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2DOF ACTIVE CONTROL OF SOUND TRANSMISSION IN INTELLIGENT COMPOUND STRUCTURE

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ABSTRACT
This paper describes 2DOF active control of sound transmission in an intelligent compound structure. The main body of the structure is piezoelectric laminate that contains three pole domains for actuators and sensors respectively. The element is sandwiched by stainless steel plates to reinforce the strength of structure. The filtered -ε and Internal Model Control algorithms (IMC) are applied to cope effectively with random nature of incident sound wave. Effectiveness of the control system is shown by experimental results.

1 - INTRODUCTION
Much attention from control engineers is attracted to the intelligent structure, which contains even sensors and actuators of the control systems in the body [1]. As well known, the compound structure has the advantage of efficient sound insulation over the single structure that possesses the same mass density as that of the compound structure. Piezoelectric material utilized as sensors and actuators has the same mechanical property as that of usual metal excepts the fragility of material strength. The intelligent compound structure we are proposing is composes of piezoelectric plate working as sensors and actuators, and stainless steel plates for supplementing the fragility of the total body. This paper proposes a new active control system of sound transmission through the compound intelligent structure. This kind of Acoustic Structural Active Control (ASAC) is supposed as one of disturbance rejection control problems. We propose the 2DOF adaptive control system to cope with random nature of the disturbance [2]. Filtered- ε algorithm is introduced for the feedforward controller that has robustness [3]. The Internal Mode Control (IMC) is introduced as the feedback controller to eliminate the instability caused by howling which is often induced in the feedback control system of the Active Noise Control.

2 - MODEL OF THE CONTROL SYSTEM
Figs. 1 and 2 illustrate the intelligent compound panel and schematic view of the experimental setup respectively. The panel size is 40 ×150 ×1.2 mm (thickness) and it is made of piezoelectric element, the thickness is 0.6mm, and it is sandwiched by stainless steel plate to reinforce the strength of structure. One side of the element has three poles for sensors and three poles for actuators as shown in Fig. 2. The intelligent compound panel is supported on the left most side of the duct, and the bending vibration is excited by the incident sound wave emitted from a loud speaker which is installed at the right side of the duct. The sound wave from the speaker is considered as the plane wave under frequency range lower than 1kHz, since the wave length is much larger than the dimension of the duct. Therefore the sensor signal from the pole 1 of the sensor is the same as the sensor from the pole 3, and the control signal applied to the pole 1 of the actuator can be the same as the signal can be same as the signal applied to the pole 3. Two microphones are applied to sense the sound pressure. One of them is installed inside the duct to detect the incident sound wave, and the other is installed outside the duct to detect the

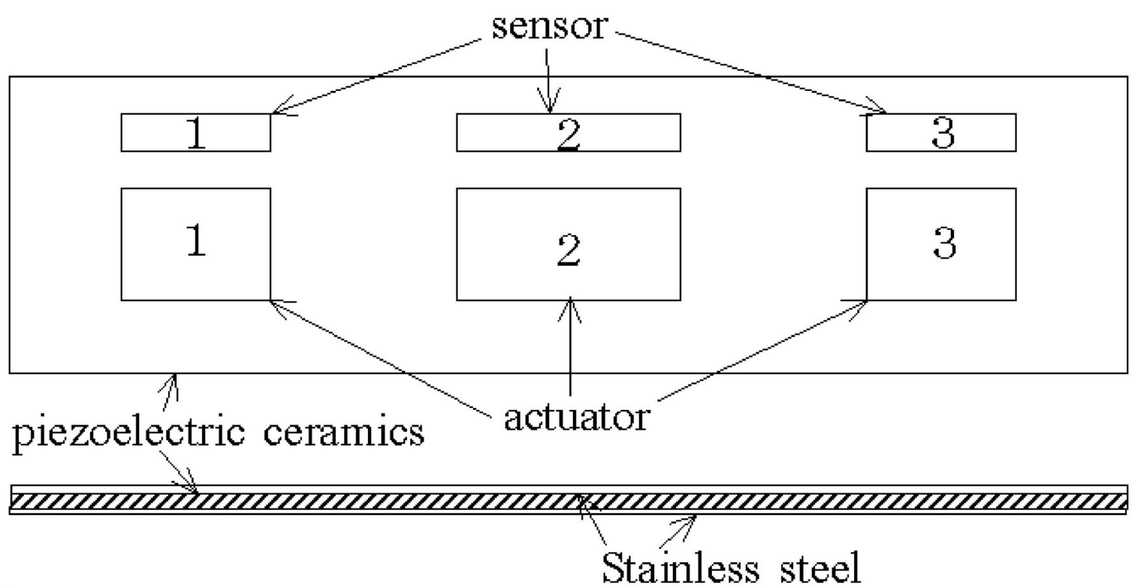

Figure 1: Intelligent compound panel.

