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ESTIMATION OF THE VIBRATIONAL POWER SUPPLIED BY THE EXCITATION FORCE OF MACHINERY TO THE SUPPORTING STRUCTURE

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1 INTRODUCTION

If a machine that generates excitation force is fixed to its supporting structure, for example, building, ship, etc., structureborne sound will be radiated from the supporting structure. To estimate the pressure of the structureborne sound by the statistical energy analysis, the value of the vibrational power supplied by the machine to the supporting structure must be known. The vibrational power could be evaluated using the mechanical impedance of the supporting structure and the vibrational velocity at the points where the machine is connected to the supporting structure. Since it is not always possible to detach the machine from the supporting structure, this paper proposes a method to estimate the mechanical impedance of the supporting structure at the connecting points under the condition that the machine and the supporting structure are connected together. First, a theory for estimating mechanical impedance is derived. And then, to examine the validity of the theory, estimation and measurement of mechanical impedance and vibrational power were performed using a theoretical model and an experimental setup.

2 THE ESTIMATION THEORY OF VIBRATIONAL POWER

If the machine is connected to the supporting structure at n points, the vibrational power supplied via point i is written as,

$$P_i = \frac{1}{2}\mathrm{Re}\left\{F_i V_i^*\right\} = \frac{1}{2}\mathrm{Re}\sum_{j=1}^{n}\left\{Z_{ij} V_j V_i^*\right\} i = 1 \cdots n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (1)$$

where **F**,**V** and **Z** are force, velocity and mechanical impedance in the form of matrices.

The estimation theory is derived using a model shown in Fig.1. In the derivation of the following theory, it is necessary that vibration isolators are inserted between the machine and the supporting structure. Subscripts **a** and **b** means points on the machine, and **c** and **d** points on the supporting structure. Points with subscripts **b** and **c** are the top and bottom of the vibration isolators. As for other subscripts, the former means the response points and the latter the excitation points. Practically excitation force is given at points **a** and **d**. Velocities in Eq.(1) should be measured at point **c**.

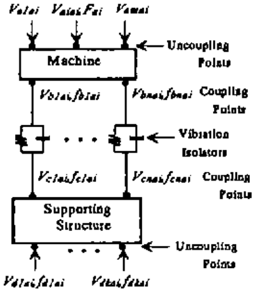

Fig.1 Model of machine and supporting structure.

Let **T** be the mobility of the connected structure, **G** the mobility of the machine, and **H** the mobility of the supporting structure, **V** the velocity at the connecting points, **F** the excitation force and **f** the force in the isolators, all being in the form of matrices.

If **F** is applied at the points **a**, the following equations are given. For the connected structure,

$$V_{aa}=T_{aa}F_a,\quad V_{ba}=T_{ba}F_a,\quad V_{ca}=T_{ca}F_a,\quad V_{da}=T_{da}F_a \cdots\cdots\cdots\cdots (2)$$

For the machine,

$$V_{aa}=G_{aa}F_a+G_{ab}f_{ba},\quad V_{ba}=G_{ba}F_a+G_{bb}f_{ba} \cdots\cdots\cdots\cdots (3)$$

For the supporting structure,

$$V_{ca}=H_{cc}f_{ca},\quad V_{da}=H_{dc}f_{ca} \cdots\cdots\cdots\cdots (4)$$

Using these equations, $\mathbf{H_{cc}}$, the mobility of the connected structure at the points **c**, is derived as follows.

$$H_{cc}=T_{ca}T_{da}^{-1}\left\{T_{cd}^{T}-T_{bd}^{T}\left(T_{ba}^{T}\right)^{-1}T_{ca}^{T}\right\}\left\{I-\left(T_{ba}^{T}\right)^{-1}T_{ca}^{T}\right\}^{-1} \cdots\cdots\cdots\cdots (5)$$

Thus, if mobilities of the connected structure $\mathbf{T_{ba}}$, $\mathbf{T_{ca}}$, $\mathbf{T_{da}}$, $\mathbf{T_{bd}}$ and $\mathbf{T_{cd}}$ are measured by applying excitation forces to the points **a** and **d**, The mechanical impedance $\mathbf{Z_{cc}}$ that is necessary to estimate the vibrational power can be obtained as the inverse of $\mathbf{H_{cc}}$.

