TRANSMISSION OF LONGITUDINAL WAVES IN COMPOSITE SYSTEMS

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1. Introduction

Considerable work has been done on the use of rubber in the construction of anti-vibration mounts for use as vibration isolators for engines, plant and machinery. Some of the well-known papers on this subject which give excellent theoretical analysis are cited as Refs. 1,2,3 & 4. However, results of experimental investigations on the performance of anti-vibration mounts are few and are mainly concerned with low frequency tests (e.g. Ref. 3) except Ref. 1 which gives some experimental results at high frequencies.

In this paper, some results of an experimental investigation into the construction of anti-vibration mountings to operate up to 10 kHz are presented. The anti-vibration mounts were constructed for use as supports for a reinforced rubber hose assembly subjected to dynamic tests. Thus, the criterion used for judging the performance of the mounts is that the transmission of longitudinal waves through the mounts should be much less than the longitudinal wave transmission through a typical hose assembly.

II. Wood and Commercial-Rubber Mounts

In order to assess the vibration isolation characteristics of wood and rubber, anti-vibration mounts were constructed using six plates (or layers) each of a soft wood and commercial rubber bonded and sandwiched between mild steel plates (Fig. 1a,b). When the mounts were tested dynamically, it was found that the attenuation of longitudinal waves was greater for the rubber than for the wood mounts (Fig. 2). However, the transmissibility signature of the rubber mount was much higher than that of a typical hose.

In an attempt to improve the vibration attenuation of the rubber mount, a hollow rubber mount was constructed from small blocks of commercial rubber (Fig. 1C). Because of the introduction of more interfaces in the rubber matrix it was expected that the attenuation of vibration by the hollow mount, which has the same overall dimensions as the solid rubber mount, would be greater. This was found to be true as shown by Fig. 2; although the improvement is only small and does not justify the extra effort involved in construction.

III. The Use of "Blocking" Plates

The effects of sandwiching metal plates between layers of rubber were next investigated. Two mounts, each consisting of three layers of commercial-rubber were made. In one mount, the layers of rubber were sandwiched between two 6.4 mm thick mild steel plates, while in the other mount the layers of rubber were sandwiched between four mild steel plates. The transmissibility signatures of these mounts (Fig. 2 cf. Fig. 3) show that the attenuation of vibration by the latter mount is greater than by the former. This is as expected for the metal interlayers serve as barrier or "blocking plates" which prevent the free and total propagation of the incident longitudinal waves by reflection. Because of the finite acoustic impedance of the plates, however, some of the incident wave is transmitted across the rubber-metal interface. From Ref. 3, and by deductions from Refs. 5 & 6, for a large plane interface, the proportion of the incident energy transmitted in the form of longitudinal waves across the interface is:

$$\frac{4(Z_1/Z_2)}{(1 + Z_1/Z_2)^2}$$

where Z_1 and Z_2 are the acoustic impedances of the two materials. For a mild steel/rubber interface the ratio Z_1/Z_2 is about 1,000 giving rise to a transmission of less than 1% of the energy of the longitudinal waves incident at each interface. In practice, however, because of the finite lateral dimensions of the rubber layers and metal plates, the transmission of energy across the interface is much higher than that given by the above expression.

The effects of the number and the thickness of the mild steel plates on the vibration attenuation characteristics of the mounts were also investigated. It was found that as the number of metal plate interlayers was increased, the vibration level transmitted was reduced (Fig. 3) due to the increase in the number of rubber-metal interfaces. However, at high frequencies, the transverse resonances of the plates modified the vibration attenuation characteristics of the rubber mount by giving rise to higher transmissions resulting from plate transverse resonances. It was found that these effects could be minimised by the use of thicker plates of higher transverse resonant frequencies (Fig. 4) and could be totally eliminated by designing them out as discussed in the next section.

IV. The Use of "Blocking" Masses

In order to eliminate completely the effects of local resonances in the metal interlayers, mild steel discs whose fundamental resonant frequency (axially, transversely and torsionally) is greater than 10 kHz (the limit of the frequency range of interest) were machined and used as "blocking" masses. The transmissibility plots (Fig. 5) show that there is a considerable increase in the attenuation of the longitudinal waves incident on the mount. This increase is due not only to the reflections of incident waves caused by the steel discs but also by the "absorption" of some of the incident acoustic energy by the masses of finite mechanical impedance, this being the amount of energy required to vibrate the masses (Ref. 5). As the mass increases, the impedance increases and the transmissibility therefore decreases as shown by Fig. 5.

V. Natural and Commercial Rubber Anti-Vibration Mounts

In order to decrease the transmissibility of longitudinal waves through the rubber mount still further, the commercial rubber layers were replaced by layers of refined natural rubber whose acoustic impedance is smaller than for commercial rubber. As expected, the transmissibility through the natural rubber mount at intermediate and higher frequencies is less than that of the commercial rubber mount (Fig. 6). However, because the loss factor for natural rubber is smaller than the loss factor for commercial rubber, the transmissibility of the natural rubber mount is greater at the low frequencies where the mount's mass-spring characteristics dominate.

