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Active noise control in three dimension enclosure using piezoceramics

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ABSTRACT

Analysis and experiment are undertaken to attenuate the three dimension enclosure noise using piezoceramics. A flexible aluminium plate and five wood walls are constructed with clamped four edges conditions. Noise is generated by speaker and transmitted to the three dimension enclosure. Piezoceramics are used to control the noise inside. A microphone is put inside to monitor the noise. State space method is used to identify the system, the vibration mode and acoustic mode is also researched. Different arithmetic is used to control the noise inside. The sound pressure level reduction at selected point is observed.

1. INTRODUCTION

The traditional noise attenuation is mainly through passive noise control, i.e., sound absorption etc. But for low frequency, the sound energy is difficult to absorb because of the large wavelength. Therefore, smart structures are paid more and more attention recent years in the low frequency vibration and noise control. There are two

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approaches in active control field, one is that second acoustic sources are used to control the radiated noise[1], the other one is that use the force to control the structure, then control the radiated noise, i.e., piezoelectric actuators or electromagnetic shakers[2]. To achieve noise reduction due to structural vibration, people often tries to control the amplitude of structural vibrations or radiation efficiency. Because piezoceramics overcomes more point force drawbacks than electromagnetic shakers, the piezoelectric actuators are used either bonded to or imbedded into the structure to control the low frequency vibration and noise. There is a broad application prospect using piezoceramics in the active noise control about three dimension enclosure, such as automobile, aircraft, submarine, and rotorcraft.

In this paper a smart acoustics box is researched, simulation and experiment were implemented. It is not only makes the vibration decreased, but also make the interior noise attenuated. State space was used into system identification, LMS control algorithm was also applied in the simulation. Finally, the sound pressure level spectrum was given.

2. EXPERIMENT SET-UP

A photograph of the experimental set-up is shown in figures 1. The box used in this study outside dimension is 0.536X0.536X0.519 m^3, the interior cavity is 0.5X0.5X0.5 m^3. Five walls of which are made of 18 mm thick wood, and the sixth wall (top) made of 1.5 mm aluminium plate. The aluminium plate is clamped along its four edges and is partially treated with a single PZT patch. The PZT patch is placed at the aluminium plate top centre. Another acceleration sensor is placed on center of the aluminium plate bottom. Table 1 lists the physical properties of the Al, wood and air. The pzt material (PZT 5X45) density is $7400\ \mathrm{kg/m^3}$, $d_{31} = -322\ \mathrm{pC/N}$, $d_{33} = 750\ \mathrm{pC/N}$.

Figure 1: Photograph of the experimental set-up

Table 1: Physical properties

Property	Density (kg m^{-3})	Thickness (m)	Modulus (Mpa)	Poisson ratio
Al	2690	0.0015	70300	0.343
Wood	702.46	0.018	11610	0.3
Air	1.115	—	0.132	—

Table 2: Vibration mode of the Al plate with and without cavity coupling effect

mode	1	2	3	4	5
Without coupling	55.766	112.82	166.06	202.51	204.72
With coupling	61.510	110.32	164.51	200.94	203.36

The first five modes of vibration of the aluminium plate with and without cavity coupling effect are shown in table 2. These modes are calculated using FEM software. It could be found that coupling the plate with the cavity has resulted in an obvious increase in its fundamental mode. It is because of the non-rigid acoustic cavity modes. The x, y, z direction acoustic cavity mode is 343.99Hz respectively, and the skew symmetric mode in x-z plane, x-y plane, and y-z plane is 486.48 respectively. They are much higher than the plate fundamental mode. Therefore, the increase in the fundamental frequency is due to the added stiffness imposed by the cavity[3-4].

The plate/enclosure system is excited using a harmonic signal which is fed into an electro-magnetic speaker placed on the top of the aluminium plate. One 1/2 inch microphone is placed inside the enclosure to measure the sound pressure level. The microphone is placed 12.5 cm away from the centre of the aluminium plate bottom. The vibration amplitude of the aluminium plate is measured by an acceleration sensor located on the center of the aluminium plate bottom. The excitation signal is adjusted to 53 Hz. The sampling rate is 1 kHz.

