Proceedings of The Institute of Acoustics

NOISE FROM VIBRATION

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The following note concerns the calculation of noise levels produced by the surface vibration of machine components in which continuous cyclic excitation occurs. In detail the exact relation between surface vibration and its resultant noise is extremely complex - for example the sound field inside containers with flexible sides - but for many engineering situations a simple approach can be taken by using the concept of radiation ratio.

The sound pressure level at any distance from a vibrating surface is given generally by the relation:

$$Lp(f) = L\bar{v}(f) - 10\log_{10}\left({}^{Strav}/_{Srad}\right) + 10\log_{10}\sigma_{rad}(f) + 10\log_{10}\left(\frac{\rho c u_o}{p_o}\right) \text{ dB} \quad (1)$$

Where $Lp(f)$ = S.P.L. measured on Strav at frequency f
$L\bar{v}(f)$ = area average mean square surface velocity
Strav = surface area of microphone array
Srad = surface area of machine component
u_o = reference velocity
p_o = reference pressure

which defines the radiation ratio σ_{rad}

Many machine elements have very high modal densities in the frequency range of high noise radiation (usually about 500 - 3000 Hz) and when these are excited by a repeating force input the resultant noise radiated tends to be rather non-directional in nature as one modal directivity pattern overlays another (1,2). Conversely, the variation of vibration levels over such machine elements tends to vary very greatly, by up to 20 dB over a distance of only four or five centimetres, and more care is required in establishing the vibration field than in establishing the resultant noise field. Vibration velocity is usually obtained from acceleration measurements and experience has shown that use of the acceleration reference levels proposed for international use cause confusion, a more useful reference being that of gravity, which is more widely appreciated. Moreover, machine vibration is often characterised by vibration of a very impulsive nature and integration techniques to obtain velocity can be substantially in error. In this work therefore $L\bar{v}(f)$ has been obtained using the acceleration frequency spectrum from the relationship :

$$L\bar{v}(f) = L\bar{a}(f) - 20\log_{10}\left({}^{f}/_{6}\right) \quad (2)$$

Where $L\bar{a}(f) = 20\log_{10}$(ACCELERATION RE 1g)

This results in velocity levels relative to a reference velocity of 0.39 m/s and equation (1) becomes

$$Lp(f) = L\bar{v}(f) - 10\log_{10}\left({}^{Strav}/_{Srad}\right) + 10\log_{10}\sigma_{rad}(f) + 138 \text{ dB} \quad (3)$$

NOISE FROM VIBRATION

The radiated noise is thus simply dependent on the average surface velocity ($L\bar{v}$ (f)), the radiating area of the component (Srad), the measuring distance (Strav) and the radiation ratio (σ_{rad}).

The size of many machine components is such that when the objective of noise analysis is for legislation purposes where overall A weighted noise levels are to be used, then the assumption of unit radiation resistance is a reasonable one. On this assumption and treating machine components, which can be identified as 'separate', (usually by bolted joints) as uncorrelated sources, the noise radiated by a machine can be estimated from vibration measurements (in all cases a minimum of 10 vibration measurements per surface is used - sometimes 80 on complex components). A comparison of measured and calculated noise levels can be used to estimate the radiation ratio to see how realistic is the assumption of unit value radiation ratio.

Figure 1 shows the radiation ratio's calculated in this way for a medium sized diesel engine (130 b.h.p.) and two diesel engine fuel pumps of approximately one-third and one-quarter the linear dimensions. The diesel engine was constructed with cast iron main structure, cast aluminium oil sump and pressed steel valve cover, the larger fuel pump from cast aluminium and the smaller fuel pump from cast aluminium with a small pressed steel cover. The results show no marked low frequency fall-off in radiation ratio even for the very small fuel pump. Only at the very high frequencies above 4000 Hz is there any marked variation from unit radiation ratio, the accuracy of measurement being of the order of ± 0.75 dB. The majority of early measurements that have been carried out reflect this general trend in measured results and as the collection of measured vibration data has grown they have been used to predict the noise source balance of diesel engines before testing. (In this case the tests were carried out by another Institute). A comparison of the differences between the distribution of sound power radiated by the various surfaces as measured by the lead cladding technique and that predicted according to equation (3) from estimated average surface vibration levels is shown in Figure 2. For the majority of surfaces the difference between predicted and measured percentage acoustic power is less than 10%. However, for both the engines shown in Figure 2 the contribution to total sound power for the oil sumps was overpredicted by some 20%. In both cases the oil sumps were of pressed sheet steel construction in which the ratio of largest overall dimension to material thickness is of the order of 1000:1. Under these conditions there is a strong reactive noise field. Figure 3 shows the measured radiation ratio for such machine elements where a broadband constant force input (one-third octave warble tone) was applied to the structure (cylinder head) to which the experimental rectangular valve covers were attached. Each sheet steel cover was double the radiating area of the next, the thickness being constant. The radiation ratio does vary from unity by up to 18 dB at low frequencies, but the measured values do not show such a marked variation as is predicted for rectangular panels. The largest cover (No.3) was judged impractical since its basic rigidity was too low for practical purposes. Thus it can be concluded that even for relatively flimsy sheet steel covers in which the coincidence frequency is very high (9000 Hz) then the maximum change in radiation ratio that can be expected is some 10-12 dB at the lower frequencies around 500 Hz.

From the work carried out four general conclusions can be drawn.

NOISE FROM VIBRATION

(1) Provided accurate area average vibration levels can be established this simple method for predicting noise from vibration can be used successfully to predict radiated sound power balances for complex machines.

(2) For structural cast components the radiation ratio can be determined with sufficient accuracy from the relation for a piston-in-baffle.

