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AN ELECTRORHEOLOGICAL FLUID-BASED PLATE FOR NOISE REDUCTION IN A CABIN: EXPERIMENTAL RESULTS

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1. INTRODUCTION

The problem of sound transmission through vibrating boundary structures into its enclosure (or cabin) can be observed in many engineering systems such as automotives and airplanes. When the external noise excites the cabin structure, the structure radiates the noise into the cavity. Thus, many research efforts to reduce the noise transmission in such systems have been made in passive or active manners. The passive noise control is normally achieved by employing constrained layer damping, while the active is achieved via various actuators with appropriate control algorithms. Recently, smart structure incorporating with piezoelectric material is used as one of the potential methodologies to reduce the cabin noise in an active fashion. Koshigoe *et al.* [1] proposed a technique for controlling noise transmission into a cavity using piezoelectric actuators on an elastic plate. They developed an analytical noise control model, and demonstrated its effectiveness via numerical simulation. Veeramani and Wereley [2] experimentally investigated the control of noise transmission through a flexible plate with piezoactuators backed by a rigid cavity. Besides these two studies, numerous research literatures on active noise control using piezoelectric actuators and sensors can be found in reference [3].

On the other hand, smart structure incorporating electrorheological (ER) fluid can be also exploited for vibration and noise control. Embedded in voids of distributed parameter structures, ER fluid enables stiffness and damping properties of the structures, to be actively tuned by the intensity of the electric field applied to the ER fluid domain. Choi *et al.* [4] experimentally implemented an active vibration control scheme for an ER fluid-based beam via the field-dependent transfer function between voltage input and damping and stiffness outputs. Yalcintas and Coulter [5] proposed an analytical model to predict field-dependent vibration control characteristics of ER-materials-based axially non-homogeneous beam. Although, many investigations on vibration control of ER fluid-based smart structures have been and are being carried out, researches on the noise control of a smart structure associated with ER fluid are considerably rare. Moreover, none deals with ER-fluid-based smart structures for noise control in a cabin.

Consequently, the main objective of this work is to present experimentally obtained noise control results of a rectangular closed cabin featuring one side of ER fluid-based smart plate. After establishing an experimental set-up, a fuzzy control logic is formulated on the basis of field-dependent sound pressure levels of the cabin. The control logic is then empirically realized and the noise control results in the closed cabin are presented in both frequency and time domains.

2. EXPERIMENTAL APPARATUS

The flexible ER plate consists of a rubber space, an ER fluid, and two elastic face layers of aluminum as shown in Figure 1. The aluminum layers (0·3 mm thickness) provide rigidity as a host structure, and also serve as electrodes. The silicone rubber spacer acts as a seal to hold the integrity of the structure as well as acts as an electrical insulator between two conductive face layers. The rubber spacer is perfectly bonded to the face layers with a silicone room-temperature vulcanite adhesive. Into the void between the two face layers, the chemically treated starch particle/silicone oil-based ER fluid is inserted. The particle concentration of the ER fluid is 55% by weight, and the volume fraction of the ER fluid to the total structure is 75%. The size of the ER plate is 300 × 300 mm with a total thickness of 2·6 mm. After manufacturing the flexible ER plate, a closed cabin is proposed. The acoustic cavity is made with five acrylic sheets of 20 mm thick, and one side is covered with 2·6 mm thick ER plate. The ER plate is fixed with bolts and the cavity box is assumed to be leak proof.

The experimental set-up for field-dependent acoustic test and noise control of the cavity is illustrated in Figure 2(a). The sound level inside the cavity is measured by microphone through a small hole in the bottom of the cavity and a loud speaker generates sound pressure from the outside of the enclosure. The loud speaker is excited with sine sweeping signals from the function generator through the power amplifier. The output signal from the microphone is analyzed with the dynamic signal analyzer (FFT analyzer) and microcomputer. The field-dependent sound pressure levels are measured by increasing the electric field from 0·0 to 1·0 kV/mm at each 0·2 kV/mm increment. On the other hand, the output signal from the microphone is fed back to the microcomputer in the noise control. Depending on the output information an appropriate input field is determined from the proposed fuzzy control algorithm, and applied to the ER plate via D/A converter and high-voltage amplifier which is a gain of 1000. The controlled responses are then presented in both frequency and time domains. The photograph of the experimental set-up is shown in Figure 2(b).