3. IDENTIFICATION OF THE PLATE/ENCLOSURE SYSTEM

In this paper the classical system identification method (subspace identification)[5-8] is used to experimentally get the state-space form from the piezoelectric mechanical structure. Through the measured input and output signals, a state-space model is to be determined. Since the subspace identification is based on sampled input/output measurement signals, the method applies to a discrete-time form of the resulting state-space model. The identification process is conducted by sending an excitation signal to the speaker to excite the aluminium plate or send control signal to the pzt patch, and the acceleration sensor is used to pick up the response. These input/output data are loaded into Matlab system identification software to build the state space model. It totally used 1000 data: the fore 500 data is used to build the state space model, the later 500 data is used to verify the model. When harmonic excitations are used for both speaker-sensor and actuator-sensor, respectively, the result indicates that the identified order of state space is 10 order.

4. FINITE ELEMENT SIMULATION

This model of clamped square plate with a speaker excitation is used to simulate the vibration of the enclosure top plate. The control is achieved using center configurations of acceleration sensor and piezoceramic actuator.

For the simple supported plate, Clark and Fuller have experimentally studied the control of sound radiation from vibrating rectangular plate bonded with piezo-electric actuators using the filtered-x LMS controller. The filterd-LMS algorithm is a gradient-based algorithm which is commonly used in adaptive signal processing and active noise control. Their results indicated that the actuators should be located near the anti-nodes of the structural modes to be controlled. For resonance excitation, a single actuator is found to be sufficient for controlling the radiated sound through modal suppression. For off-resonance excitation, attenuation of sound was achieved through modal restructuring using multiple actuators[9].The efficiency of the active control is dependent on the location of the excitation and the actuators. The numerical result shows that significant attenuation of vibration and radiated sound power for volumetric modes (odd, 1) in the low frequency range can be achieved with one control actuator located at the center of plate for simple supported rectangular plate[10]. It should be mentioned that the boundary conditions is simple supported according the above literature. This paper researches the clamped aluminium plate vibration and the interior box noise with direct control and LMS simulation and experiment. Only one actuator and one acceleration sensor is used in the simulation and experiment. Figure 2.1 and figure 3.1 show direct control and LMS control algorithm. Figure 2.2 and figure 3.2 are the direct control and LMS control simulation result. The red line is the original signal, and the green line is the controlled signal. From the simulation, it can be concluded that after 0.6 s the LMS algorithm make the vibration attenuate completely.

