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TRANSMISSION OF BENDING WAVES ON PLATES FORMING A T-JUNCTION

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1. INTRODUCTION

In general, measurement of sound transmission in buildings does not give a clear indication of the relative importance of indirect and direct transmission. In particular, little information exists on the reductions in level that occur at the junction of structural plates. Steady-state measurements of the reverberant bending wave fields on walls and floors forming a junction can prove useful [1] but it is difficult, if not impossible, to separate the effect of the junction under investigation and the constraints operating on other junctions shared by the wall or floor. In addition plate dimensions dictate the allowed frequencies of vibration and, particularly at low frequencies, the power flow is dependent on the resonances of the coupled system.

S.E.A. techniques may also be employed [2] but the coupling loss factor is calculated using an angle averaged transmission coefficient, assuming a diffuse vibrational field. This is not likely to be true at low frequencies for bending waves, or at any frequency within the range of interest when dealing with faster in-plane waves.

In this investigation a junction of semi-infinite plates is simulated by isolating the direct component of the response of the plates to an impulsive source from delayed signals resulting from reflections from other junctions and free edges. The isolation is achieved by suitable geometry and by the use of short duration driving signals. Unwanted signals are then set to zero and the frequency response of the signal of interest obtained by a Fast Fourier Transform.

2. EXPERIMENTAL METHOD

The experimental measurement was of a T-junction made of free standing perspex sheets, each of dimensions 1.2 metres by 2.4 metres. The source used was a loudspeaker speech coil bolted directly to one of the plates (now called the source plate) forming the junction. The input signal used in this investigation was of a square wave form, of duration 0.05 milliseconds.

The vibration response of the plate was measured by means of a hand held probe accelerometer. The measurements were reproducible both in signature and level (within 1 dB) and good spatial resolution was also possible.

Averaging techniques were used to improve signal to noise ratios, but it was still necessary to incorporate a high pass filter in order to exclude low frequency noise resulting from activity within the building. This filter had a 3dB point of 100 Hz and a roll off of 36 dB/octave.

The dispersive nature of bending waves can result in the faster high frequency components of reflected waves arriving at the measurement position before the direct signal has effectively finished. A low pass filter was thus employed to increase the duration between direct and reflected signals.

The 3dB point was 4 Hz and the roll off was again 36 dB/octave.

In general structure-borne waves are faster than airborne waves and larger path differences are required to allow adequate signal separation. This problem was reduced by careful selection of material and geometry. The perspex plates were as thin as was practicable in order to produce slower bending waves. Thus the bending wave velocities on the coplanar plates of thickness 13mm ranged from approximately 150 m/sec at 500 Hz to 450 m/sec at 4 kHz. On the orthogonal plate of thickness 6mm the velocity was approximately 100 m/sec at 500 Hz and 270 m/sec at 4 kHz. At 1 kHz on the 13mm plate, a path difference of one metre gave a time delay of approximately 4 milliseconds.

It was found necessary to position the speech coil near the junction (at a distance of 300mm) in order to allow a reasonably large range of angles of incidence to be measured. However, with this arrangement the reflected signal from the junction may mask some of the direct signal. This problem was overcome by averaging the response at points on the arc of a circle centred on the source. By this method the direct signal is reinforced while reflected components can be expected to have no fixed phase relationship and should average to zero.

It was necessary to ensure that all measurement points were suitably distant from the junction where quasi-stationery near fields will destructively combine with the travelling wave component. It was found that at a distance of 300mm from the junction exponentially decaying nearfields effectively cease to contribute to the response signal

The investigation was further complicated by the occurrence of vibration modes other than that of flexure. In addition to travelling and evanescent bending wave fields on each plate. A bending wave incident at a junction will give rise to, in-plane vibration in the form of fast quasi-longitudinal and transverse shear waves.

These waves could, after reflection at free edges, convert back to bending waves at the junction and reduce the time separation available.

3 POINT SOURCE MEASUREMENTS

The effect of the junction on the transmission of bending waves was evaluated by observing a transient signal before and after its passage across the discontinuity. With the measuring point at a distance of 800mm from the source it was possible to produce a spatial average (on the arc of a circle) and thus produce an anechoic reference signal (figure 1a). With the same source receiver distance on the coplanar plate the angular variation of the transmitted signal by the junction can be observed. Here no correction for distance (and internal and radiative loss) is necessary. Measurements of level difference were made up to an angle of 60° with a resolution of 5°. The upper limit being set by the plate size and speech coil position. The coplanar plates were of the same thickness and material and the angle of incidence and transmission were equal. Typically, the time histories of the response of source and reception plates were windowed at 0 milliseconds and 3 milliseconds approximately, the rest of the time history being set at zero.

Figure 2 gives level difference on the coplanar plates as a function of angle at one third octave intervals. Clearly seen is a peak at each frequency which increases in angle with increased frequency. However there is little agreement at the lower frequencies between measured peaks and peaks predicted from theory [3] and variation in magnitude with frequency is greater than that given by theory.

