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METHOD TO DETERMINE STRUCTURE-BORNE NOISE LEVEL FROM MACHINERY IN SEA APPLICATION

Sang R. Kim, Jae S. Kim, Hyun S. Kim, and Hyun J. Kang

Acoustics Research Group, KIMM
P.O. Box 101, Yusung
Daejeon, 305-600, Korea

ABSTRACT

Statistical energy analysis is one of popular analytical methods for the prediction of shipboard noise levels. When applying SEA to ship structures, the evaluation of source levels of structure-borne noise from machinery such as propulsion engines, generators, and etc. is important, because noise levels of compartments far from noise sources are determined by the structure-borne noise. However the evaluation of input power from structure-borne noise sources is not clear compared with that from air-borne noise sources.

In this paper, results of a statistical energy analysis for a machinery foundation are compared for different source models. The source models used in the study are; 1) applying the measured vibration level directly on the source plate, 2) estimating the input power by use of mobility and velocity, and 3) adopting the measured power levels.

1. INTRODUCTION

SEA[1] is known to be one of practical methods available for the prediction of noise onboard ships based on theoretical background. In order to apply SEA, it is required to define power input from external exciting forces. For the case of air borne noise source, the energy input to structure is represented by means of its acoustic power which is well defined. The acoustic power is the characteristics of noise source itself for most cases and the measuring method has been standardized[2].

As for structure-borne noise sources, the international standard of the measurement is appeared recently[3]. But, the qualitative and quantitative representation of their source levels have been actively studied until now[4], although free vibration at mounting points of a machinery has been commonly used as structure-borne noise source levels. This is partially due to the fact that the vibration at machinery feet are affected by the surroundings of the machinery such as foundation structures as well as its own characteristics.

For example, no motion would be allowed at the contact points between the machinery and the foundation if the stiffness of the foundation is infinite. It means that the power input to receiving structures is zero for any machinery. In other words, the source levels are determined by supporting structures only that is impossible for real systems. In real systems, machinery vibration at its feet transmits to structures in consideration through mounting points due to the finite stiffness of the foundation. Therefore in order to get power input to structures, vibration of machinery and stiffness of the foundation at contact points must be considered at the same time.

In this paper, a comparison of SEA result of a machinery foundation is described. The source models adopted are prescribing the vibration level at the source plate, applying power input calculated from vibration and point mobility, and using measured power directly.

2. MOBILITY

The mobility(M) of a structure is defined as the ratio of force(F) applied and velocity(V) at a position of the structure, both of which have magnitude and phase.

$$M = \frac{V}{F}$$

Particularly, if the driving point is identical to the position where velocity measured it is called the driving point mobility. The driving point mobilities of infinite beam and infinite plate are also called the characteristic mobilities and they are calculated rather easily[5].

The driving point mobility of finite structure varies from a point to the other point and it changes considerably with frequencies because of resonance effects of the structure. The resonant frequencies could be calculated by numerical methods such as finite element method(FEM) for complex structures. Although FEM is useful to get resonant frequencies for lower mode vibrations, it is impractical for higher mode vibrations.

As the frequency increases, the vibration is characterized by the average resonance behavior rather than individual resonant mode. According to this fact, the concept of modal density, averaged squared-velocity, and so on were introduced. It is well known that the mobility of finite structures is equal to that of infinite structures at high frequencies in the average sense[5].

2.1 MOBILITY EXPERIMENT

An experiment in order to measure driving point mobility was carried out using the foundation model shown in fig.2.1, which is similar to Trach[6]. The experimental model consists of two parts; the first the source plate where external force acts and the other plates. The source plate is mainly responsible for accepting the magnitude of the power transmission from external source.

The experiment was carried out using two kind of foundation models with different thickness of source plate, i.e., 2mm and 5mm thick respectively. And the driving point mobility was measured using an excitor and an impedance head. A total of 6 measurement points are shown in fig.2.2.