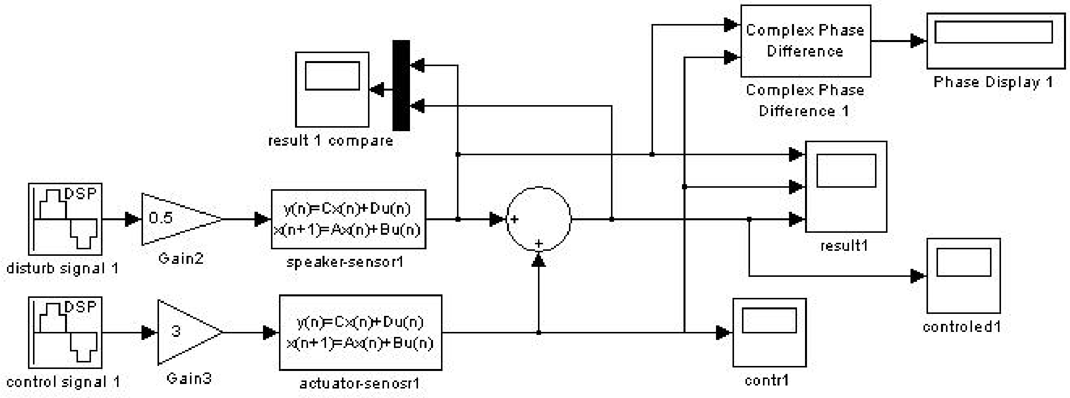


Figure 2.1 The simulink direct control algorithm

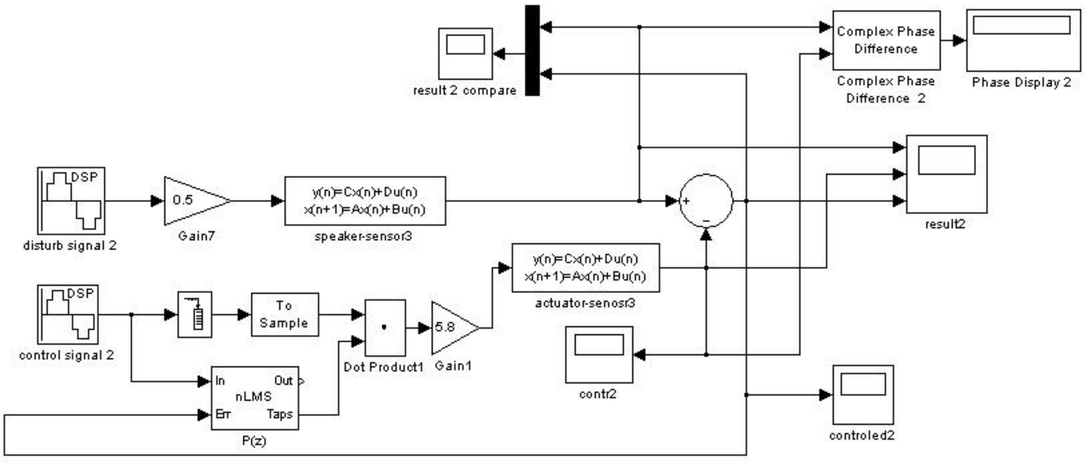


Figure 2.2 The simulink LMS control algorithm

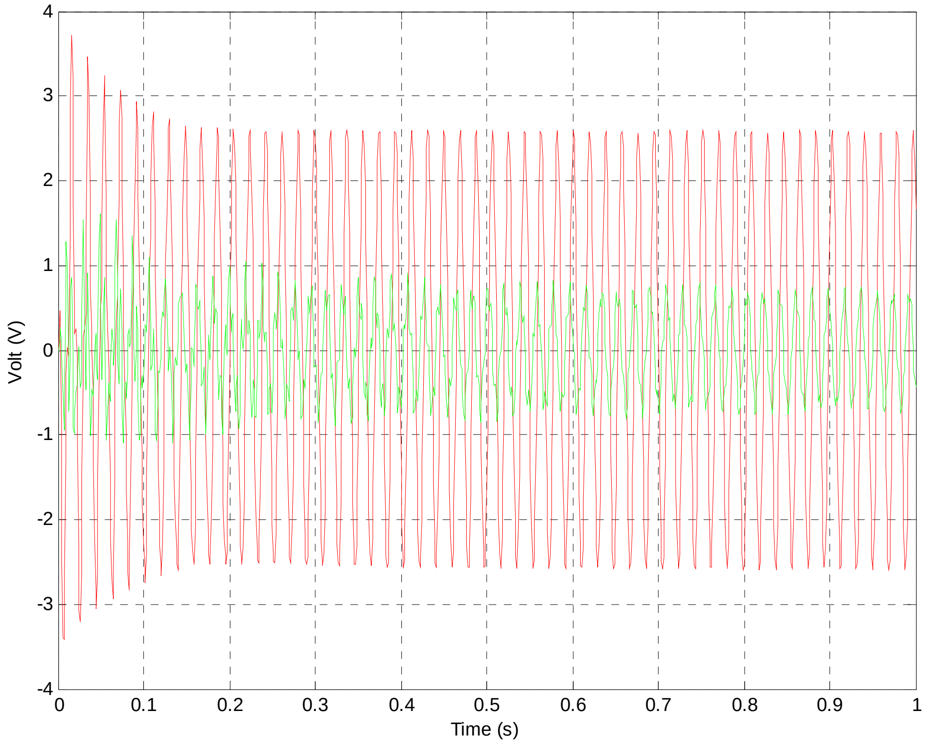


Figure 3.1: Direct control simulation result

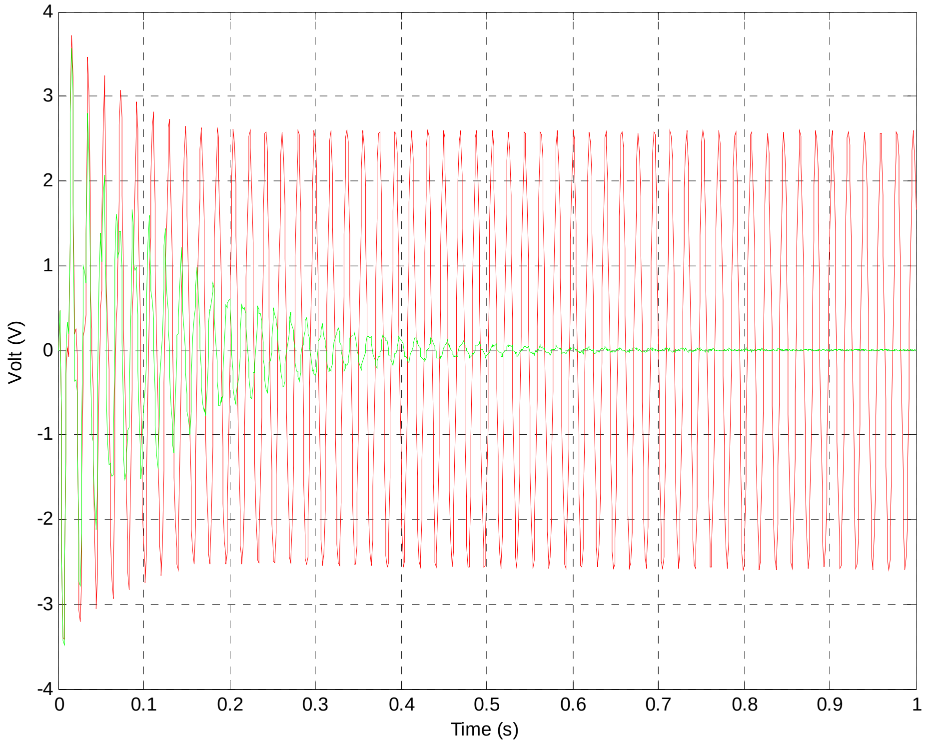


Figure 3.2: The LMS control algorithm simulation result.

5. EXPERIMENT RESULT

