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MEASUREMENT OF STATISTICAL ENERGY ANALYSIS PARAMETERS BY A TRANSIENT TEST METHOD

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1. INTRODUCTION

Statistical Energy Analysis (SEA) was developed several years ago to tackle noise and vibration problems associated with systems having a high modal density (e.g. reference 1). The analysis scheme is based on the steady-state energy balance between predetermined sub-assemblies (called "subsystems") of the overall system, within a frequency band broad enough to include sufficient modes for an "average" mode to be a meaningful concept. Initially SEA was envisaged as a method of predicting noise/vibration levels at the design stage. More recently interest has also been focussed on setting up an SEA model of an existing system by measurement alone, both to analyse an existing problem and to explore the effect of design extrapolations. Bies and Hamid showed [2] how the SEA parameters (internal loss and coupling loss factors) necessary to construct the model could be measured on the complete built-up system, provided it was relatively simple. Recently Lalor [3] has developed this method so that any complex system can be modelled. However, the number of measurements required to construct these models is large and therefore, if employing normal shaker excitation technique, is very time consuming. This paper gives details of a novel method of obtaining the same SEA parameters, using an instrumented hammer, with subsequent considerable saving in time. Comparison of results with those obtained by the conventional shaker method, shows good agreement for a number of structures.

2. THEORY

The power balance equations for a system of N connected substructures can be described as follows.

$$\bar{P}_{ik}/\omega = \bar{E}_{ik}\sum_{j=1}^{N}\eta_{ij} - \sum_{\substack{j=1 \\ j\neq i}}^{N}\bar{E}_{jk}\eta_{ji} \qquad (1)$$

where, $\bar{P}_{ik}$ = external power input to the i th system

$\bar{E}_{ik}$ = energy of i th system

$\bar{E}_{jk}$ = energy of j th system

η_{ii} = internal loss factor of i th subsystem ($= \eta_i$)

η_{ij} = coupling loss factor from i th subsystem to j th subsystem.

The index k is introduced to indicate that the subscripted quantities are those under the excitation of k th subsystem. If each subsystem is excited in turn, the following equations can be obtained.

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$$\begin{bmatrix} \overline{P}_{11}/\omega & 0 & \cdots & 0 \\ 0 & \overline{P}_{22}/\omega & \cdots & 0 \\ \cdots & & & \\ 0 & 0 & \cdots & \overline{P}_{NN}/\omega \end{bmatrix} = \begin{bmatrix} \eta_1+\eta_{12}+\cdots+\eta_{1N} & -\eta_{21} & \cdots & -\eta_{N1} \\ -\eta_{12} & \eta_2+\eta_{21}+\cdots+\eta_{2N} & \cdots & -\eta_{N2} \\ \cdots & & & \\ -\eta_{1N} & -\eta_{2N} & \cdots & \eta_N+\eta_{N1}+\cdots+\eta_{N(N-1)} \end{bmatrix} \begin{bmatrix} \overline{E}_{11} & \overline{E}_{12} & \cdots & \overline{E}_{1N} \\ \overline{E}_{21} & \overline{E}_{22} & \cdots & \overline{E}_{2N} \\ \cdots & & & \\ \overline{E}_{N1} & \overline{E}_{N2} & \cdots & \overline{E}_{NN} \end{bmatrix}$$

or

$$[\overline{P}/\omega] = [\eta][\overline{E}] \tag{2}$$

To characterise the system, the loss factor matrix $[\eta]$ must be obtained. The process of the conventional method is as follows. While the k th subsystem is excited by a shaker, the measurement of input power $\overline{P}_{kk}$ at the excitation point and stored energies in each subsystem $\overline{E}_{ik}$, are made. They are calculated by these equations.

$$\overline{P}_{kk} = \mathrm{Re}\{G[f_k,v_k]\} = (1/\omega)\ \mathrm{Im}\ \{G[f_k,a_k]\} \tag{3}$$

$$\overline{E}_{ik} = m_i\ G[v_i,v_i]_k = (1/\omega)^2\ m_i\ G[a_i,a_i]_k \tag{4}$$

where, $G[,]$ = cross spectrum function
m_i = mass of i th subsystem.

Instead of the above mentioned direct measurement, the input power and sybsystem energies may be calculated by the following equations.

$$\overline{P}_{kk} = G[f_k,f_k]\ \mathrm{Re}[M_{kk}] = (1/\omega)\ G[f_k,f_k]\ \mathrm{Im}[I_{kk}] \tag{5}$$

$$\overline{E}_{kk} = m_i\ G[f_k,f_k]\ |M_{ik}|^2 = (1/\omega)^2\ m_i\ G[f_k,f_k]\ |I_{ik}|^2 \tag{6}$$

where, M_{ik} = mobility ($= v_i/f_k$)

I_{ik} = inertance ($= a_i/f_k$)

Hence, if unit force is assumed, $\overline{P}kk$ and $\overline{E}ik$ are obtained by the measurement of point and transfer inertances. This process can be achieved by an instrumented hammer if the structure is linear.