VI. Conclusions

The results presented are for the transmission of longitudinal waves through anti-vibration mounts and they show that:

1. The use of metal interlayers greatly improve the performance of anti-vibration mounts.
2. Local resonances in the metal interlayers can adversely affect the characteristics of the mounts especially at intermediate and high frequencies.
3. The use of "blocking" masses as metal interlayers greatly increases the attenuation characteristics of the mounts.

VII. References

1. J.C. SNOWDON 1968 John Willey & Sons, Inc., 21-77.
   Vibration and Shock in Damped Mechanical Systems.
2. J.C. SNOWDON 1979 J. Acoust. Soc. Am., 66(5), 1245-1274.
   Vibration Isolation: Use and Characterisation.
3. A.R. PAYNE 1964 Rubber Chem. & Tech., 37, 1190-1244.
   Transmissibility Through and Wave Effects in Rubber.
4. C. DYRBYE and F.B. PEDERSEN 1977 Structural Research Lab., Technical University of Denmark, Rapport N.R.R. 78.
   Rubber Mountings and Vibration Isolation.
5. L. CREMER and M. HECKL, Translated by E.E. UNGAR, 1973 Springer-Verlag, 306-366.
   Structure-Borne Sound: Structural Vibrations and Sound Radiation at Audio Frequencies.
6. L.M. BREKHOVSKIKH, Translated by R.T. BEYER, 1980 Academic Press, 1-25, 151-160.

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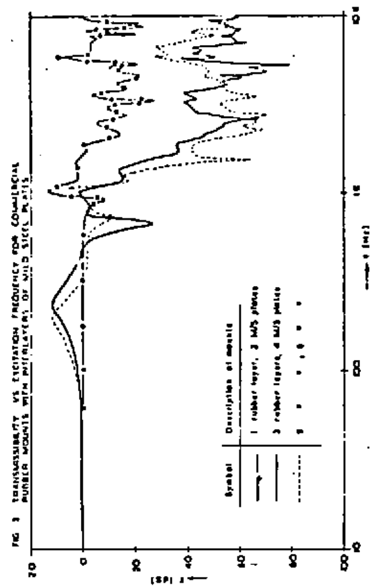

FIG 3 TRANSMISSIBILITY VS EXCITATION FREQUENCY FOR COMMERCIAL RUBBER MOUNTS WITH INTERLAYERS OF MILD STEEL PLATES

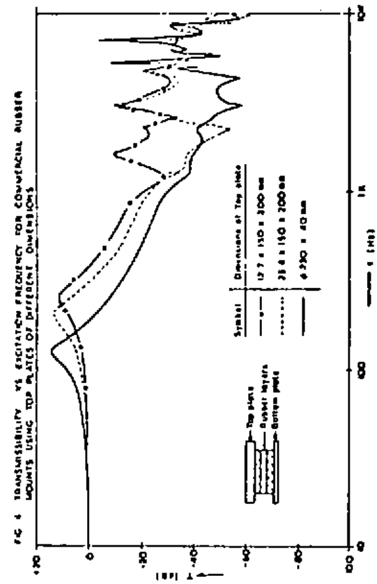

FIG 4 TRANSMISSIBILITY VS EXCITATION FREQUENCY FOR COMMERCIAL RUBBER MOUNTS USING TOP PLATES OF DIFFERENT DIMENSIONS

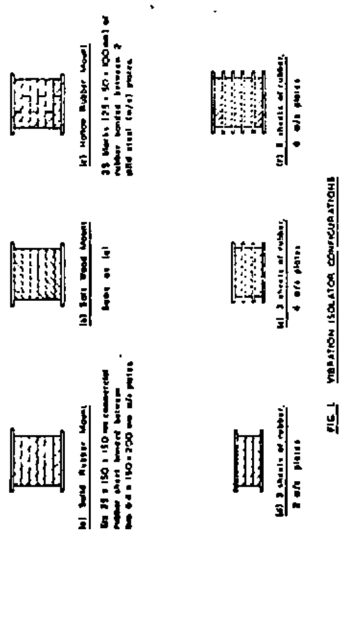

FIG 1 VIBRATION ISOLATOR CONFIGURATIONS

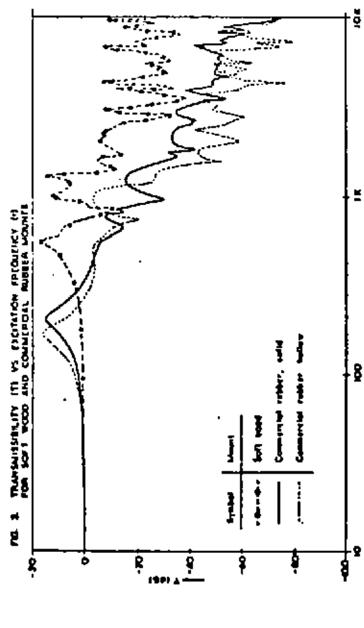

FIG 2 TRANSMISSIBILITY (T) VS EXCITATION FREQUENCY (f) FOR SOFT WOOD AND COMMERCIAL RUBBER MOUNTS