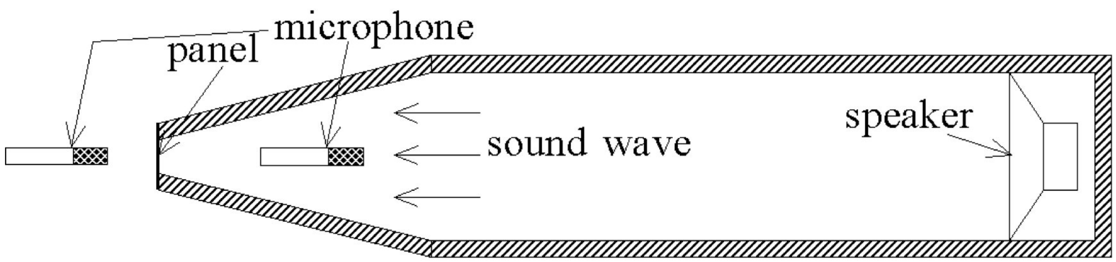

Figure 2: Experimental setup.

radiating sound wave. The objective of this system is to reduce effectively the radiation sound power from the plate caused by the excited bending vibration.

3 - CONTROL SYSTEM

3.1 - LMS algorithm

FIR model is applied to identify the control system by using LMS algorithm for the following two reasons; firstly, it is so simple method to implement as is suited to real-time identification for an adaptive control, secondly, the method is robust and suitable for identifying the distributed-parameter structure. Fig. 3 illustrates the basic block diagram of this identification algorithm. $P(z)$ is the transfer function to be identified, and $\hat{P}(z)$ is the identified transfer function represented as follows,

$$\hat{P}(z) = \sum_{i=0}^{n} w_i z^{-i} \tag{1}$$

where z denotes the shift operator in the discrete system, n the order and w_i is the weight of the FIR model. The LMS algorithm leas to the recursive equation of $w_j(k)$ at time step k as follows:

$$w_i(k+1) = w_i(k) + 2\mu e(k)\, x_i(k) \ ;\ i = 1, 2, , n \tag{2}$$

3.2 - 2DOF Control System

2DOF control system is consisted of the feedforward system and also the feedback system where designing of the control system is independent on each other. Fig. 4 illustrates the block diagram of the signal flow. p_a is incident sound wave and y is sensor output signal.

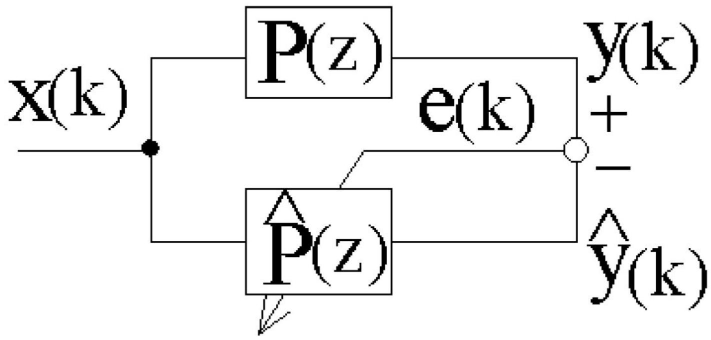

Figure 3: Basic diagram of the LMS algorithm.

