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COMPLICATION APPRAISED BY WAVE FORM OF ENVIRONMENTAL NOISE

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1 Introduction

There are a lot of noise generators in our living space. Vehicle noise, aircraft noise, road traffic noise, machinery noise and flow noise are in our environment. Environment noise has some features in each area. These features are often characterized by the spectrum in the frequency domain. Noise produced from many sound generators has spectrum over wide frequencies range. Impulsive, continuous, repetition, period, levels and the other many expressions are evaluated as factors of various features in time domain and frequency domain. The environmental noise measured in short duration shows often the non-stationary time series. This process for the sound generation can be expressed in terms of the state space model with non-Gaussian distribution. The factors in a generating noise system will be able to be calculated by the Kalman filter. Modeling for the environmental noise and these estimated results will be shown. Noise evaluation should be carried out by use of both quantity and quality. In generally, sound pressure level of noise is measured as quantity. To decide sound quality, hearing test is carried out and spectrum are measured. It is hard to decide sound quality personally. The entropy indicates the quantity of a complication quality and appraisal of sound complexity objectively. The entropy can be calculated from the measured noise waves in environmental noise. The entropy is estimated as averaged values over a long measuring period. However, environmental noise is changing for a moment and it is to estimate the entropy immediately. Fractal dimension is proposed as evolution at momentary complication. And the estimating method of the fractal dimension and these calculated results will be shown.

2 Separation Processing of the Trend Element

The state space equation is set up two parts. One is the trend element for variations in the low frequency ranges by which the non-stationary time series are caused. The modeling of the trend element can be expressed by the first order differnce equation or the secondary order differnce equation. The other is the rapid element which depends on many variations of the noise generation system and/or influences in measuring around conditions. And the model equation can be explained in terms of the auto-regressive process(AR). These variation factors are estimated by the Kalman filter with non-Gaussian process. From the Akaike's Information Criterion (AIC) of these estimated results, the dynamic model is useful for the model mechanism of the environmental noise generator. This section shows a preprocessing method for separating the trend signal from the environmental noise.

The trend element which has low frequency spectrum can be estimated by the least square method by use of the polynomial equation.

Let the equation for trend element be the difference equation as follow

$$\Delta^d t_n = w_n, \tag{1}$$

where Δ denotes the difference operator defined by $\Delta t_n = t_n - t_{n-1}$ and d is order of defference equation. The state space model is constructed by two equation which are the state equations $\boldsymbol{x}_n$ and the observation y_n. The model is expressed in Eq.(2).

$$\begin{aligned} \boldsymbol{x}_n &= \boldsymbol{F}\boldsymbol{x}_{n-1} + \boldsymbol{G}\boldsymbol{w}_n \\ y_n &= \boldsymbol{H}\boldsymbol{x}_n + v_n. \end{aligned} \tag{2}$$

$\boldsymbol{x}_n$ is the state vector which shows a producing system of a sound generator, and y_n is the observation at time n.

The state space equation of the first order difference equation are given as follows [1]:

$$\begin{aligned} x_n &= [1]\, x_{n-1} + [1]\, w_n \\ y_n &= [1]\, x_n + v_n. \end{aligned} \tag{3}$$

In equations, system noise w_n and the observation noise v_n are assumed to be white noise of $N(0, Q)$ and $N(0, \sigma^2)$ respectively. Here, for factor $N(\mu, P)$,μ is expection value and P is variance of white noise. As the state equation for modeling of the environmental noise, the first order differnce type indicated by Eq.(3) is proposed in this paper.

Using the state space model for the observation, a generating state of the noise is estimated by the Kalman filter. After estimating the state vector $\boldsymbol{x}_n$ and filtering, the expectation and covariance with the Gaussian density function will be calculated under the condition of the observation data $\boldsymbol{Y}_{n-1} = \{y_1, \cdots, y_{n-1}\}$ which are obtained at time $n-1$. The one-step-ahead prediction and filtering can be evaluated from the Kalman filter algorithm by following Eqs.(4) and (5).

