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PROBABILISTIC EVALUATION OF TRANSMITTED SOUND BASED ON IMPROVEMENT OF INSULATING STRUCTURE SYSTEM FROM VIEWPOINT OF MODIFIED S.E.A. METHOD

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INTRODUCTION

For the purpose of obtaining a better acoustic life in our noise-filled living environment, including such as road traffic noise and airplane noise, most people find it necessary to make improvements in walls and/or windows. In this paper, a general and fundamental consideration for statistical evaluation of transmitted sound through an insulating structure is theoretically proposed, considering that the structure of the sound insulating system is changed by improvement work, such as double-walls and single-walls. This kind of systematical estimation method, about an improvement of noise reduction under the probabilistic evaluation, has not been so well reported up to now.

From the practical viewpoint of structural improvement , the next two cases are considered in this paper. One of them is the case when the acoustic characteristics of the structural material is changed from the viewpoint of quality. The other is the case when the geometrical dimensions of the structure is changed from the viewpoint of quantity. In our theory, any other parameters, such as acoustic characteristics and geometrical dimensions, need not be directly and individually estimated from an analytical viewpoint. A new trial of probabilistic evaluation, based on estimating only newly introduced characteristic parameters directly matched to the difference between the output response before improvement work, and the output response after improvement work, is considered by use of the Modified S. E. A. method (statistical energy analysis method).

Basically speaking , our theory has been experimentally confirmed by applying it to the actually observed data obtained in our acoustic laboratory. The results of our experiment are in good agreement with our theory.

THEORETICAL CONSIDERATIONS

To make good improvements in the sound insulating characteristics for a double-wall, the change of the relationship between the input and output must be considered according to the change of thickness of the panel. More concretely, we especially consider the change in panel thickness for only one of two panels in this case. The relationship between the sound energy of the input and that of the output for a double-wall has been consequently derived by the Modified S.E.A. method as follows [1],[2] :

$$\frac{D_R}{D_s} = \frac{\begin{vmatrix} \eta_{2t} & -\eta_{32} & 0 & \eta_{12} \\ -\eta_{23} & \eta_{3t} & -\eta_{43} & \eta_{13} \\ 0 & -\eta_{34} & \eta_{4t} & 0 \\ 0 & -\eta_{35} & -\eta_{45} & \eta_{15} \end{vmatrix}}{\begin{vmatrix} \eta_{2t} & -\eta_{32} & 0 & 0 \\ -\eta_{23} & \eta_{3t} & -\eta_{43} & -\eta_{53} \\ 0 & -\eta_{34} & \eta_{4t} & -\eta_{54} \\ 0 & -\eta_{35} & -\eta_{45} & \eta_{5t} \end{vmatrix}} \cdot \frac{V_s}{V_R} ,$$

with

$$\begin{cases} \eta_{2t} \equiv \eta_2 + \eta_{21} + \eta_{23} \\ \eta_{3t} \equiv \eta_3 + \eta_{31} + \eta_{32} + \eta_{34} + \eta_{35} \\ \eta_{4t} \equiv \eta_4 + \eta_{43} + \eta_{45} \\ \eta_{5t} \equiv \eta_5 + \eta_{51} + \eta_{53} + \eta_{54} \end{cases} . \qquad (1)$$

When the thickness of the panel is changed from t_1^0 to t_1^1, its form after modification can be expressed as $t_1^1 = t_1^0 / (1+\delta)$. Similarly, other factors can also be expressed in the same way as $\eta_2^1 = \eta_2^0(1+\delta)$, $\eta_{21}^1 = \eta_{21}^0(1+\delta)$, $\eta_{23}^1 = \eta_{23}^0(1+\delta)$, $n_2^1 = n_2^0(1+\delta)$, $\cdots$. After an improvement based on changing the thickness of the panel, the relationship between the input and output is analytically expressed by making use of the S.E.A. parameters (like η_i^0 , η_{ij}^0) obtained before changing its thickness and modification rate of the thickness δ . Thus, after evaluating the determinant based on the above change of thickness, Eq.(1) is rewritten as follows :

$$\frac{D_R}{D_s} = \frac{\begin{vmatrix} \eta_{2t}^0 & -\eta_{32}^0-\eta_{32}^0\Delta & 0 & \eta_{12}^0+\eta_{12}^0\Delta \\ -\eta_{23}^0 & \eta_{3t}^0+\eta_{31}^0\Delta' & -\eta_{43} & \eta_{13}^0+\eta_{13}^0\Delta' \\ 0 & -\eta_{34} & \eta_{4t} & 0 \\ 0 & -\eta_{35} & -\eta_{45} & \eta_{15}^0+\eta_{15}^0\Delta''' \end{vmatrix}}{\begin{vmatrix} \eta_{2t}^0 & -\eta_{32}^0-\eta_{32}^0\Delta & 0 & 0 \\ -\eta_{23} & \eta_{3t}^0+\eta_{31}^0\Delta' & -\eta_{43} & -\eta_{53} \\ 0 & -\eta_{34} & \eta_{4t} & -\eta_{54} \\ 0 & -\eta_{35} & -\eta_{45} & \eta_{5t}^0+\eta_{51}^0\Delta''' \end{vmatrix}} \cdot \frac{V_s}{V_R} ,$$

with

$\Delta \equiv 2\delta+\delta^2$, $\Delta' \equiv \Delta - K_1(1+\Delta)\, ln(1+\delta)$, $K_1 \equiv 1 / ln\{\omega\rho_m t_1^0/2\rho c\}$, $\Delta'' \equiv 2\delta'+\delta'^2$, $\delta' \equiv t_1\delta / (t_1+t_2+t_2\delta)$, $\Delta''' \equiv \Delta_o + \Delta'' - K_2 \cdot (1+\Delta'')\, ln(1+\delta') + \Delta_o\{\Delta'' - K_2(1+\Delta'')\, ln(1+\delta')\}$. (2)

