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DETERMINATION OF THE PROPAGATION PATH OF STRUCTURE-BORNE SOUND

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INTRODUCTION

When machinery is installed in buildings it is usual to reduce the transfer of structure-borne sound from the machine by specification of av (anti-vibration) mounts of adequate efficiency. However, in many situations there are other structural connections, such as pipes and ducts, which form alternative, and possibly more efficient paths for sound transfer. In such a situation it would be desirable to identify the various paths and rank them in order of importance before making any attempt to reduce transmission This paper presents results of a field study performed on a 3kW centrifugal fan installation with structural connections to the plant room floor via both anti-vibration mounts and by steel columns supporting ductwork on the intake side. In the study measurement methods analogous to airborne intensity techniques have been used to quantify the flow of structure-borne sound energy from the machine through each connection and thereby identify the dominant path.

DESCRIPTION OF THE INSTALLATION UNDER TEST

The installation under investigation was a fairly typical centrifugal supply fan, arranged as shown in fig. 1. The 3kW motor, with a syncronous speed of 1415rpm was coupled to the fan via a belt drive. The fan had a scroll diameter of 1m and a running speed of 62rpm. Fan and motor were both mounted on a 100x50x6mm steel channel section raft which was supported by 4 steel spring isolators each with a stiffness of 71kN/m, and this entire arrangement was mounted on a 100mm high concrete plinth. The main floor of the plant room was suspended 300mm concrete slab. On the intake side of the fan the ductwork was supported by two 50x50x6mm steel angle section columns which were imbedded directly into the floor. It was suspected that these would form an efficient path for the transfer of structure-borne sound energy from the fan into the floor, and hence to the rest of the building.

MEASUREMENT OF STRUCTURE-BORNE SOUND POWER FLOW

Three different methods were used to measure power flow, all of which are to some extent analogous to airborne intensity measurement but use two phase-matched accelerometers rather than microphones. All the methods require the cross spectrum of two acceleration signals for which an 'ONO-SOKKI' dual channel FFT was used. Signal conditioning amplifiers were chosen for their accurate phase matching at frequencies down to 1Hz. Readings were each averaged 512 times over a period of about 2 minutes so as to reduce background noise. After capture of the results the cross spectra were transferred to a BBC micro computer for further processing.

<u>(i) Measurement of power flow through av mounts.</u>
Power flow through the av mounts was measured by attaching a 'unigain' accelerometer to the raft above the mount, and a high sensitivity, seismic

accelerometer to the plinth next to the same mount. Theory for this measurement technique can be found in ref. [1]. Background noise in the floor due to other sources in the building is incoherent with the acceleration signal from the raft, and hence can be effectively removed by time averaging. In this method the force at the bottom of the mount is inferred from the velocities at the top of the mount and the dynamic stiffness of the spring. For steel springs the dynamic stiffness is equal to the static stiffness below the onset of internal spring (wave effect) resonances, but above this frequency measured spring properties are required. Such information is not usually provided by manufacturers and was not available in this case, hence the power flows could not be accurately estimated above the first internal resonance of the spring which in this case was at 190Hz.

(ii) Measuremant of power flow down duct support columns.
Power may be carried down the ductwork support columns by two wave types, namely as longitudinal and bending waves; bending waves may occur in two perpendicular directions so there are three components of power flow in all to be considered for each column. Measurement of power transmitted by longitudinal and bending is slightly different (see refs. [2] and [3]), each wave type requiring a slightly different arrangement of accelerometers as shown in fig. 2. Two matched 'unigain' accelerometers were used for both wave types.

Measurement of longitudinal power required as wide a separation of the transducers as possible (fig. 2a) because the wavelengths were long (50m at 100Hz), and errors could be reduced by maximising the phase differences between channels. A low transverse sensitivity was required so as to reduce contamination of the measured vertical velocities by the larger horizontal velocities. The accelerometers used had a transverse sensitivity of 0.5% which was found to be adequate at most frequencies.

When measuring bending power the accelerometers were placed as far as possible from the ends (fig. 2b) so as to reduce end effect errors (ref. [3]). The spacing could be much closer because the bending wavelengths were much shorter than for the longitudinal case.