One-step-ahead Prediction Equations are

$$\begin{aligned} \boldsymbol{x}_{n|n-1} &= \boldsymbol{F}\boldsymbol{x}_{n-1|n-1} \\ \boldsymbol{V}_{n|n-1} &= \boldsymbol{F}\boldsymbol{V}_{n-1|n-1}\boldsymbol{F}^T + \boldsymbol{G}\boldsymbol{Q}\boldsymbol{G}^T \end{aligned} \tag{4}$$

Time Update Equations are

$$\begin{aligned} \boldsymbol{K}_n &= \boldsymbol{V}_{n|n-1}\boldsymbol{H}^T[\boldsymbol{H}\boldsymbol{V}_{n|n-1}\boldsymbol{H}^T + \sigma^2]^{-1} \\ \boldsymbol{x}_{n|n} &= \boldsymbol{x}_{n|n-1} + \boldsymbol{K}_n[y_n - \boldsymbol{H}\boldsymbol{x}_{n|n-1}] \\ \boldsymbol{V}_{n|n} &= [\boldsymbol{I} - \boldsymbol{K}_n\boldsymbol{H}]\boldsymbol{V}_{n|n-1} \end{aligned} \tag{5}$$

$\boldsymbol{K}_n$ in Eq.(4) is the Kalman gain at time n, $y_n - \boldsymbol{H}\boldsymbol{x}_{n|n-1}$ is the innovation, and $\boldsymbol{H}\boldsymbol{V}_{n|n-1}\boldsymbol{H}^T + \sigma^2$ is the conditional variance of $y_{n|n-1}$ in the observation process. These values are calculated from the past data $\boldsymbol{Y}_{n-1}$.

3 Modeling for the Environmental Noise

The stationary time series is able to indicate the model by the AR model or ARMA model with constant coefficient factor. Expectation and variance of the environmental noise are changing as function of time. This section describes the time-varying model of the environmental noise by use of AR process [2, 3].

The trend element is set up the model by the same difference equation indicated in Section 2. Let z_n be the non-stationary time series with time varying system. The time series can be calculated from the trend element $t_{n|n}$ and the observed signal y_n as follow.

$$z_n = y_n - t_{n|n}. \tag{6}$$

Consider the modeling for the environmental noise using the time-varying AR model which is formulated by Eq.(7).

$$z_n = \sum_{i=1}^{p} a_{i,n} z_{n-i} + v_n. \tag{7}$$

In the system, the coefficients are varying.

$$\boldsymbol{x}_n = [a_{1,n}, \cdots, a_{p,n}]^T. \tag{8}$$

v_n in Eq.(7) is the white noise with $N(0, \eta^2)$.

It is possible that the coefficients given by Eq.(8) are represented by the first order differnce equation.

The state space eqution of the time-varying AR model is mentioned by Eq.(9).

$$\begin{aligned} \boldsymbol{x}_n &= [I_p]\,\boldsymbol{x}_{n-1} + [I_p]\,\boldsymbol{w}_n \\ z_n &= \boldsymbol{H}_n \boldsymbol{x}_n + v_n. \end{aligned} \tag{9}$$

I_p in Eq.(9) is the initial matrix. The system noise and transient matrix are given by

$$\begin{aligned} \boldsymbol{w}_n &= [\epsilon_{1,n}, \cdots, \epsilon_{p,n}]^T \\ \boldsymbol{H}_n &= [z_{n-1}, \cdots, z_{n-p}]. \end{aligned} \tag{10}$$

The system noise $\boldsymbol{w}_n$ and the observation noise v_n are $N(\boldsymbol{O}_p, \boldsymbol{Q}) = diag\{\tau_1^2, \cdots, \tau_p^2\}$ and $N(0, \eta^2)$ respectively. Using the state space model in Eq. (9), the signal process is carried out. And the observation $\{z_1, \cdots, z_n\}$ is estimated by eliminating the trend wave from the measured noise. In Kalman filter algorithm for estimating the coefficients in the dynamic model, the one-step-ahead equation is given by Eq.(4). The same equation is utilizable in process for estimating the trend element.

The Time Update Equations are

$$\begin{aligned} \boldsymbol{K}_n &= \boldsymbol{V}_{n|n-1} \boldsymbol{H}_n^T [\boldsymbol{H}_n \boldsymbol{V}_{n|n-1} \boldsymbol{H}_n^T + \eta^2]^{-1} \\ \boldsymbol{x}_{n|n} &= \boldsymbol{x}_{n|n-1} + \boldsymbol{K}_n [z_n - \boldsymbol{H}_n \boldsymbol{x}_{n|n-1}] \\ \boldsymbol{V}_{n|n} &= [\boldsymbol{I} - \boldsymbol{K}_n \boldsymbol{H}_n] \boldsymbol{V}_{n|n-1}. \end{aligned} \tag{11}$$