2.1.1 MEASUREMENT RESULTS

Fig.2.3 shows results of driving point mobilities measured in the case of 2mm-thick source plate model. Note that mobilities for different points differ each other, particularly at low frequencies. In the low frequency region, the magnitude shows a tendency to increase with frequencies and peak at certain frequencies. These peaks are related to the resonance of the subsystem of the model. In the high frequency region, it has many peaks but there is the almost constant mean level independent of driving points. Similar results was shown in the case of 5mm model.

The comparison of 2mm model and 5mm model is shown in fig.2.4. The mobilities of the two models are measured at the same position but one is considerably different from the other. The difference is due to the thickness of the source plate of each model. Specifically, mobility of thin plate is higher than that of thick plate in the average sense.

2.2.2 NUMERICAL CALCULATION

In order to calculate the mobility of the models mentioned before, an FEM analysis was performed using ANSYS. Fig.2.5 represents the comparison of the measured and numerical results. The tendency of mobility from numerical result agrees with the measured one with reasonable accuracy for low frequencies, although the peak value shows a large differences. It is believed that the difference comes from the inaccuracy of damping factors in the numerical analysis.

Owing to the calculation time required and the limit of memory of a computer, such a numerical method is generally practical for low frequencies, say up to few hundreds hertz depending on the FEM model. In this study, the upper frequency of the analysis was limited to

300Hz on the account of such restrictions. And 80 resonant modes were utilized to get mobility of the model.. It took about ten hours to get the result shown in the figure using workstation HP WS C110.

2.2.3 SIMPLIFED MOBILITY CALCULATION

As stated in 2.2.2, it takes computing time too long to be practical to calculate mobility of real structures up to few thousands hertz required for most noise control problems. Moreover, FEM analysis for such a high frequency region also requires for smaller element size than the wave length of the structure. Therefore if we could simplify the calculation of mobility, the simplified method have a great advantage in a practical sense.

A simplified mobility curve is also shown in fig. 2.5. The horizontal straight line of the simplified mobility in the region of high frequencies is equal to the mobility of infinite plate and the inclined straight line in the region of low frequencies corresponds to the mobility calculated from the static stiffness of the whole structure at the exciting point. The stiffness of the whole structure was calculated numerically using ANSYS. Note that the simplified mobility curve fitted well with the experiment in the average sense.

3. STRUCTURE-BORNE NOISE ANALYSIS OF FOUNDATION MODEL

3.1 EXPERIMENT

Structure-borne noise measurement of the machinery foundation model was performed with an air compressor mounted on the model as a noise source. The air compressor was rigidly connected to the model at three positions and the inner pressure of the air compressor was uniformly kept during the experiment.

The acceleration levels were measured at three random points of each plate and the averaged value of those levels was taken as the averaged acceleration level of the plate. And the acceleration and exciting forces at the mounting points were measured to get power transmitted to the foundation model from the air compressor.

3.2 APPLICATION OF SEA

A numerical model of the foundation made up of 54 SEA elements was used for the theoretical analysis. The plate element was modeled with bending and inplane modes.

As for the source level, estimations from 3 methods were applied. The first method was to restrict the acceleration level of the source plate as the measured ones. The second one was to apply power inputs estimated from the measured acceleration levels at the driving points and simplified mobility curve. And the last was to use the measured power input.

A typical result is shown in fig.3.1. This figure represents the comparison of the measured acceleration of plate ⓐ in fig. 2.1. In the figure, the line 'measured mob.' stands for the case of using the measured mobilities and accelerations of connecting points as input power to the foundation model. The line 'estimated mob.' represents the result with the simplified mobility and accelerations measured. The line 'squared vel.' is the case that the averaged squared velocity was utilized as input power.

The result of 'estimated mob.' and 'measured mob.' agrees with the measured result., while the result of 'squared vel.' shows a slightly different behavior.

4. CONCLUSION

The study on the mobility of a foundation was carried out to estimate the amount of power flow from source into the structure and a method to evaluate mobility of complex structures by simple calculations was proposed. A SEA application to a machinery foundation shows the usefulness of the proposed method of the mobility estimation.

