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ACTIVE FORCE CANCELLATION OF STRUCTURE VIBRATIONS

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INTRODUCTION

A new method which may prove to be very effective in noise control is active cancellation. Active noise control is now widely accepted, but the concept of active force or vibration control is completely new. Like active noise systems, active force control systems cannot be regarded as some magic method which can be used even when no other noise design precautions have been taken. This method of noise control should only be used when all other methods have failed, and this is because of the complexity of implementation.

The concept is similar to active noise control, but in this case the vibrations of the structure are controlled by actively cancelling the force excitation. Stress waves in a structure travel much faster than acoustic waves in air; therefore for an active system to be effective, its response must be very fast, faster than the response of the structure. This creates some problems in implementing such a system, especially in impact situations.

Active force control systems can take two forms, depending on the duration of the impact force. If the force pulse is relatively of a long duration with sharp changes of the force, like in the case of the operation of a power press, then only the rapid changes need to be controlled. However, for metal-to-metal impacts, like the final forging blows in a drop hammer, that is the force pulse is of very short duration, then the cancellation of the whole pulse is necessary.

This second type of control system is investigated, to obtain how critical the system is on the various parameters. This type of system is much easier to implement in some situations than the system where only the sharp force changes are cancelled. The hardware for the latter system is not yet available.

The function of the active system is to measure the vibration level of the structure and adjust the control force so that the structure vibrates at a lower level at the measuring position. Active force control systems have been developed for structures under constant excitation [1,2] to control one particular mode. The output from the measuring transducer is fed to the control system, which outputs the control force a whole number of cycles later and this is adjusted until the measured response is at a minimum.

Such a system is not practicable in the case of a highly damped structure, which is impact excited. Since the structure is highly damped, most of the noise radiated comes from the initial deformation of the structure, and the ringing of the structure will decay very rapidly. Therefore a conventional active force control system will be too slow to adjust the control force. In such cases the control force must be exactly synchronised with the excitation force and in the case of complete cancellation of the force, both forces must be as identical as possible.

EXPERIMENTAL SET-UP

An active force control system is built to control the vibrations of a plate structure excited at the centre by an impact force. An equal and opposite control force is applied to the plate on the opposite side of the excitation force. Although the vibrations are not completely cancelled, the mode of vibration of the plate is changed from flexural or bending waves to dilational waves, which occur at a much higher frequency and are of a much lower amplitude.

The control force was in exact synchronisation with the excitation force by having a system whereby the position of the hammer before impact is known and this triggers a pulse generator, which, a pre-set delay time later, outputs a pulse such that the output from a shaker is at exactly the same time as the impact of the hammer on the plate.

Using this set-up, the decrease in the noise energy radiated from the plate is of about 14 dB in total, and is constant throughout the whole frequency range. This latter observation suggests that the control of vibration is not complete. An active force control system will give a reduction in the level of noise energy radiated but the reduction is dependent on the matching of the excitation and control forces, both in the time domain and their frequency spectra. In the case of cancellation of only the sharp changes of the force, the extent of the cancellation at each frequency band will depend on the matching of the spectra of the sharp force changes of the excitation and the control systems.

SEPARATION BETWEEN EXCITATION AND CONTROL FORCES

It is not always possible to have the control force at the same location as the excitation force. The effect of a separation distance between the two forces is that the structure is now acted upon by a torque of magnitude Fx, where F is the excitation force and x the separation distance. This effect is investigated in the case of the flat plate and then generalising the results for other types of structures.

The response of a plate structure away from the point of excitation is given by the empirical formula [3]

$$M_t = M_c \qquad kr \leq 0.63$$

$$= M_c \sqrt{\frac{2}{\pi kr}}\; e^{-j(kr - \frac{\pi}{4})} \qquad kr \geq 0.63$$

where M_c is the characteristic mobility of the plate given by $M_c = (8\sqrt{B\rho_s})^{-1}$; k is the bending wave number; B is the bending stiffness; ρ_s is the surface density and r is the distance from the point of excitation. Therefore if a structure is acted upon by two forces with opposite direction with respect to each other, then the two forces are completely coupled only if the separation between the two forces satisfies the relation $kx \leq 0.63$. Outside this range, $kx > 0.63$, the coupling between the two forces diminishes as x increases, until the two forces are completely independent. In this case, the structure can be considered to be under the excitation of two totally independent forces, with twice as much energy input as compared to single point excitation.

In the case of torque excitation, the structural response of a flat plate is independent of frequency, while the response for point force excitation has a slope of -10 dB per frequency decade. Thus the input energy per unit force under torque excitation will be higher than that for the point force above a certain frequency. This frequency is dependent on the bulkiness of the structure and the separation distance between the two forces.

Therefore the noise radiated from a plate under two forces, separated by some distance, increases at 6 dB per doubling of the separation. However, because the coupling between the two forces diminishes as $kx > 0.63$, the increase of noise with separation is less. This result is observed in the experiments carried out in the plate, when the control force was moved away from the excitation point. Figure 2 shows the change in noise level with separation, in one-third octave bands. The results in other bands are similar. The noise is at its lowest level when the two forces are exactly at the same point and then increases due to the torque excitation as the two forces become separated. At large separation, the two forces are completely independent and the noise after reaching a maximum decreases again and remains at a level 3 dB higher than the noise level if the plate is excited by one force.

CONCLUSION

This investigation shows that the performance of an active force control system is critical on the timing of the two pulses; the separation distance of the control and excitation force; and the exact shape of the force pulse or its spectrum. Different time durations, or in the case where only the sharp changes are being cancelled, the force changes are not identical; the spectra of the control and the excitation will have different levels at different frequencies and cancellation occurs only in some frequency ranges, while other frequencies are not affected at all.

Other uses of the active system include changing the noise radiated from a structure at will, which will be of great use in naval defence. Ships and submarines are identified from the noise signature that is radiated; thus if this signature can be modified at particular frequency ranges, then the noise signature radiated can be altered to some desired shape.

For multiple impacts, like backlash, the active system is not very useful, but if the vibrations from the principal source are cancelled, then these secondary impacts should also be eliminated. In the case of a finite number of mounts, active control is useful provided the force function at each mount is known or measurable.

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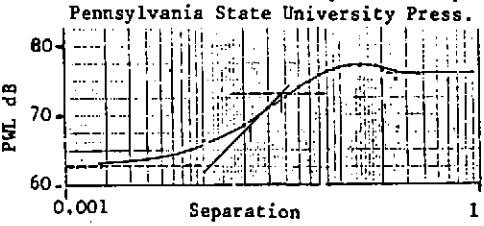

Fig. 1 Change of noise with separation distance. —·—·— , level due to one force; ------, forces at same point