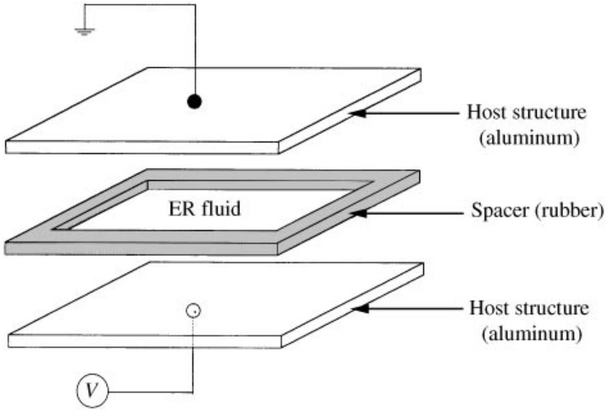

Figure 1. Schematic configuration of the proposed ER plate.

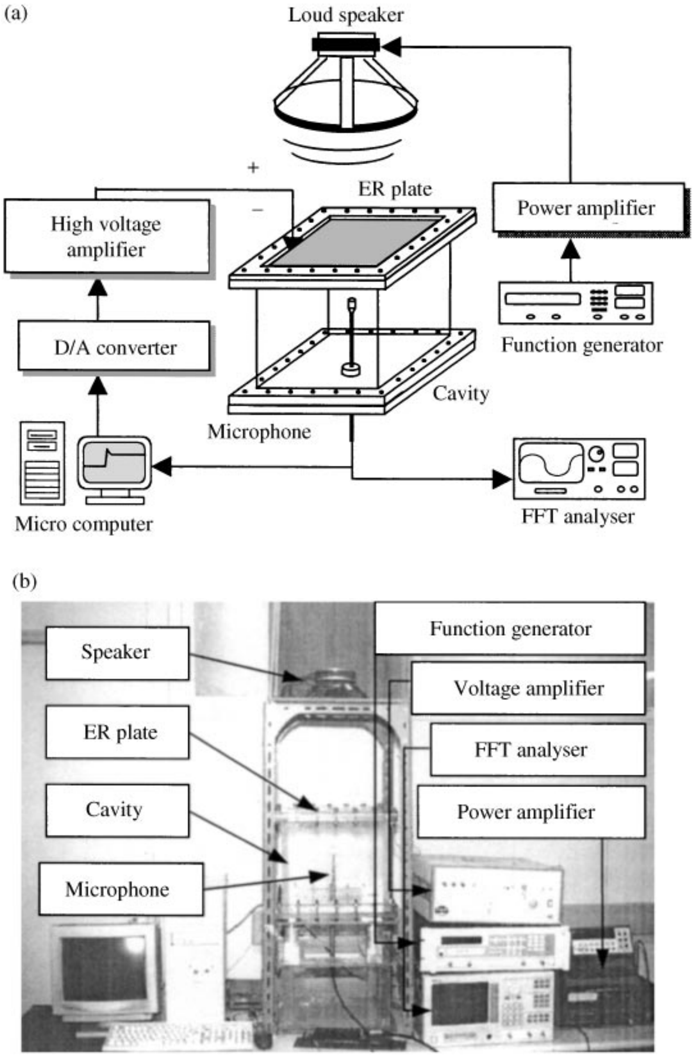

Figure 2. Experimental set-up for noise control. (a) Configuration; (b) photograph.

3. CONTROLLER FORMULATION

In this work, the fuzzy control algorithm is adopted in order to reduce sound transmission from the speaker to the inside of the closed cabin. The basic configuration of the fuzzy control comprises fuzzification, decision-making logic and defuzzification as shown in Figure 3(a). In the fuzzification interface, fuzzy variables are modified into linguistic values, while the inferred control actions in the decision-making logic are changed into a numerical value for real control input in the defuzzification part. In this study, there exists only one fuzzy variable. That is field-dependent sound pressure (P_m) measured by the microphone positioned inside the acoustic cavity. Thus, a linguistic input variable ($\tilde{P}_m$) is defined to describe the fuzzy variable as follows