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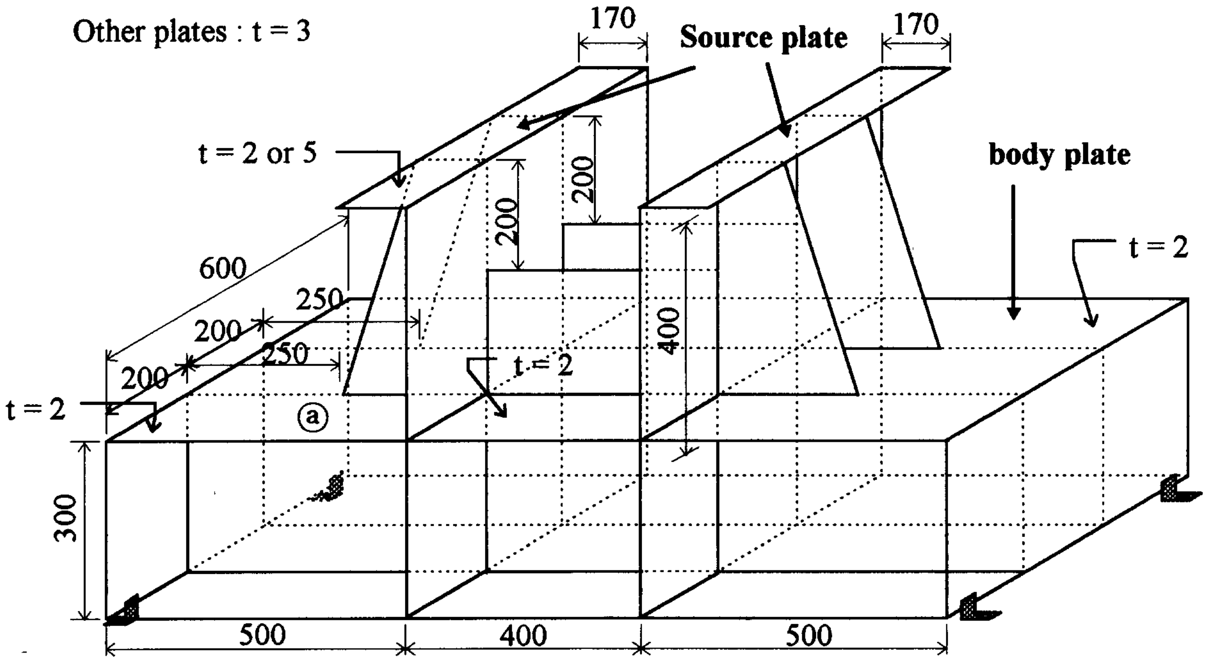

Fig.2.1 Experimental model of a foundation(unit : mm)

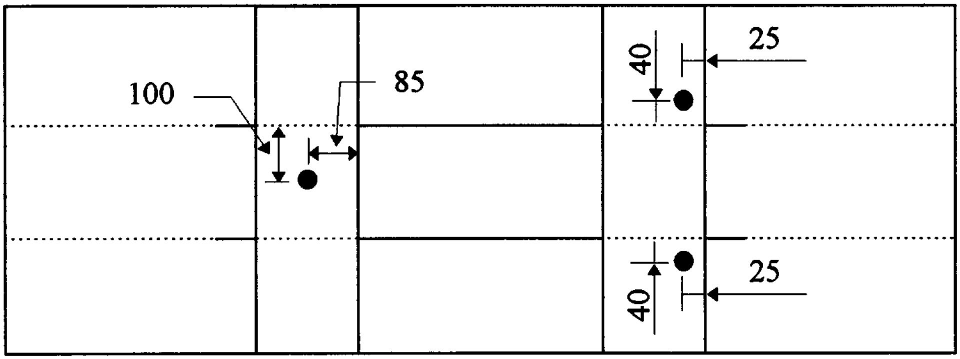

Fig.2.2 Positions for mobility measurement(unit : mm)