4 AIC for the Time-varying AR Model

The results of the time-varying coefficients for the environmental noise will be shown in this section. The initial values in the Kalman filter algorithm are $\boldsymbol{Q}= 1 \times 10^{-4}[\boldsymbol{I}_4]$, $\eta^2 = 1.0$, $\boldsymbol{V}_{0|0} = 100[\boldsymbol{I}_4]$ and $\boldsymbol{x}_{0|0} = [\boldsymbol{O}_4]$. Figure 1 shows the environmental noise. The result which the trend elements are eliminated by use of the first order difference equation model is demonstrated in Fig. 2. Figure 3 shows the signal eliminated the trend element from the obsserved signal. Figure 4 shows AIC as functios of model order which is changing from 4 to 300 for the time variant AR model. Minimum value of AIC is 2828 and optimum order of the AR model is up to 240. For signal processing without separation of trend element, minimum value of AIC is 5365 and optimum order of the model is 21. From the calculated AIC results, modeling with non-trend signal estimated under the condition of statinary state is well fitted.

5 Fractal dimension

In generally, we measure sound pressure level of noise as quantity and hear sound characteristics as quality. The entropy indicates the quantity of a complication quality and can be calculated from the noise waves measured in environmental noise. Generating state is changing at every moment. In estimating, entropy indicates averaged value over a long measuring duration. As the results, entropy disagreement with current complication for environmental noise. Momentary complication is calculated from fractal dimension which is concerned with self-similarity of sound wave forms[4]. The range of the calculated fractal dimension is about from 1.3 to 1.5 for sound wave of the environmental noise in quiet area.

6 Conclusions

The modeling for the generation of the environmental noise and the estimation for coefficient factors are shown by use of Kalman filter. The environmental noise is assumed to be the non-stationary time series with non-Gaussian distribution. The noise model is constructed from two elements, one is the trend wave and the other is sound wave contained with wide frequency spectrum. The trend element is able to set up the state space model by the first order difference equation. The time-varying AR model is shown in Section 3. The Kalman filter method by the dynamic model is useful for the analysis of the model for the non-stationary time series such as the environmental noise. And fractal dimension is measured as a factor of the complication of environmental noise. This dimension is concerned with transmission path, a noise generating system, surrounding state and other factors. The measured area is very quiet. The fractal dimension of the environmental noise measured at the quiet parks in Tokyo is about from 1.3 to 1.5.

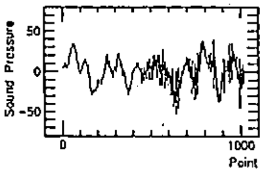

Fig. 1 The environmental noise.

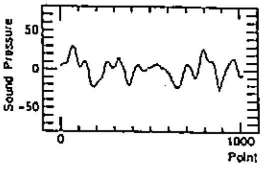

Fig. 2 The trend element estimated from the first order difference equation model.

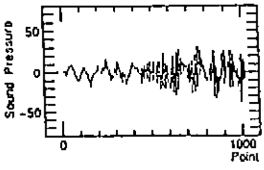

Fig. 3 The signal eliminated the trend element from the observated signal.

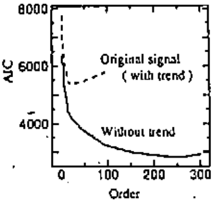

Fig. 4 The AIC of the time-varying AR modeling.

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AN ENERGETIC MOBILITY FOR STRUCTURES ASSEMBLING

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1. INTRODUCTION

The prediction of the vibratory transmission in the acoustic frequency range presents numerical and experimental difficulties. SEA method is a convenient model but coupling loss factors (CLF) are not easy to obtain. A way of measurement of the CLF using the mobility method was recently presented in ref. [1], [2]. However the SEA gives the mean value of the energy over space and the total power flow, theses *global* results are often not sufficient. Presently different authors try to develop methods using more *local* energy variables, for example [3] to [7]. In this field, we present here an energetical mobility approach. The aim is to obtain the energy and the power flow at some points of the assembly using a little number of data on the uncoupled structures.

2. THE ENERGETICAL MOBILITY

Assumptions And Definitions

We consider one structure excited at one point in a given frequency band Δf. Let us introduce the mean square velocity (MSV) at point i, $\mathbf{Ei} = <|V_i|^2>_{\Delta f}$ and the injected power at point j, $\Pi_j = <Re\{F_j V_j^*\}>_{\Delta f}$. We define the energetical mobility H_{ij} as the ratio:

$$H_{ij} = Ei / \Pi_j \quad (1)$$

For several points of excitation, each injected power contributes to the MSV at point i. We assume energetical additivity following equation (2).

$$E_i = \Sigma H_{ij} \; \Pi_j \quad (2)$$

These two relations must be taken in an approximate sense because of the non unicity of the energetical mobility defined in relation (1), and because the cross power contributions are neglected in (2); this point will be discussed later.