$$\tilde{P}_m = \{VS, S, M, L\}, \tag{1}$$

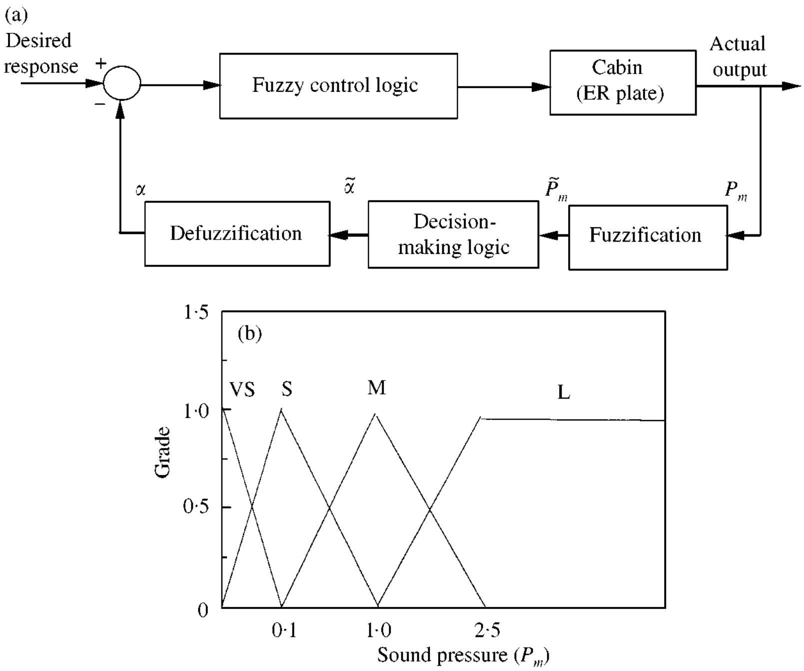

Figure 3. Fuzzy control scheme. (a) Block-diagram; (b) membership function.

where VS = very small, S = small, M = medium, and L = large. Also, linguistic output variable ($\tilde{\alpha}$) is defined to describe the electric field as follows:

$$\tilde{\alpha} = \{P_1, P_2, P_3, P_4\}, \tag{2}$$

where P_i is a fuzzy value of the electric field. In view of control objective which is to reduce the sound level inside the cabin, the following fuzzy control rules are adopted:

$$\begin{aligned} &R_1\text{: If } \tilde{P}_m \text{ is } VS \quad \text{then } \tilde{\alpha} = P_1,\\ &R_2\text{: If } \tilde{P}_m \text{ is } S \quad \text{then } \tilde{\alpha} = P_2,\\ &R_3\text{: If } \tilde{P}_m \text{ is } M \quad \text{then } \tilde{\alpha} = P_3,\\ &R_4\text{: If } \tilde{P}_m \text{ is } L \quad \text{then } \tilde{\alpha} = P_4. \end{aligned} \tag{3}$$

Control rules (3) are normally represented in terms of a “look-up” table and the fuzzy control rules can be inferred from the center of gravity method. Figure 3(b) shows membership function for the fuzzy control system implemented in this work. The detailed implementation procedures of the fuzzy control algorithm are referred to in reference [6].

4. RESULTS AND DISCUSSIONS

The second pressure level (SPL) is measured at four selected points as shown in Figure 4(a). The height from the bottom surface for 1, 2, 3 and 4 is 125, 100, 75 and 50 mm respectively. Figure 4(b) presents the SPL measured at four points in the absence of electric