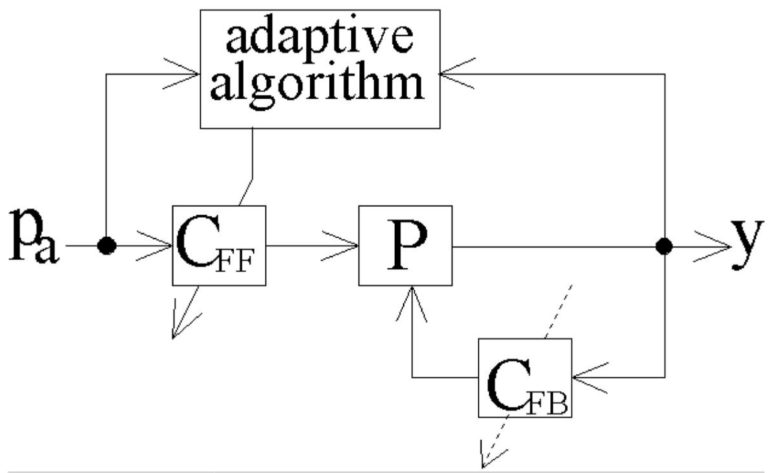

Figure 4: 2DOF control system.

3.3 - Feedforward Control System

Fig. 5 illustrates the block diagram of filtered- ε algorithm. P_1 and P_2 is plant transfer function from the disturbance signal to the sensor output signal, and actuator input signal to the sensor output signal respectively. The inverse model $\hat{P}_2^{-1}$ of the plant P_2 is identified off-line, and it is applied to this adaptive feedforward control.

3.4 - IMC System

Fig. 6 illustrates the block diagram of adaptive IMC system similar to the feedforward control system because this system contains plant inverse model. Introducing of delay stabilizes the inverse transfer function of the nonminimum-phase plant. $\hat{P}$ is the FIR modeled transfer function of the plant P, if the modeling is perfect then the estimated signal $\hat{w}$ will be equal to the disturbance signal w. It means that when the input signal of feedback controller C ceases to change in this adaptive process; the signal can function as the feedforward control input. It is found that this system works well enough to prevent howling which is induced in the feedback control system.

4 - CONTROL EXPERIMENT

Fig. 7 and Fig. 8 show an example of FF control and FB control result, respectively. The figures illustrate spectral analysis of the microphone signal installed outside the duct. The sharp peak of the dotted line (at 380Hz) is supposed as to be resulted from the first eigen mode of the panel. The level of the peak is reduced effectively by about 17dB and 6dB respectively. The reduction effect by 6dB is seemed to be small compared with that by the FF control. The result is quite new, because it is found that the filtered- ε algorithm can be useful without the reference signal. Problem exists in that amplitude does not change in other frequency range. One of the reasons is deduced from structural problem. From preparatory experiment, it is confirmed that the bending vibration is not excited in the intelligent compound panel with low input voltage. We will reconstruct this panel and examine the

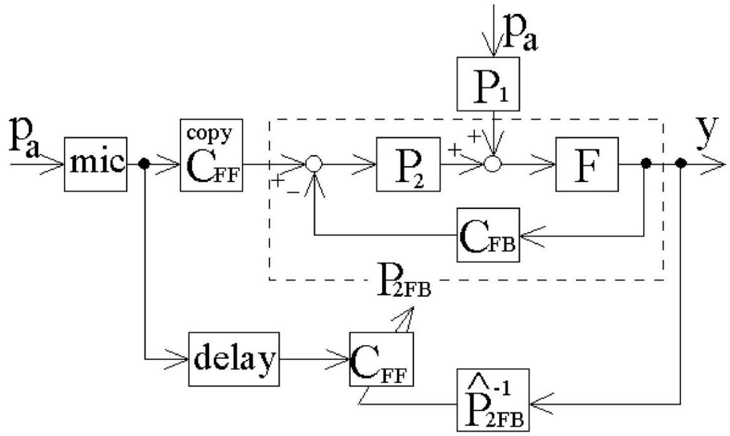

Figure 5: Filtered- ε control block diagram.