MEASURED POWER FLOWS

(i) Power flow through av mounts
Fig. 3 shows the total power flow through all four mounts. The figure was obtained by measuring power through each foot individually and then summing the spectra. The spectrum consists of many peaks at harmonics of the motor speed (24Hz), and the fan speed (10.3Hz), and the power flow drops off rapidly with frequency as would be expected from the transmissibility of the springs. The structure-borne sound power is ~70dB (ref. 1pW) at 6Hz, dropping to 25dB at 180Hz. The large peak at 190Hz corresponds to the first internal resonance of the spring so, as already mentioned, without the measured properties of the spring the power could not be accurately estimated. However, it would be expected that relatively large power flows would occur here due to the resonance effect.

The contributions of individual mounts are far from equal as shown in fig. 4. At all frequencies there is some circulation of power with power flowing down some mounts and up others. The net flow of energy is usually directed into the floor, however, at some frequencies, notably at 32Hz, the net flow of energy via the mounts is negative, ie. up the mounts. The source of this energy must be the same machinee since contributions from other sources would be incoherent and therefore average out over the period of measurement. This is a clear indication that there is an alternative path for sound transmission.

The average velocities of the raft and the floor are shown in figs. 5 and 6. It can be seen that the levels in the floor are generally 10-30dB below those on the raft.

<u>(ii) Power flow down duct support columns.</u>
The power transferred by longitudinal and bending waves is considered separately.

The longitudinal path was expected to be the most efficient at low frequencies, the impedance mismatch being of the order of 19dB (calculated from the impedances of an infinite rod and an infinite plate, see ref. [4]). The power flow summed for both columns is shown in fig. 7. Results at some frequencies were inevitably subject to large errors and these have not been shown. The structure-borne sound power levels are ~85dB at 40Hz, dropping to ~40dB at 180Hz. Power transferred via this path therefore dominates that through the av mounts. Some circulation occurs with power flowing down one foot and up the other, but the net flow from both feet is usually positive. An exception to this is the peak at 190Hz, which is negative in both columns suggesting that at this frequency some other path is dominant.

Power transmitted down the columns as bending waves was not expected to be as important as via longitudinal waves due to the greater impedance mismatch between the column and the floor in bending (44dB at 100Hz). The total power transmitted by bending in the two perpendicular directions is shown in fig. 8. It can be seen that levels are ~60dB at 20Hz, and drop to ~30dB at 180Hz. The drop in transmitted power with frequency is thus less marked than for the longitudinal power, so the relative importance of the bending component increases with frequency. This trend is consistent with the calculated impedance mismatch between column and floor which decreases at a rate of 5dB/octave for bending, but is constant for longitudinal. The bending component is therefore less important than the longitudinal component, especially at low frequencies, but is still more important than the power through the avs. Some negative powers are observed, for example the peak at 55Hz.

Some negative power flows are observed in the spectra of both bending and longitudinal contributions, but where this happens there is usually a larger, positive contribution from the other component giving a net positive power flow down the column. The exception is the large peak at 190Hz which is negative for both the longitudinal and bending components, giving a net flow of energy up the column. This energy is thought to emanate from the same machine rather than from some external source because the relatively high accelerations in the floor at this frequency are 98% coherent with accelerations of the machine raft. It has already been mentioned that this corresponds to the first internal resonance frequency of the spring mounts, which would undoubtedly result in efficient power transfer, so the most likely path would appear to be through the mounts.

(iii) Other paths for sound transfer

The av mounts and the duct support columns account for all the structural connections from the machine to the plant room floor. It is of course possible that energy from the machine could enter the structure via the air. However the energy flow via this path would be very difficult to measure in practise since the transfer could occur over the entire area of the floor and walls of the plant room.

CONCLUSIONS

The transmission of structure-borne sound from a typical 3kW centrifugal fan via structural connections to the floor has been measured. The possible paths were firstly via the anti-vibration mounts, and secondly via columns supporting ductwork on the intake side. By quantifying the flow of energy through each connection it has been possible to rank the various paths in order of importance.

The total power flow through the av mounts was of the order of 70dB. Power flow down the duct support columns was 10-50dB greater at all frequencies except in a narrow band at 190Hz corresponding to the first internal resonance of the mount. At this frequency the mounts appeared to provide the dominant path. Most of the energy down the column was transmitted longitudinally, but there was also a bending component which increased in importance at higher frequencies.