Bringing the effect caused by the thickness change of panel into relief, Eq.(2) can also be expressed as follows :

$$\frac{D_R}{D_s} = \frac{1 + \Delta_2 C + \Delta_2' C' + \cdots\cdot}{A + \Delta_1 B + \Delta_1' B' + \cdots\cdot} \cdot \frac{V_s}{V_R} \longrightarrow \alpha \,, \qquad (3)$$

where A corresponds to the noise reduction before modification of the thickness of the panel.
After once identifying the structural parameters (A, B,B', ··· , C,C', ···) in Eq.(3) by use of the actural noise excitation, the evaluation of the noise reduction due to the arbitrary change of panel thickness can be accomplished. First, the parameters (A,B,B', ··· ,C,C', ···) in Eq.(3) are identified by the recursive estimation algorithm based on a stochastic approximation method well matched to the observed actual data by taking one by one under the well-known least-square type error criterion. As touched on in the above , this is not an analytical identification of the acoustic characteristic parameter or geometrical parameter. That is , taking the background noise V from the outside of the room (in a form of mean value < V >) into consideration , the error evaluation due to the identification can be expressed as :

$$\varepsilon = D_R - \alpha \cdot D_s - \langle V \rangle \,. \qquad (4)$$

By use of the least-square type error criterion $\langle \varepsilon^2 \rangle \longrightarrow \min$, an energy transmission coefficient α is estimated with the modification rate δ of panel thickness , as follows :

$$\alpha = \frac{\langle D_R D_s \rangle - \langle V \rangle \langle D_s \rangle}{\langle D_s^2 \rangle} \,. \qquad (5)$$

Practically speaking, α is estimated in a specialized recursive form based on Robbins-Monro's stochastic approximation method. Thus, the estimation algorithm can be reduced as follows :

$$\alpha^{k+1} = \alpha^k + \Gamma_k \{ (D_R^k - \alpha^k \cdot D_s^k - \langle V \rangle) D_s^k \} \,, \qquad (6)$$

with a time point k .

EXPERIMENTAL CONSIDERATIONS

If the above structural parameters in Eq.(3) are restricted to only A, B and C', those parameters can be deterministically identified by use of three kinds of estimated parameters α's in three cases with different values of the panel thickness. Those parameters have been concretely estimated by use of the least-square type error criterion. Especially in the case using an ordinary aluminium double-wall with d= 100mm air-gap thickness, when one panel has a constant thickness (1.2

mm), the sound transmission loss of an arbitrary panel thickness has been predicted under three different conditions of an additional panel with thickness of 0.8mm, 1.2mm or 2.0mm. Fig.1 shows the sound transmission loss of the double-wall with another panel thickness (1.5mm) from three different viewpoints —— the prediction by use of other different three thickness values , the estimation by use of data concluding the same thickness (1.5mm) and experiment. In Fig.2, the estimated and predicted cumulative distribution for the transmitted sound of double-wall are shown with the experimental result. Agreement between the proposed theory and the experimental result has been effectively confirmed.

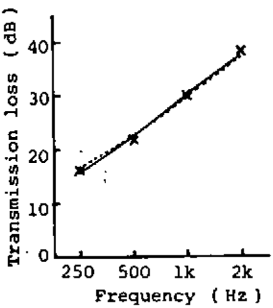

Fig.1 Transmission loss of aluminium double-wall (t_1= 1.5 mm, t_2=1.2 mm, d=100 mm),
—— Predicted value ,
----- Estimated value ,
x Experimentally sampled point.

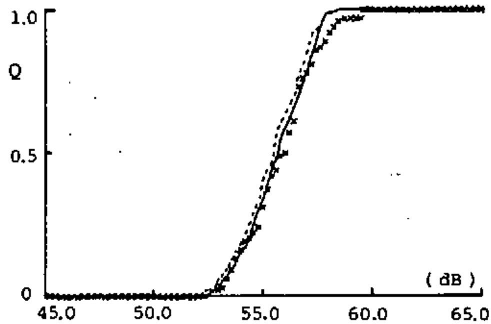

Fig.2 Cumulative distribution of transmitted sound through aluminium double-wall (t_1=1.5 mm, t_2=1.2 mm, d=100 mm),
—— Predicted value, ------ Estimated value,
x Experimentally sampled point.

CONCLUSION

This new trial of probabilistic evaluation for transmitted sound has been considered from the energy flow viewpoint based on the Modified S.E.A. method. By and large, we have validated the above theory by experimental confirmation of application of actually observed data.

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