(3) For thin components in which the ratio of major overall dimension to thickness exceeds 500:1 the radiation ratio can be approximated to that for rectangular panels, although this will under-predict the radiated noise levels slightly.

(4) It is unlikely that substantial noise reductions (greater than 10 dB) can be achieved by redesign of machine components to make use of a reduced radiation ratio.

References

(1) C.M.P. CHAN and D. ANDERTON 1972 Proceedings Internoise 72, Washington D.C. The correlation of machine structure surface vibration and radiated noise.

(2) C.M.P. CHAN and D. ANDERTON 1974 Winter Noise Control Engineering, p.16-24. Correlation between engine block surface vibration and radiated noise of in-line diesel engines.

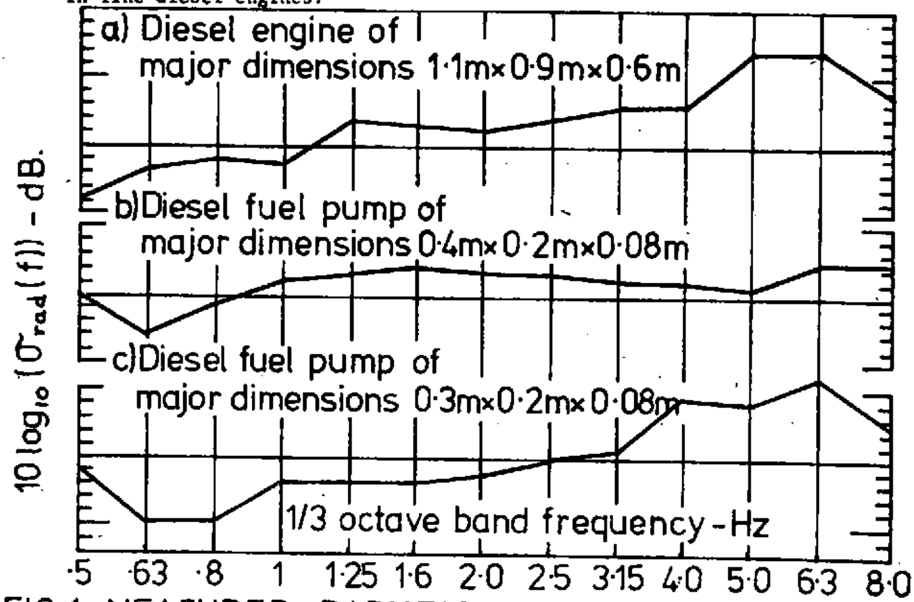

FIG. 1 - MEASURED RADIATION RATIO FOR MACHINES OF VERY DIFFERENT SIZE.

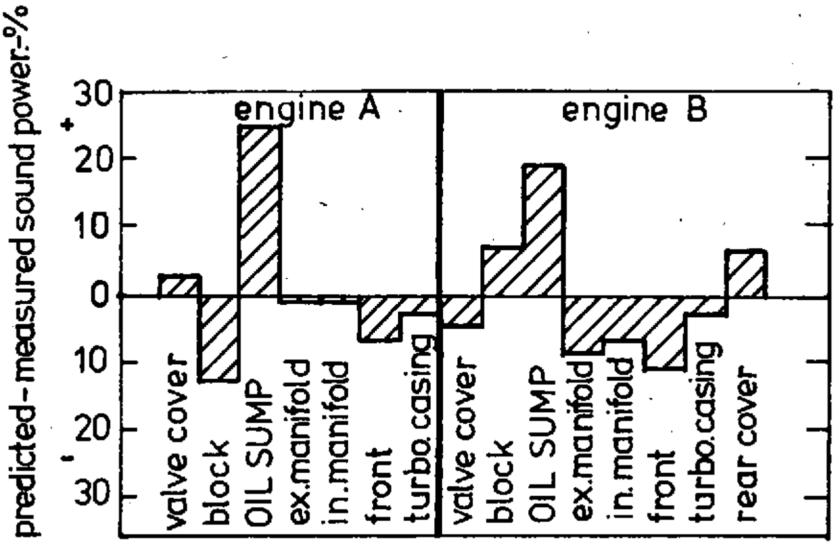

FIG. 2 - COMPARISON OF PREDICTED AND MEASURED SOUND POWER BALANCES.

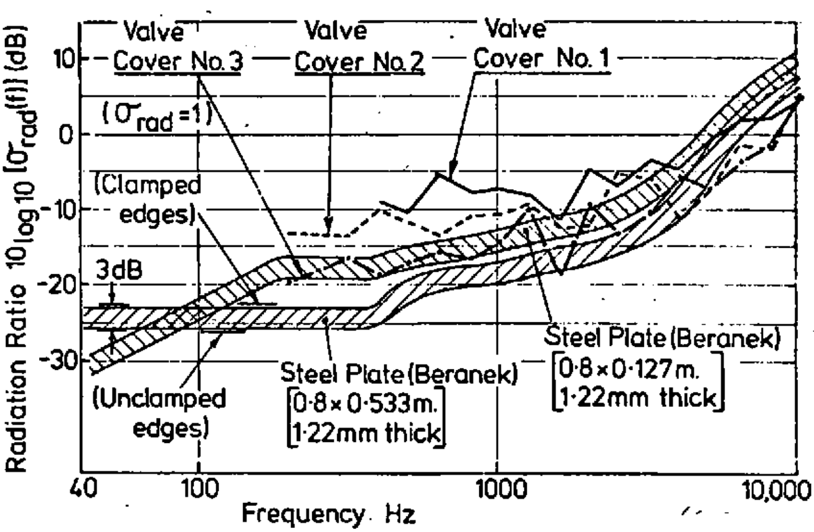

Fig. 3 MEASURED RADIATION RATIO FOR THIN STRUCTURES.