of a signal using the equation:

$$E_{(0,t)} = \frac{1}{\rho c} \int_0^t p^2(t) dt$$

3. MEASUREMENT PROCEDURE

The measurement of the impulse response of a transmission path has three main elements; the source used to produce the impulse, the method of capturing the signal, and the method of analysing the record obtained.

Of the three sources that we have developed to date - gunshot, spark discharge and omnidirectional loudspeaker - the spark discharge has been found to be the most suitable for building acoustics measurements on account of its intensity, short duration, clear signature and omnidirectionality. The sound field produced by the 37 Joule source used for the current measurement has been found to be linear within 0.1 dB over the range $>2m$ adopted in the measurements. Signal capture is carried out using B&K $\frac{1}{2}$ " microphones and a Nagra IV SJ tape recorder. An FM recorder was used initially but was rejected in favour of a high quality A M machine on the basis of the much higher signal to noise ratio that can be achieved.

The aim of the signal processing is to obtain the integrated energy characteristics of the impulse response as a function of time and frequency. The three main aspects that need to be chosen are the sampling frequency, the number of bits in the A/D converter, and the size of the FFT data set. In terms of frequency analysis, the sampling frequency is determined by the Nyquist criterion that it should be greater than twice the highest frequency of interest. However, for energy measurements, a much larger number of points per cycle is required, especially when only one cycle is present. In the case of the spark signal which has a duration of 0.2msec, it was found desirable to use a sampling frequency of the order of 200KHz to reduce the random error of measurement to less than 0.1dB. This was achieved by means of an actual sample rate of 20KHz combined with a 10:1 speed reduction using the tape recorder. The number of bits in the A/D converter determines the signal to noise ratio and the quantization error that is achieved and should be 12 bits or greater if a linear converter is used. Finally, the FFT transform size needs to be large enough to include the whole of the signal. For measurements of sound transmission through walls, the signal that needs to be captured can be up to 0.8 sec long which, combined with a 20KHz sampling rate, means that the size of the FFT data set should be 16k points.

The measurements described in the following sections were obtained using a 14 bit A/D converter operating at a basic rate of 20KHz. The data was initially stored on floppy discs using a PDP11 minicomputer and the discs then transferred to a VAX 11/780 for the calculation of the 16K FFT's, each of which takes only 12 secs to complete.

3.0 SOUND TRANSMISSION WITHIN ROOMS.

The procedure adopted in each room studied consists of choosing a set of source positions and propagation axes that reflects the geometry of the room and then measuring the impulse response at a series of points along the axis of each source/axis combination. In addition, the impulse response is recorded simultaneously at a fixed distance of 2m from the source, the intensity of the direct pulse calculated and the result used to normalize the impulse response under study to a constant source level. This procedure allows valid comparisons of the results of different tests to be directly made.

The results of measurements taken along some 40 axes in 12 rooms showed that the differences between the energy arriving in the 0-50msec time interval and the total energy was small, and generally 0.4dB. This suggests that steady state measurements of sound transmission within rooms with ordinary ceiling heights are likely to be adequate for speech intelligibility predictions.

However, what the results did show was that the conventional model of the sound field in a room does not correspond to what occurs in practice. The model states that the sound field falls into two categories: a 'near' field in which the level falls at a rate of 6dB/doubling of distance, and a 'far' field in which the level is constant and independent of distance from the source. A summary of our results are illustrated in Figure 1 which shows that the energy level falls with the log of the distance from the source over the full range of measurement distances, and that it does so in rooms of all sizes. The rate of attenuation depends on two main factors: (i) the size of the room, the larger the room the higher the rate, and (ii) the level of room absorption present, the greater the absorption the higher the rate.

4.0 SOUND TRANSMISSION BETWEEN ROOMS

The method used to measure the sound transmission between rooms using an impulse source closely follows that which is employed for steady state tests. The source is positioned near one of the corners opposite the test wall and simultaneous recordings of the signal in the source and receiving rooms are carried out. This procedure is repeated for a number of positions in each room. The recordings are processed as described in Section 3.