ACKNOWLEDGEMENTS

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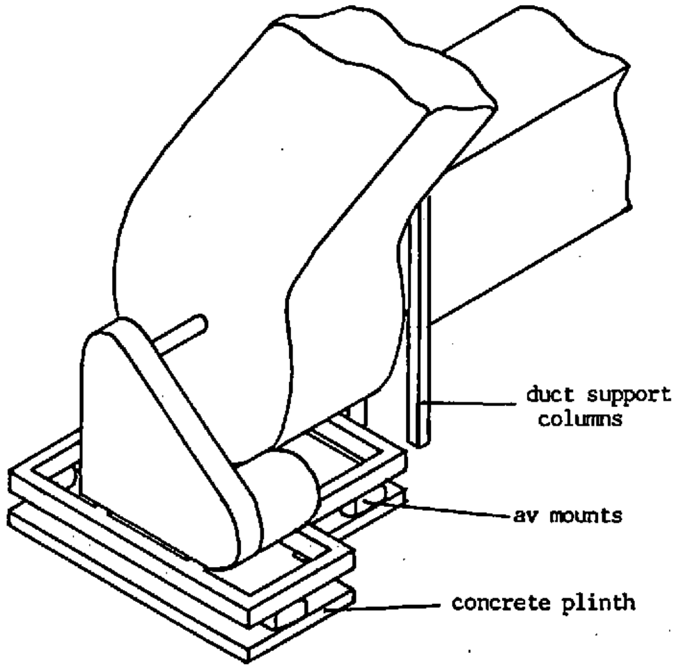

Fig. 1 Arrangement of Fan and Ductwork

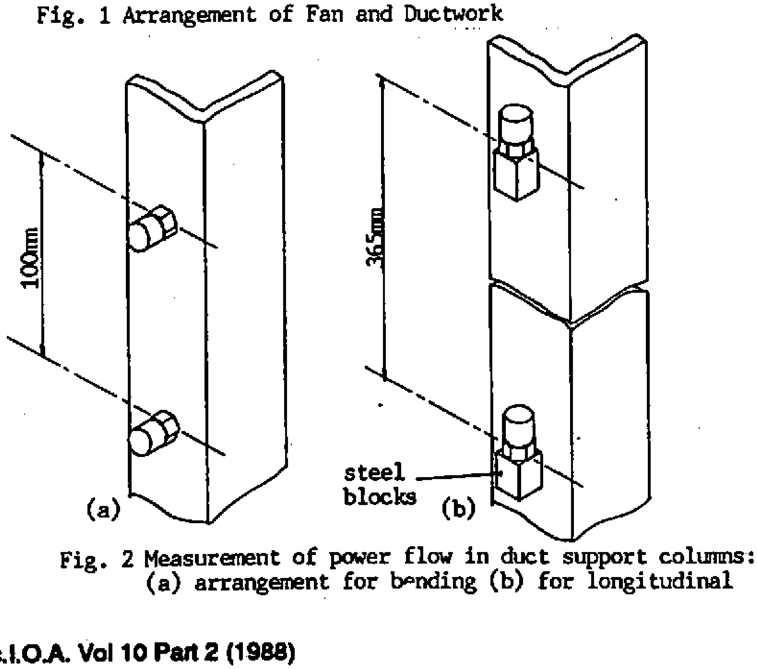

Fig. 2 Measurement of power flow in duct support columns: (a) arrangement for bending (b) for longitudinal