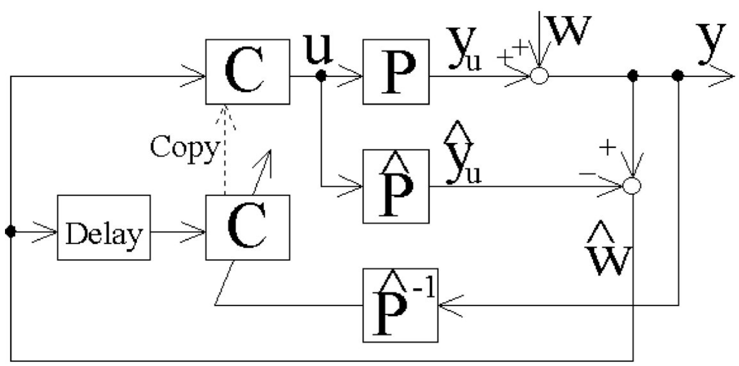

Figure 6: Adaptive IMC system.

effectiveness of the algorithm in the near future.

5 - CONCLUDING REMARKS

The intelligent compound structure that contains sensors and actuators in it proved its effectiveness in the eigen mode frequency of the panel. An improvement of the structure is needed to obtain good attenuation in the wide frequency range.

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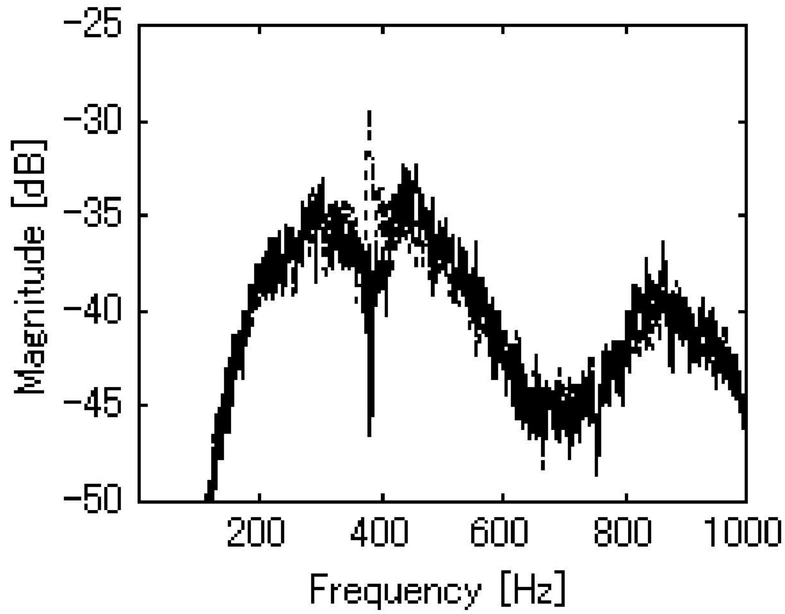

Figure 7: Spectrum of microphone signal with FF control (solid line) and without control (dotted line).

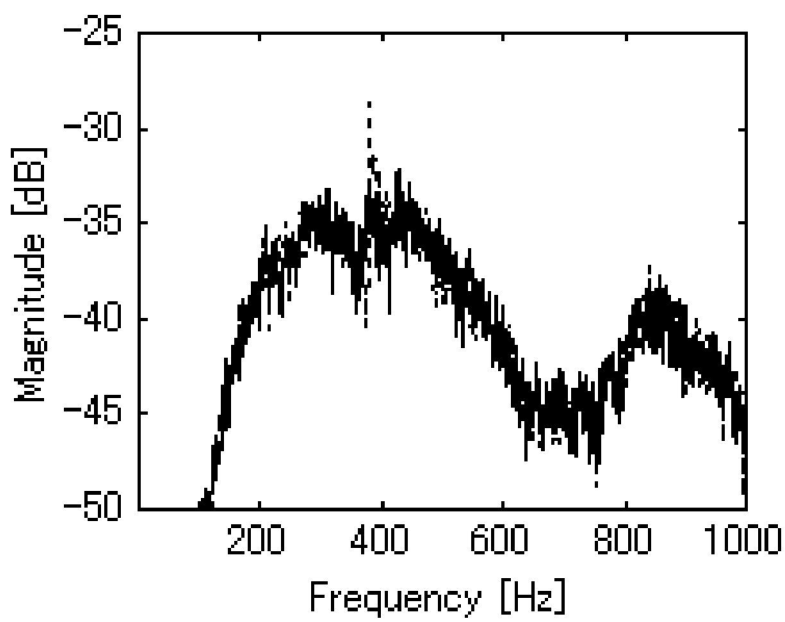

Figure 8: Spectrum of microphone signal with FB control (solid line) and without control (dotted line).