Energetic Connectivity
The scope is now to evaluate the energetic behaviour of an assembly using the energetical mobilities of the substructures 1 and 2 before coupling. We consider rigid links at the coupling points i. That implies continuity of MSV and opposite injected powers at each connection point i. In vectorial form :

$\{E_{1i}\} = \{E_{2i}\}$ (3) $\{\Pi_{1i}\} = -\{\Pi_{2i}\}$ (4)

Let us introduce the mean square velocities before coupling at each connection point i, $\tilde{E}_{1i}$ and $\tilde{E}_{2i}$. The exchanged powers at the coupling points j can be calculated using (2), (3) and (4) in a similar way as in the classical mobility technique, one obtains :

$$\{\Pi_{1j}\} = [H_{2ij} + H_{1ij}]^{-1}\{\tilde{E}_{2i} - \tilde{E}_{1i}\} \quad (5)$$

Using those powers one can then calculate the MSV at every point m and n of the substructures 1 and 2 with equations (6) and (7).

$$\{E_{1m}\} = \{\tilde{E}_{1m}\} + [H_{1mg}]\,[H_{2cg} + H_{1cg}]^{-1}\{\tilde{E}_{2c} - \tilde{E}_{1c}\} \quad (6)$$
$$\{E_{2n}\} = \{\tilde{E}_{2n}\} - [H_{2ng}]\,[H_{2cg} + H_{1cg}]^{-1}\{\tilde{E}_{2c} - \tilde{E}_{1c}\} \quad (7)$$

Here, it is implicitely assumed that the external injected powers remain unchanged after coupling.

Discussion About The Concept Of Energetical Mobility
Let us consider one structure excited at two points e and f ; using the classical mobilities for pure tone excitation, one can write the MSV at point i and the injected powers as follows :

$$|V_i|^2 = |Y_{ie}|^2\,|F_e|^2 + |Y_{if}|^2\,|F_f|^2 + 2\,\mathrm{Re}\{Y_{ie}F_eY_{if}^*F_f^*\} \quad (8)$$

$$\mathrm{Re}\{F_eV_e^*\} = |F_e|^2\,\mathrm{Re}\{Y_{ee}\} + \mathrm{Re}\{F_eY_{ef}^*\,F_f^*\} \quad (9)$$
$$\mathrm{Re}\{F_f\,V_f^*\} = |F_f|^2\,\mathrm{Re}\{\,Y_{ff}\,\} + \mathrm{Re}\{F_eY_{ef}\,F_f^*\} \quad (10)$$

The last terms of equations (8) to (10) are fluctuating. So, making a frequency average renders those terms negligible compared to the others positive ones (8) (9) and (10) become then :

$$<|V_i|^2>_{\Delta f} = <|Y_{ie}|^2\,|F_e|^2>_{\Delta f} + <|Y_{if}|^2\,|F_f|^2>_{\Delta f} \quad (11)$$
$$<\mathrm{Re}\{F_eV_e^*\}>_{\Delta f} = <|F_e|^2\,\mathrm{Re}\{Y_{ee}\}>_{\Delta f} \quad (12)$$
$$<\mathrm{Re}\{F_fV_f^*\}>_{\Delta f} = <|F_f|^2\,\mathrm{Re}\{Y_{ff}\}>_{\Delta f} \quad (13)$$

If the forces have a constant modulus in the frequency band Δf , one can relate the MSV and the injected powers through the relation (14).

$$<|V_i|^2>_{\Delta f} = H_{ie}<\mathrm{Re}\{F_eV_e^*\}>_{\Delta f} + H_{if}<\mathrm{Re}\{F_fV_f^*\}>_{\Delta f} \quad (14)$$

Where

$$H_{ij}(\Delta f) = \frac{<|Y_{ij}|^2>_{\Delta f}}{<\mathrm{Re}\{Y_{jj}\}>_{\Delta f}} \quad (15)$$

Equation (14) is formally identical to equation (2) and permits to define the energetical mobility with(15). Note that this definition is unique and intrinsic to the structure. It doesn't depend on the distribution of injected powers or measured energy because it only uses the classical mobilities. Check off that these mobilities are not symmetric because $Re(Y_{ii}) \neq Re(Y_{jj})$:

$$H_{ij}(\Delta f) \neq H_{ji}(\Delta f) \qquad (16)$$

To check the validity of the method we compare this approach with exact theoretical results and experimental ones in the particular case of coupled plates.