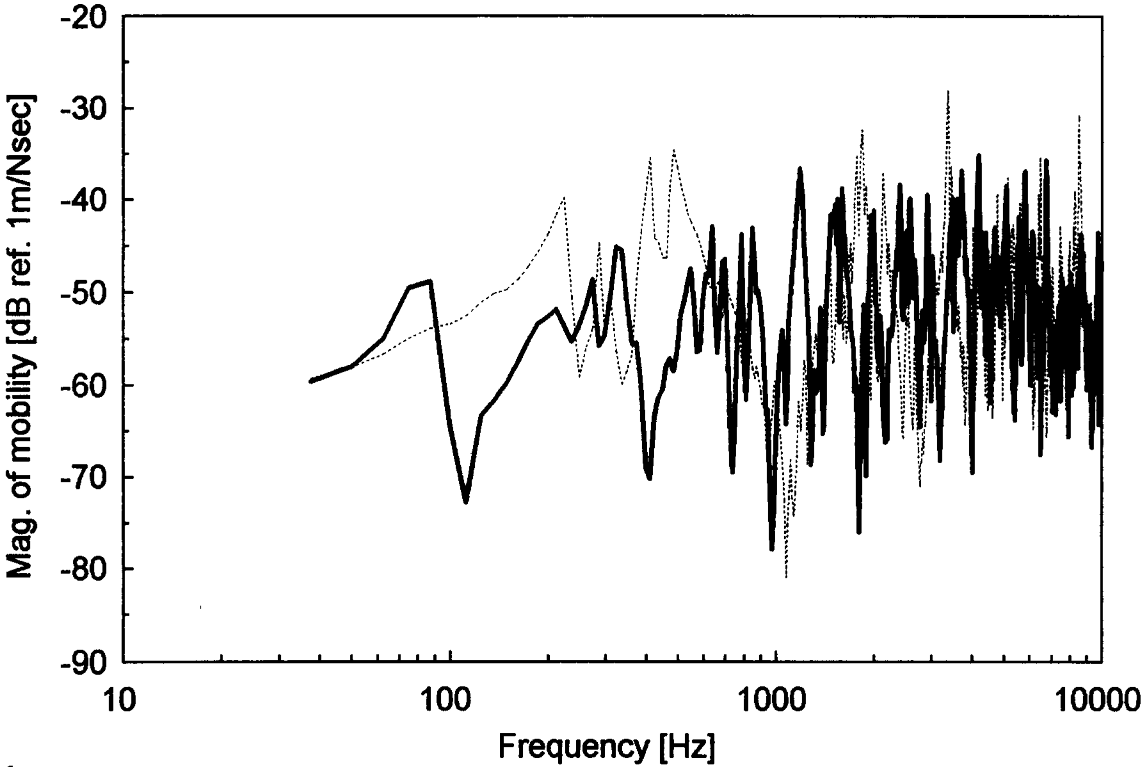

Fig.2.3 Measured mobility of 2mm model

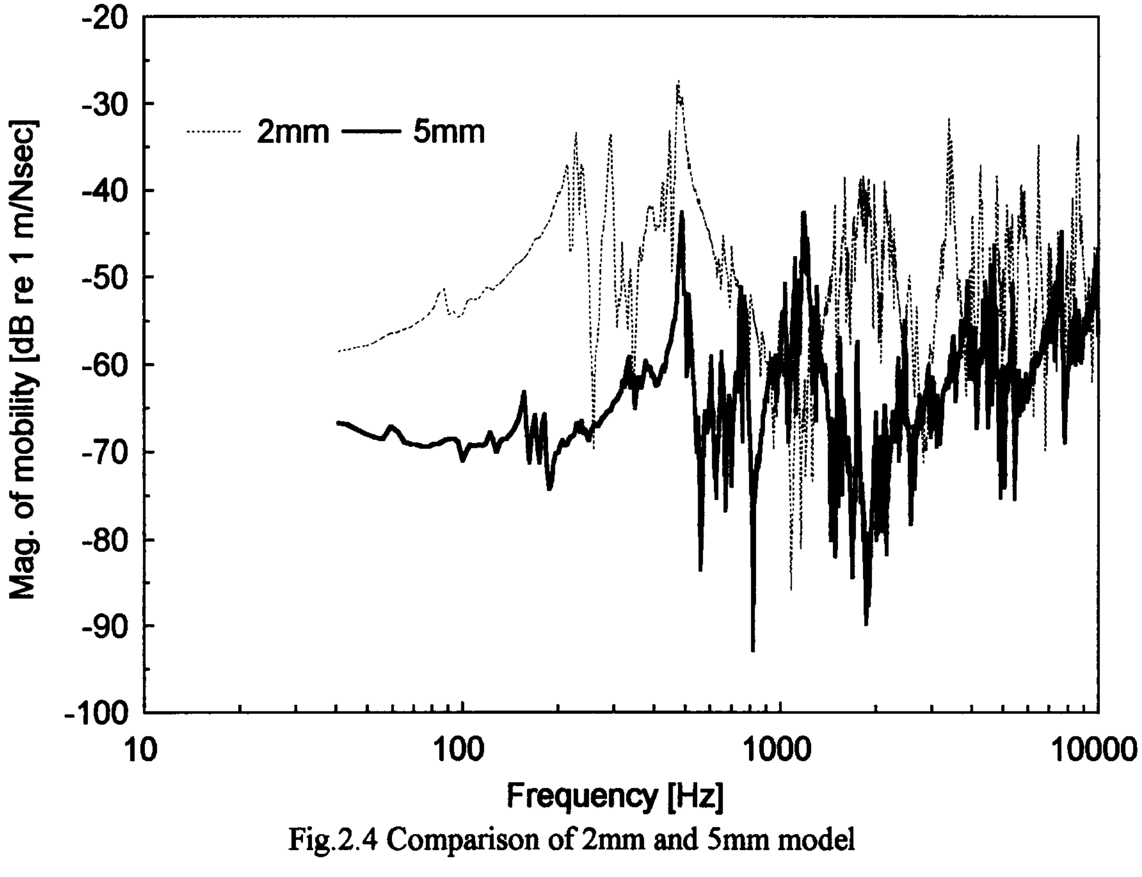

