A METHOD TO PREDICT SOUND PRESSURE LEVELS RADIATED BY MACHINES AT THEIR DESIGN STAGE

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INTRODUCTION

To date there are essentially two methods available for predicting sound pressure levels around a machine, having first obtained vibration information. One method involves the acoustic finite element technique whilst the other method uses multiple input single output linear system theories. The first method has always been found to be very difficult even in the case of simple sound sources and the second involves a great deal of computation and can only be used to evaluate the effect of changing the design of existing machines. This paper shows how acoustic modelling can be used to approximate the transfer functions in the second method and thus avoid the need for long computation and experiment. Results obtained by the new method are compared with measured data from a full scale drop hammer.

MULTIPLE INPUT SINGLE OUTPUT LINEAR SYSTEM

The process by which the vibrational energy in industrial machines is converted into sound energy can be considered as a linear process. Therefore one can study this process by using multiple input single output linear system theories. The entire theories describing such a system (Fig 1) is governed by two basic equations:

$$G_{yy}(f) = \sum_{i=1}^{N} \sum_{j=1}^{N} H_i^*(f)\, H_j(f)\, G_{ij}(f) + G_{zz}(f) \qquad (1)$$

and

$$G_{iy}(f) = \sum_{j=1}^{N} H_j(f)\, G_{ij}(f) \qquad i=1,2,\ldots\ldots N \qquad (2)$$

Until now equation (2) together with experimental data have been used to obtain the transfer functions $H_i(f)$ needed in Equation (1) to calculate the auto energy spectrum $G_{yy}(f)$ of the sound output. Solving equation (2) is very tedious and the set of transfer functions obtained is only valid for the particular point. The next section describes how the transfer functions can be approximated by the use of simple acoustic models thus making it unnecessary to establish them by experiment and very tedious computation.

ACOUSTIC MODELS

In the same way Skudryzk |1| could theoretically predict the mean line through the frequency response curve of complex vibrators one can provide mean lines through the transfer function in equation (1) by acoustic modelling. Idealised sound sources are used in the acoustic model to represent the acoustical properties of the various machine elements. This modelling approach has obvious limitations if applied to complicated machinery but is readily applicable to any machinery which can be identified as having discrete sound source components. The acoustic models used to describe a full scale drop hammer shown in Fig 2 are presented in Fig 3.

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TRANSFER FUNCTIONS FOR THE MODELS

The theoretical transfer functions relating the space averaged acceleration on each machine element to the pressure in the sound field is given in reference |2|. They are:

$$H(f) = \rho_o \frac{a^2}{r} \frac{1}{1+jka} e^{-jk(r-a)}$$ for pulsating spherical sound source (4)

$$H(f) = \rho_o \frac{a^3}{r^2} \cos\theta \frac{(1+jkr)}{2-(ka)^2+j2ka} e^{-jk(r-a)}$$ for oscillating spherical sound source (5)

$$H(f) = \rho_o \frac{c}{w} \frac{J_o(kr) - jY_o(kr)}{J_1(ka) - jY_1(ka)}$$ for pulsating circular cylinder (6)

ACCELERATION AND SOUND PRESSURE MEASUREMENTS

Acceleration signals were taken at the positions shown in Fig 2 and sound pressure were taken at positions shown in Fig 4. It was assumed that symmetrical hammers would radiate in a similar way into each quadrant and sample points in other quadrants confirmed this. All measurements were taken with die to die blows to obtain good repeatability of force/time history. The average acceleration spectrum which were measured are shown in Fig 8.

MEASURED AND PREDICTED TRANSFER FUNCTIONS $|H_i(f)|$

Figure 5, 6 and 7 show the measured and predicted transfer functions. The theoretical mean values from the modelling are in good agreement with those evaluated by experiment. Only for the column the theory and experiment show opposite trends at low frequencies. In practical cases we are not interested in very low frequency information (< 50 Hz) and this model should not produce serious error in Leq calculations between 50 Hz and 6000 Hz.