A similar subtractive method was employed when measuring level difference between the orthogonal plate (plate 2 in figure 1) and one of the coplanar plates. A different plate thickness results in slower wave velocity and according to Snell's law, an angle of transmission less than the angle of incidence. Figure 3 gives predicted level difference and the mean of values measured over a frequency range of 500 Hz and 2 kHz. Agreement is encouraging but measurement indicated a clear frequency dependence whereas the theoretical curve is frequency invariant.

So far, measurement involved the use of a point source and comparison has been made with theory in which a plane wave source is assumed. The discrepancy between measurement and prediction might be reduced if a line source was used or simulated.

4 LINE SOURCE SIMULATION

An ideal line source is continuous and infinitely long. A line source can be simulated by use of a line array of point sources provided distance between neighbouring point sources is small compared to wavelength and the line array is long compared to distance from receiver position.

A quicker and more convenient method results from envoking reciprocity. The average response of n equally spaced accelerometer positions along any line at a distance from a speech coil will be equal to that of n speech coils, of the same spacing, along a parallel line passing through the real speech coil (Figure 1b). However, when using this method, windowing of the line average response proves more difficult on the reception plate than on the source plate and is accomplished by visual inspection plus knowledge of the time history of the most distant accelerometer position contributing to the line array response.

Measured level difference was compared with theory and again, only at higher frequencies could there be seen to be some agreement. Figure 4 shows direct comparison of measured coplaner level difference with theoretical prediction for a frequency of 2 kHz. In general agreement was fair at angles above those of maximum level difference and it is suggested that this may be due to angles of transmission having been attained where in-plane vibration becomes evanescent and thus do not contribute so readily to the plate response at distance from the junction. Results obtained for orthogonal plate transmission were in general no better than those obtained using a point source and are not presented.

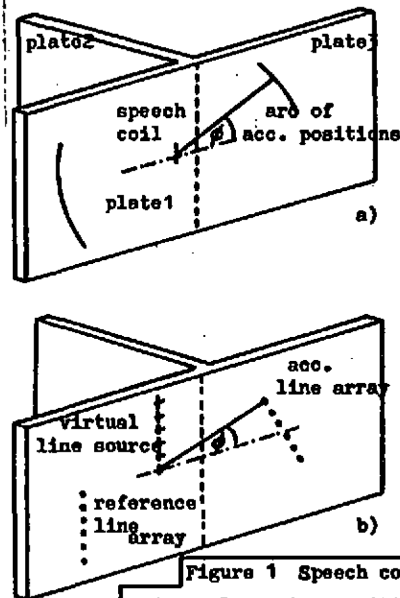


Figure 1 Speech coil and accelerometer positions

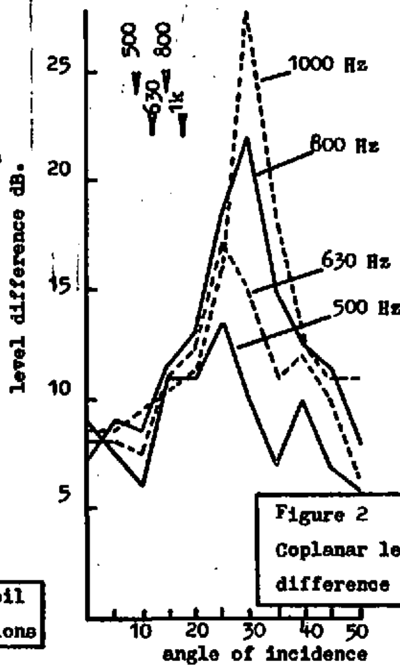
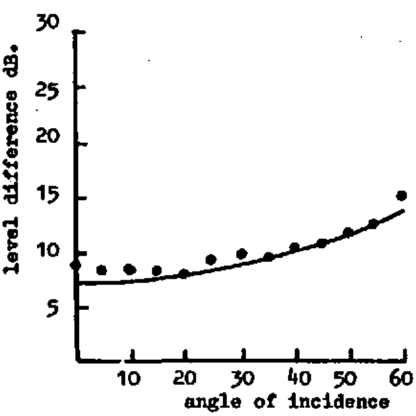


Figure 2 Coplanar level difference



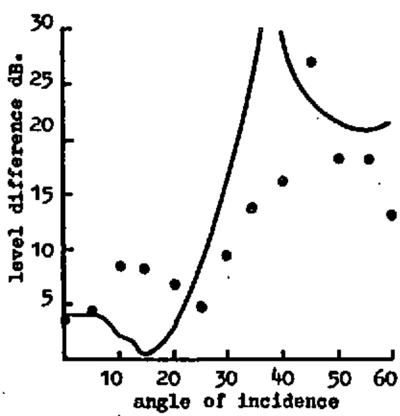


Figure 3 Level difference on orthogonal Plate

Figure 4 Coplanar level difference

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