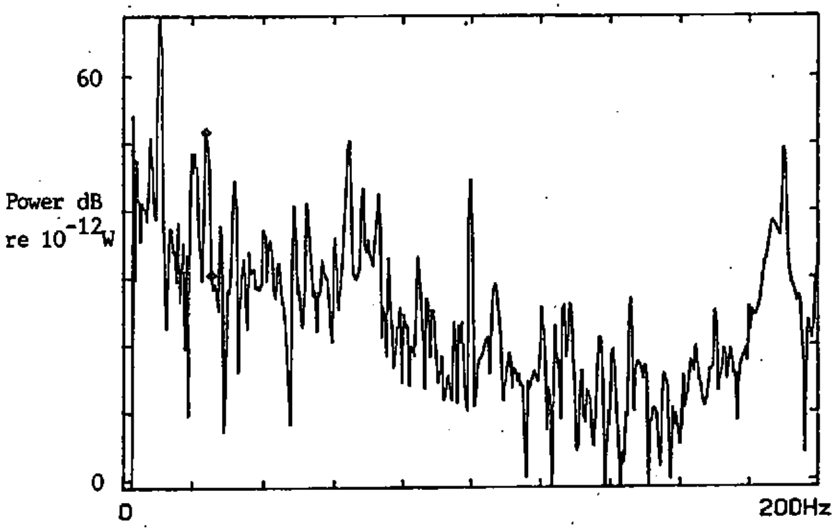

Fig. 3 Total power through av mounts

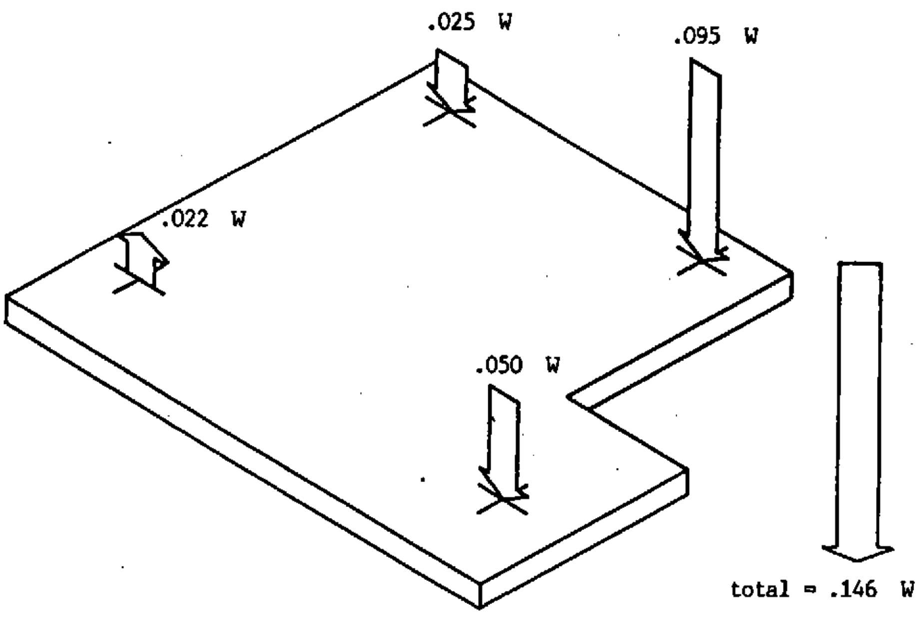

Fig. 4 Power flow through av mounts at 64.5Hz

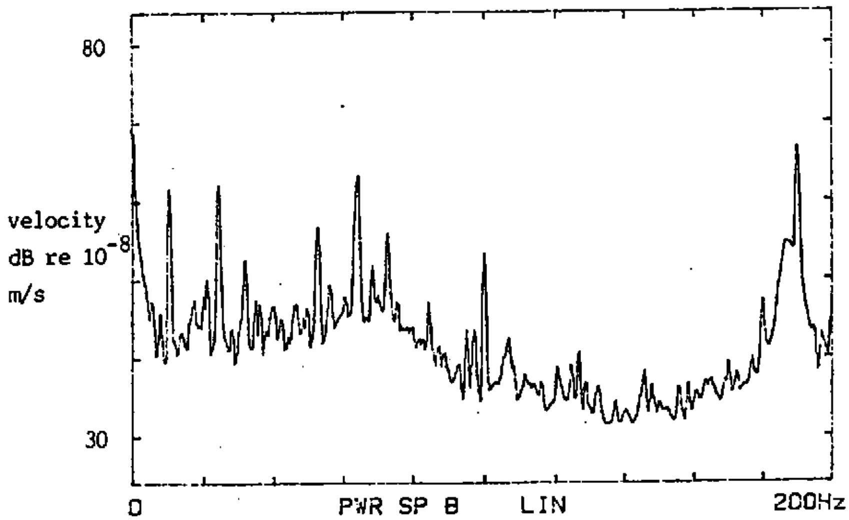

Fig. 5 Average velocities on machine plinth