Although this work is in its early stages, a number of clear patterns are emerging which show that, in the case of transmission between rooms, impulse and steady state measurements do yield different results. These findings are illustrated in Figures 2-4 which present the results of sound transmission measurements of a blockwork wall. The following points can be made:

- (i) in the source room, the spectrum of the early (0-50msec) energy closely follows that of the total energy in both amplitude and shape,
- (ii) in the receiving room, the spectrum of the early energy is significantly different from that of the total energy in both amplitude and shape,

(iii) the sound insulation as measured by the impulse method using the total energy closely follows the steady state results (as reported by Tricaud'),

(iv) the sound insulation is measured by the 0-50msec energy can differ substantially from the steady state values.

Figure 4 shows that the difference between the two sets of results for the blockwork wall was some 4-5 dB on average and up to 10 dB at individual frequencies. Results for other walls have given values of the early to total energy ratio of the transmitted sound, in the range 3-9 dB.

These results suggest that steady state tests alone have limitations as far as the control of speech intelligibility between rooms is concerned and should be supplemented by data obtained from impulse tests. The need for further work on other types of impulse source is also implied.

5.0 REFERENCE

1. P. DE TRICAUD, Impulse techniques for the simplification of insulation measurement between dwellings. Applied Acoustics (8), 1975 pp. 245-256.

Figure 1 Effect of room size and absorption on impulse sound propagation

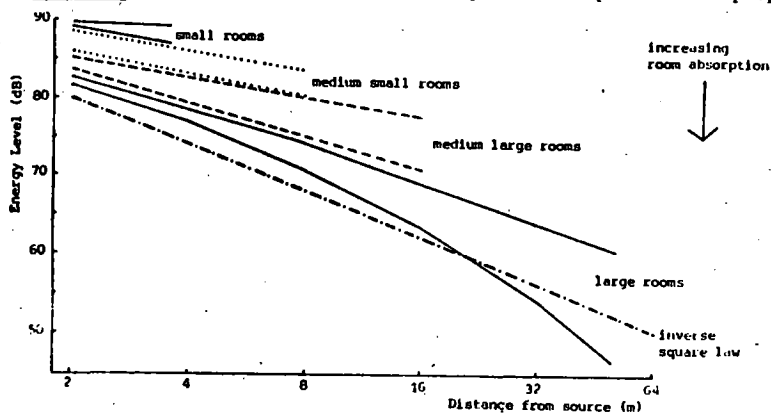


Figure 2 Impulse spectra in source room

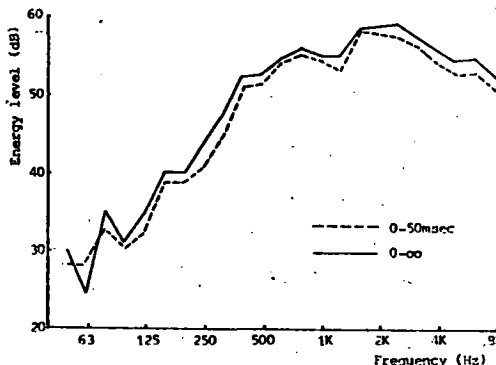


Figure 3 Impulse spectra in receiving room

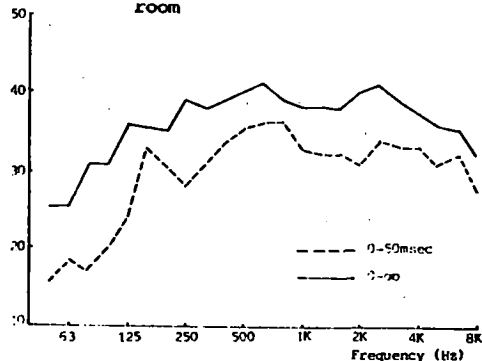


Figure 4 Comparison of steady state and impulse sound insulation values

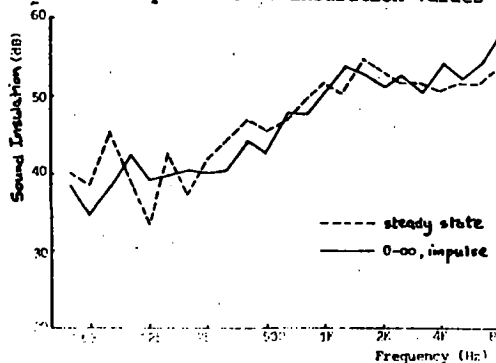


Figure 5 Comparison of impulse sound insulation values using different time intervals