3. THEORETICAL EXAMINATION

3.1 Theoretical model Since Eq.(5) was complicated, its reliability was examined using a theoretical model, in which the machine was modelled by a uniform beam and the supporting structure was also modelled by a uniform beam supported by two sets of parallel spring and damper. Two beams were connected also by two sets of parallel spring and damper. Mobilities T_{ba} etc., forces and velocities at the connecting points were theoretically calculated.

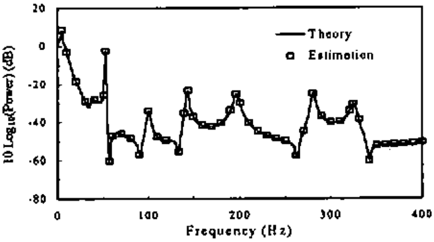

Fig.2 Theoretical and estimated vibrational power.

3.2 Result of Examination Figure 2 shows two vibrational powers. The theoretical power was obtained as the time average of the product of forces and velocities at the connecting points, and the estimated power was obtained using Eq.(5). Figure 2 shows the Reliability of Eq.(5).

4 EXPERIMENTAL EXAMINATION

4.1 Experimental Setup The experimental setup is shown in Fig.3. The machine was modelled by an electro- magnetic exciter mounted on a 500 × 400 × 2mm steel plate. The supporting structure was a 700 × 600 × 2mm steel plate mounted on four vibration isolators on a big steel bed. The excitation force of the machine was given by the inertia force of the circular steel disc (1.78kg) mounted on the top plate of the exciter. Four vibration isolators were inserted between the upper plate and the lower plate. Accelerometers and load cells were installed as shown to measure vibrational power as the product of force and velocity.

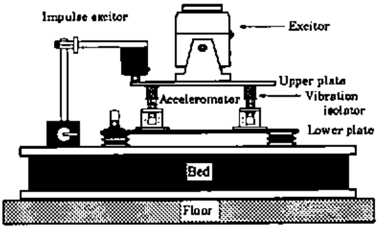

Fig.3 Schematic diagram of the machine- isolator- supporting structure configuration.

4.2 Measurement and Estimation Followings were performed.

(1) Direct measurement of $\mathbf{H_{cc}}$ with the machine detached.

(2) Estimation of $\mathbf{H_{cc}}$ by Eq.(5) using mobility $\mathbf{T_{ba}}$ etc. of the connected structure measured by applying excitation forces to points **a, d** on the both plates.

(3) Measurement of vibrational power using accelerometers and load cells installed at the connecting points.

(4)Estimation of vibrational power using H_{cc} (measured and estimated) and measured velocity.

4.3 Results of experiments Several results are as follows.

(1)Figure 4 shows measured and estimated mobilities at a connecting point.

(2)Figure 5 shows vibrational power via a connecting point. Measured power was obtained in 4.2.(3) and estimated power was obtained by measured H_{cc} and measured velocity(estimation 1).

(3)Figure 6 shows two estimated total powers. Esatimation 1 was made as stated above, and estimation 2 was made using H_{cc} given by Eq.(5) and measured velocities at the connecting points.

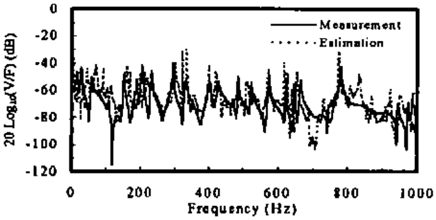

Fig.4 Comparison of measured and estimated mobilities

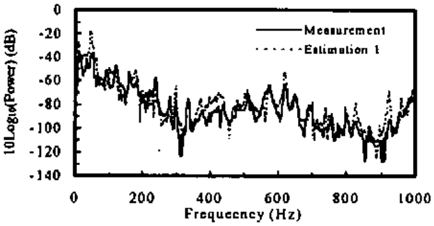

Fig.5 Comparison of measured and estimated vibrational powers

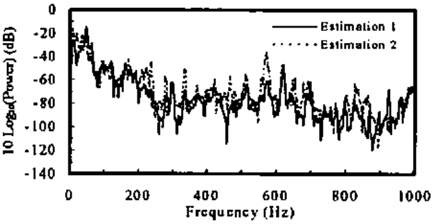

Fig.6 Comparison of estimated total vibrational powers

5 CONCLUSIONS

(1) if it is not possible to detach a machine from its supporting structure, the mechanical impedance at the connecting points can be estimated using measured mobilities of the connected structure.

(2) The vibrational power supplied to supporting structure can be estimated by using the estimated mechanical impedances and measured velocities at the connecting points.