Fig.2.4 Comparison of 2mm and 5mm model

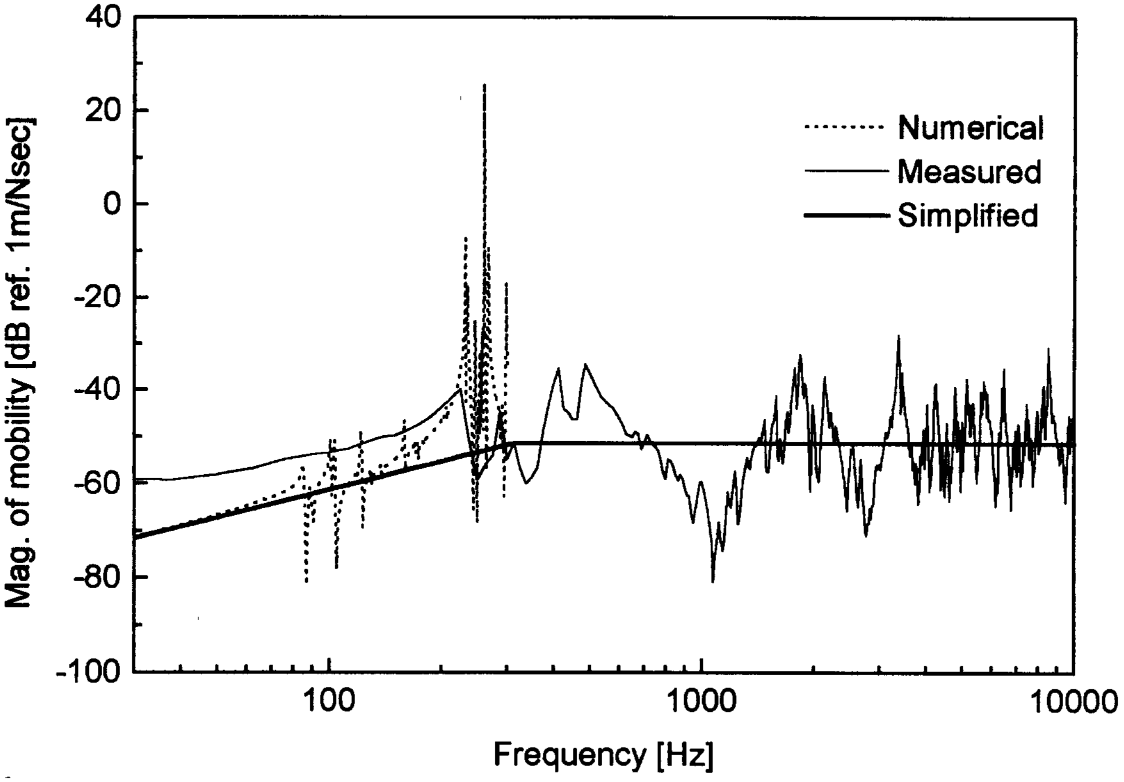

Fig.2.5 Comparison of numerical and