MEASURED AND PREDICTED L_{eq} VALUES (40 ms, 50 Hz - 6kHz)

The Leq values measured at positions shown in Fig 4 are given in Fig 9. On the same figures the predicted values using the two models are also shown. The operator position or in this case area is typically between positions 5A and 6A, at a height of ≈ 2m. Agreement between predicted and measured values at this position (see Fig 8) with either model is accurate to within 1 dB.

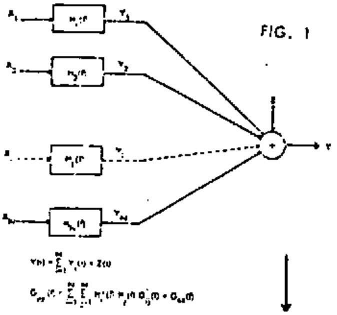
CONCLUSIONS

Simple acoustic models can be successfully used to approximate transfer functions between vibration and sound pressure thus long computer times and experimental measurement is avoided. This method completes the chain of calculations whereby the vibration information can now be transformed theoretically with ease into sound pressure levels. The modelling technique is restricted to use with industrial machines which can be identified as a combination of separate sound sources.

REFERENCES

1. E SKUDRZYK, 1980, JASA 67, 1105-1135. The mean-value method of predicing the dynamic response of complex vibrators.
2. R K JEYAPALAN and N A HALLIWELL (Accepted for publication in Applied Acoustics 1981). Machinery noise predictions at the design stage using acoustic modelling.

A METHOD TO PREDICT SOUND PRESSURE LEVELS RADIATED BY MACHINES AT THEIR DESIGN STAGE



MULTIPLE INPUT SINGLE OUTPUT LINEAR SYSTEM MODEL

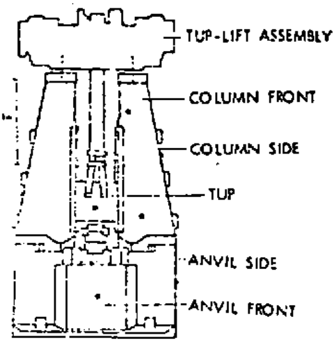


FIG. 2 THE FORGE HAMMER AT THE D.F.R.A.
• - ACCELEROMETER POSITIONS

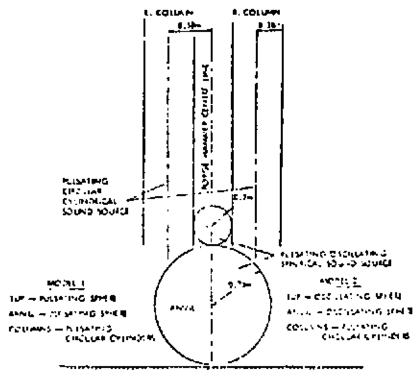
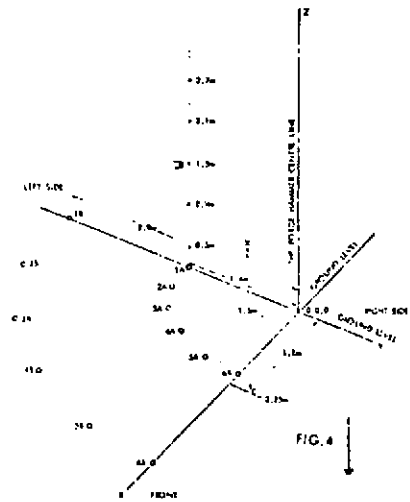
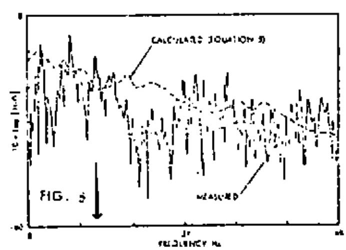


FIG. 3 ACOUSTIC MODELS FOR THE D.F.R.A. FORGE HAMMER

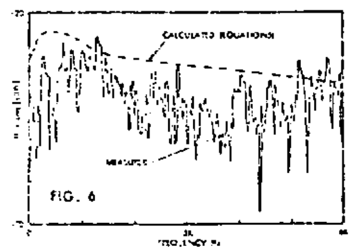


THE SOUND PRESSURE MEASUREMENT POINTS, "x"- MICROPHONE POSITIONS.