3. TESTING THE APPROACH

The first example concerns a numerical simulation of an assembly of two identical, thin, rectangular, simply supported, steel plates (see Fig. 1). The damping loss factor is η = 0.01. The general coordinate system is located on the edges of the plates. Dimensions of plates : 1.2 x 1.0 x 0.001 They are coupled with three rigid links located at P_1(0.2 ; 0.4), P_2(0.5 ; 0.1), P_3(0.8 ; 0.6). The energetical transfer mobility between the points (0.5 ; 0.4) on each plate after coupling are compared in Figure 2.

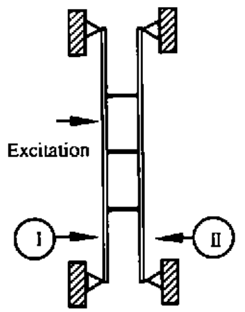

Figure 1 : Analytical model

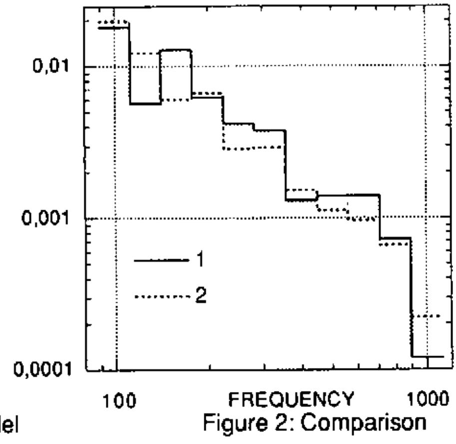

Figure 2: Comparison

We have the exact classical mobilities of the uncoupled plates and the exact classical mobilities of the assembly. The energetical mobility can be calculated on the assembly using the definition (15), the curve 1 presents this calculation. The energetical mobility can be also predicted from (6) (7) using energetical mobilities of uncoupled plates. The curve 2 presents this calculation. There is a good agreement between these results.

The second example (Fig.3) concerns the experiment described in [2]. On figure 4, the curves 1 and 2 are obtained as in the previous example but the input data are the measured mobilities on the uncoupled plates. The curve 3 presents the energetical mobility defined by (15) and directly obtained using the measured mobilities on the assembly. It is the reference result. The prediction with the energetical mobility method (curve 2) is as accurate as the classical mobility method (curve 1). As expected the frequency averaging reduces the influence of the numerical singularities frequently encountered with the classical mobility method. Consequently the large discrepancy observed at 800 Hz with the classical mobility calculation is avoided.

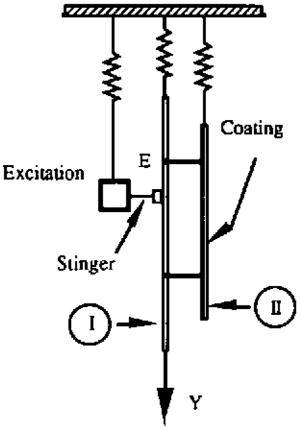

Figure 3 : Experiment

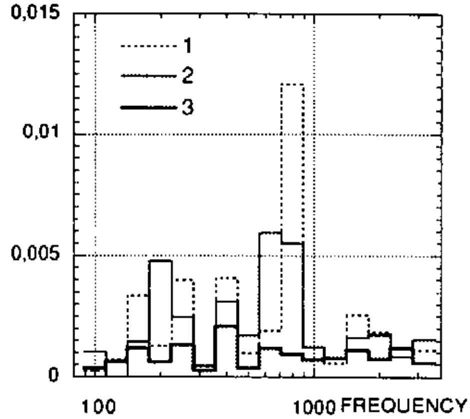

Figure 4 : Comparison

4. CONCLUSION

The energetical mobility approach presented here allows us to calculate the mean quadratic velocity and the power flow at different points of an assembly, using a little number of data of the uncoupled structures. This calculation may be an alternative way to the SEA method when the CLF are not known, or when the local energy is needed. The domain of validity of the calculation is presently not established, however it seems applicable for structure of high modal overlap. Works in this direction are coming up.

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