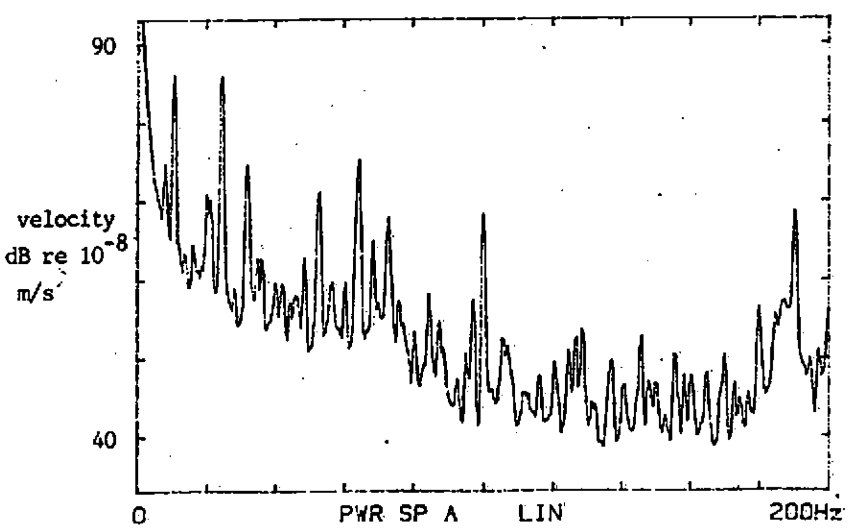

Fig. 6 Average velocities on machine raft

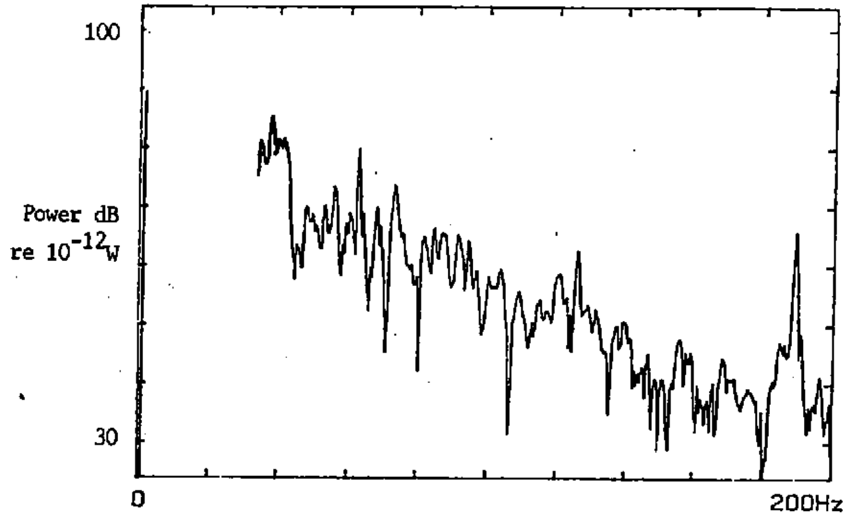

Fig. 7 Total longitudinal power flow in duct support columns

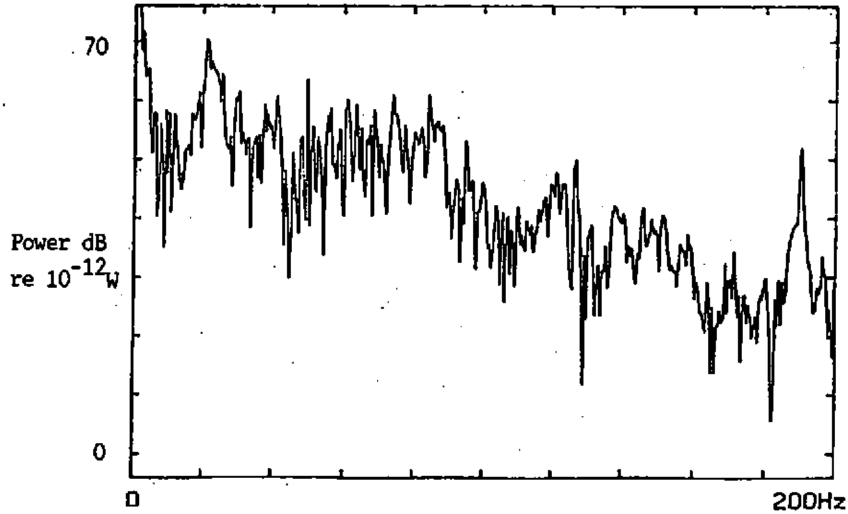

Fig.8 Total bending power flow in duct support columns