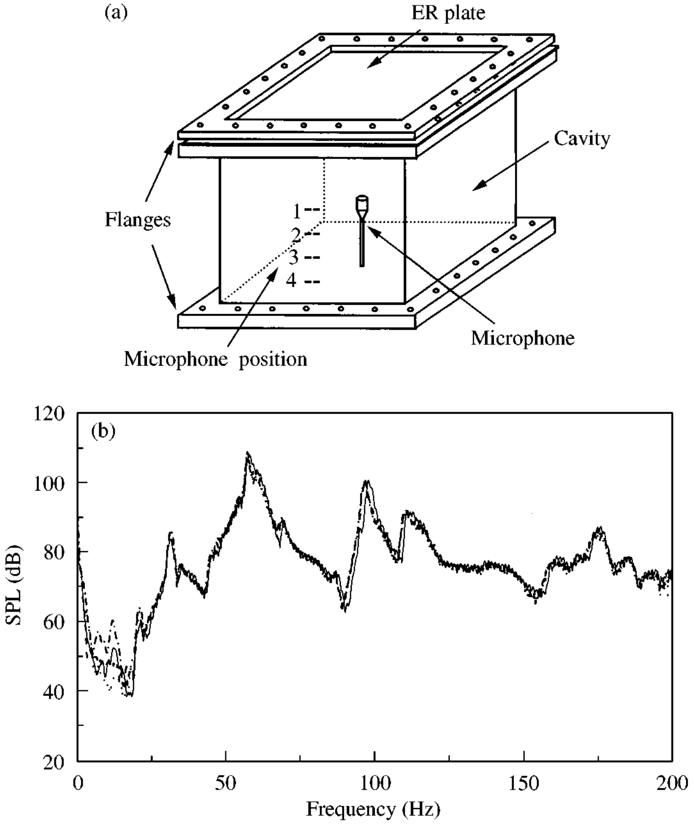

Figure 4. Sound pressure levels at different measuring points. (a) Measuring point; (b) Sound pressure level: ——, position 1; – – – –, position 2; ······, position 3; _._._._., position 4.

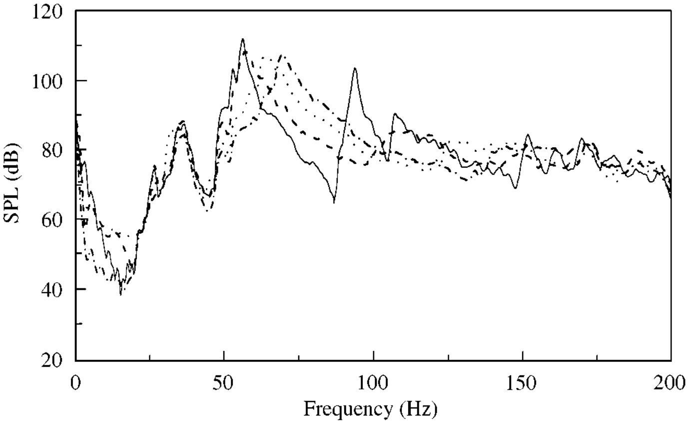

Figure 5. Sound pressure levels at various electric fields. ——, 0·0; – – – –, 0·2; ······, 0·6; and _._._._., 1·0 kV/mm.

field. It is clearly observed that the SPL is almost the same regardless of the location of the microphone. Therefore, the microphone located at position 1 is adopted as a feedback sensor in the closed-loop control. Figure 5 shows field-dependent effect of the SPL measured at position 1. It is seen that the significant effect of the electric field on the SPL occurred at two resonant frequencies: 62 and 98 Hz. In the mean time, it has been identified

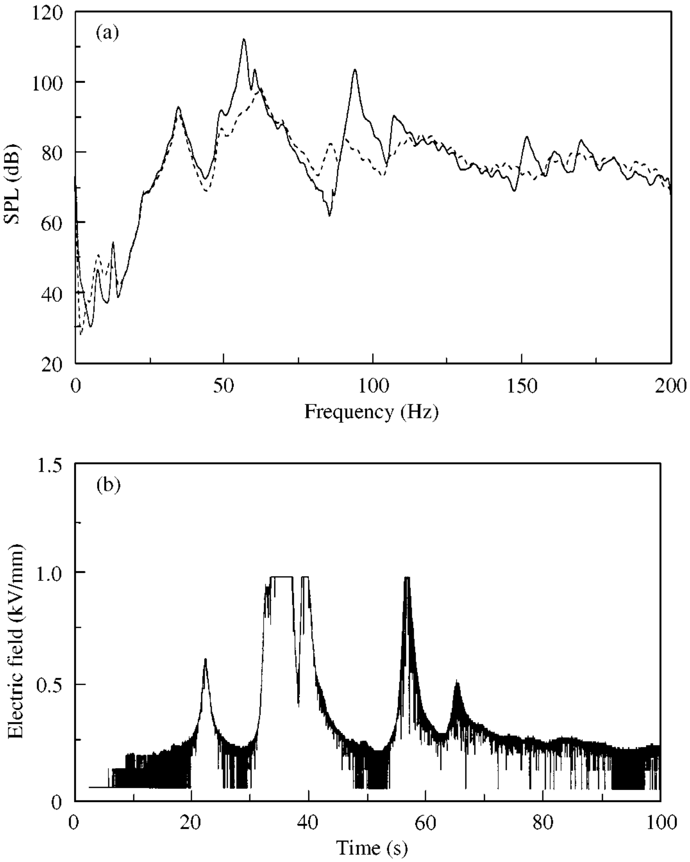

Figure 6. Control response in frequency domain. (a) Frequency response: ——, uncontrolled; - - - - -, controlled; (b) control point.