THE AVERAGE VALUE OF THE TRANSFER FUNCTION |H(f)| BETWEEN THE SOUND PRESSURE AT THE POINT 1.2m x 0.25m x 1.5m (see Fig.4) AND THE ACCELERATIONS ON THE ANVIL.

THE AVERAGE VALUE OF THE TRANSFER FUNCTION |H(f)| BETWEEN THE SOUND PRESSURE AT THE POINT 1.2m x 0.25m x 1.5m (see Fig.4) AND THE ACCELERATIONS ON THE TUP SURFACE. →



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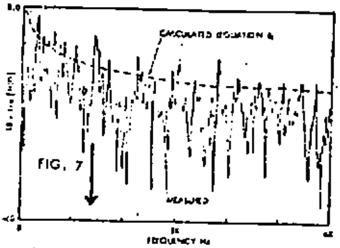

THE AVERAGE VALUE OF THE TRANSFER FUNCTION |H(f)| BETWEEN THE SOUND PRESSURE AT THE POINT 1.2m x 0.25m x 1.5m (see Fig. 4) AND THE ACCELERATIONS ON THE RIGHT COLUMN.

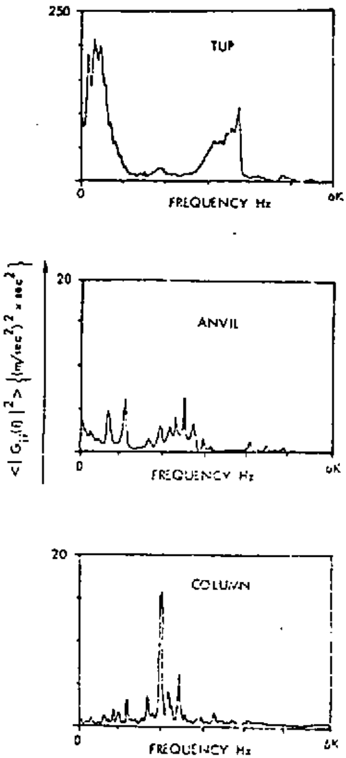

FIG. 8 SPACED AVERAGED ACCELERATION SPECTRUM

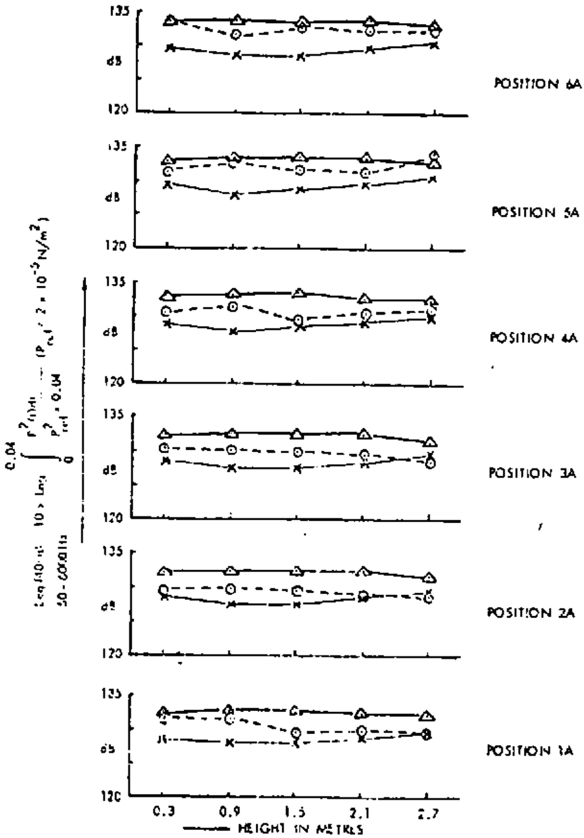

FIG. 9 COMPARISONS OF MEASURED AND PREDICTED Leq (40ms) FOR THE POINTS SHOWN IN FIG 4 ⊙ - MEASURED, △ - BY MODEL ONE; x - BY MODEL TWO