3. RESULTS

Measurements were made on two thin plates spot welded together. The measured internal loss factors of plate 1 from the transient test and the conventional stationary test are shown in Figure 1. The results from both tests agree very well, with a discrepancy of less than 3 dB. The comparison of coupling loss factors obtained from the two methods is shown in Figure 2. These results also give good agreement. In this measurement, careful attention should be paid to the measurement of point inertance, with the force and acceleration signals at exactly the same point on the structure. Similar measurements were then made on more complex structures. Here the maximum error increases to 8 dB at certain frequencies, although the general trends were identical.

The quick and easy transient method thus shows considerable promise. Furthermore, this method does not suffer from the problems caused by the constraint and loading of the structure by a shaker. However, there are inevitable disadvantages. For example, the excitation due to impact is likely to be small and the energy input may not be large enough to excite the subsystems far from the excitation point.

4. REFERENCES

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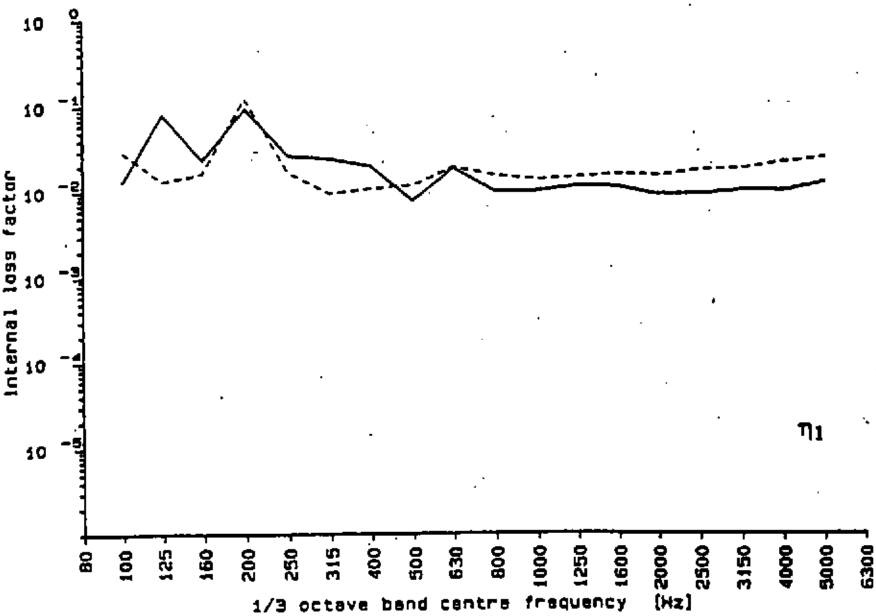

Fig. 1 Internal loss factors of structure (I) measured by a transient test (——) and the conventional one (– – –)

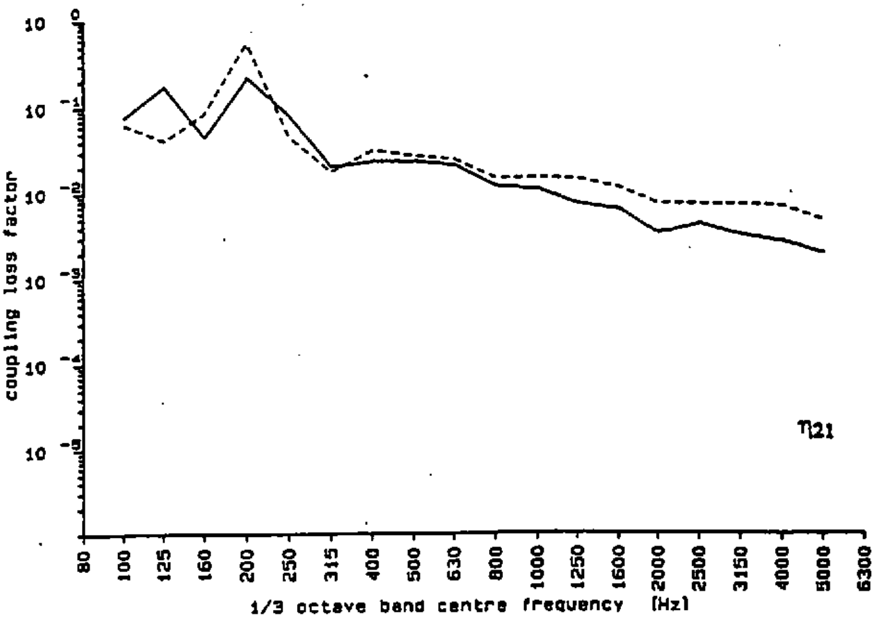

Fig. 2 Coupling loss factors of structure (I) measured by a transient test (——) and the conventional one (– – –)