during this experimental investigation that the sound transmission is not changed above 200 Hz by applying an electric field. Thus, we focus on the noise control at two dominant resonant frequencies of 62 and 98 Hz.

Figure 6(a) presents experimentally obtained sound pressure responses in the cabin featuring one side of ER fluid-base smart plate. It is obviously observed that the sound pressure levels at 62 and 98 Hz are remarkably reduced by implementing the proposed control scheme. It is noted that the uncontrolled response is obtained without activating the controller. Figure 6(b) presents control electric field supplied for the first 100 s in control action. It is seen that the control input is saturated at 1·0 kV/mm in order to avoid the breakdown of the electric field. In order to observe more explicity the amount of noise reduction, time responses of the sound pressure are measured at 62 and 98 Hz, and presented in Figure 7. It is distilled from these results that the SPL is reduced by 20 and 19 dB at 62 and 98 Hz respectively, by applying control electric field.

5. CONCLUDING REMARKS

An experimental investigation on the noise control of a rectangular cabin featuring one side of electrorheological fluid-based smart structure was undertaken in this work. After establishing the experimental set-up, a fuzzy control logic was formulated on the basis of

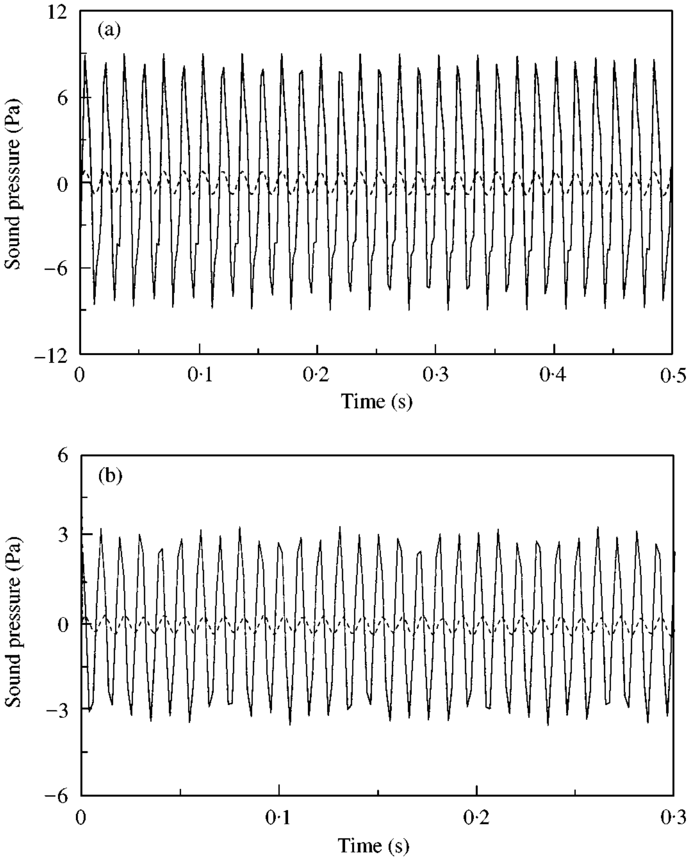

Figure 7. Control responses in time domain. (a) 62 Hz; (b) 98 Hz: ——, uncontrolled; - - - - -, controlled.

the field-dependent sound pressure levels of the cabin. The control logic was then experimentally realized and control responses were obtained. It has been shown that the noise levels at dominant natural frequencies are substantially reduced by applying control electric fields. These control results presented in this work are self-explanatory justifying that the smart structure associated with electrorheological fluid can be effectively exploited to various applications in noise control such as automotives and airplanes. It is finally remarked that analytical approach for dynamic modelling and noise control of a closed cabin integrated with the electrorheological fluid-based smart structure will be explored as the second phase of this preliminary experimental work.

ACKNOWLEDGMENT

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