measured results (2mm model)

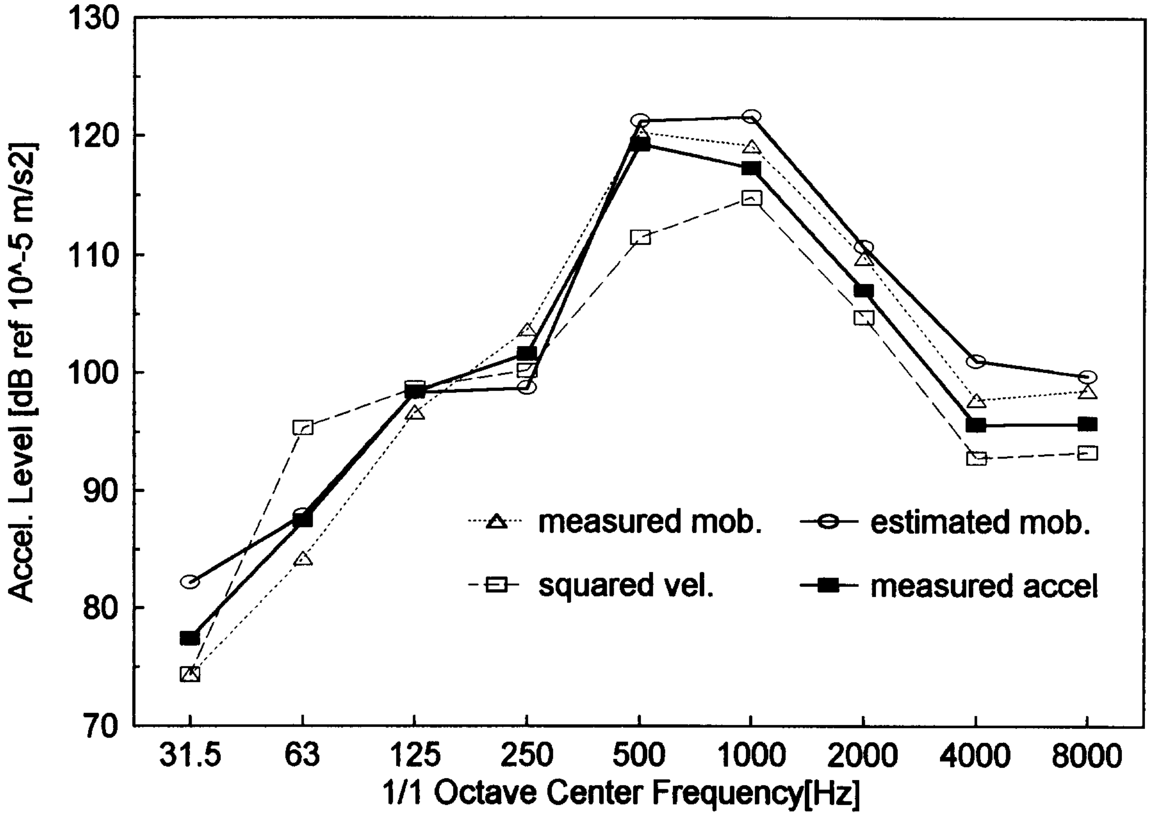

Fig.3.1 Acceleration of body plate ⓐ (2mm model)