The figure 4.1 and figure 4.2 is the direct control vibration level and interior noise control experiment result respectively. The red line is the original signal, and the blue line is the controlled signal. It could be found that the vibration level at 52.7Hz decreased 3.96 dB with direct control, through 1/3 octave analysis, it also found at 50Hz, it decrease 2.7 dB, the total sound pressure level decreased 1.9 dB in the frequency range 0-400 Hz when the actuator acts.

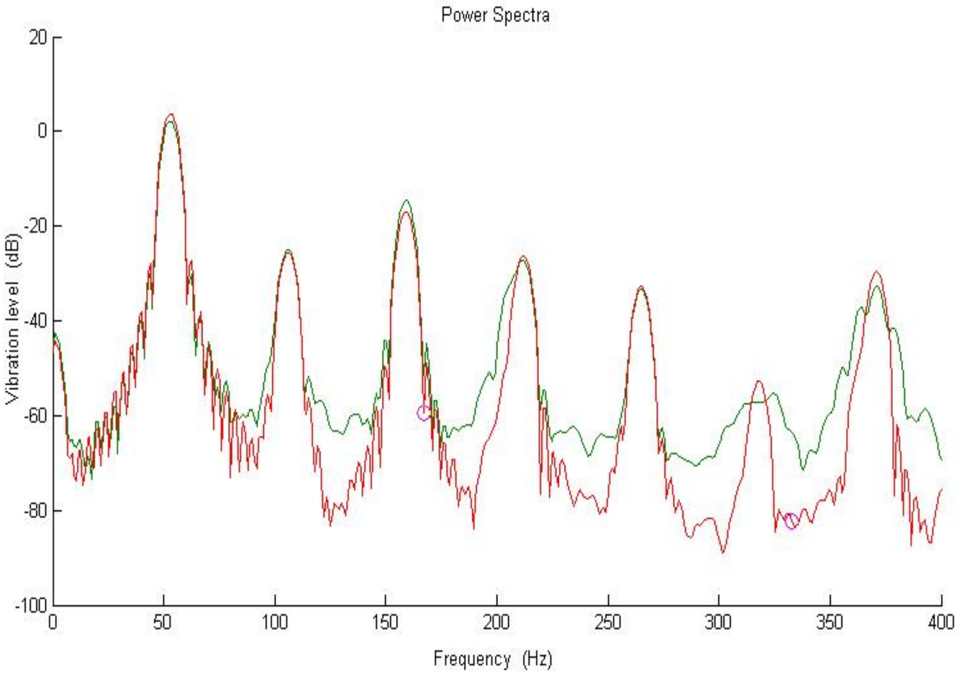
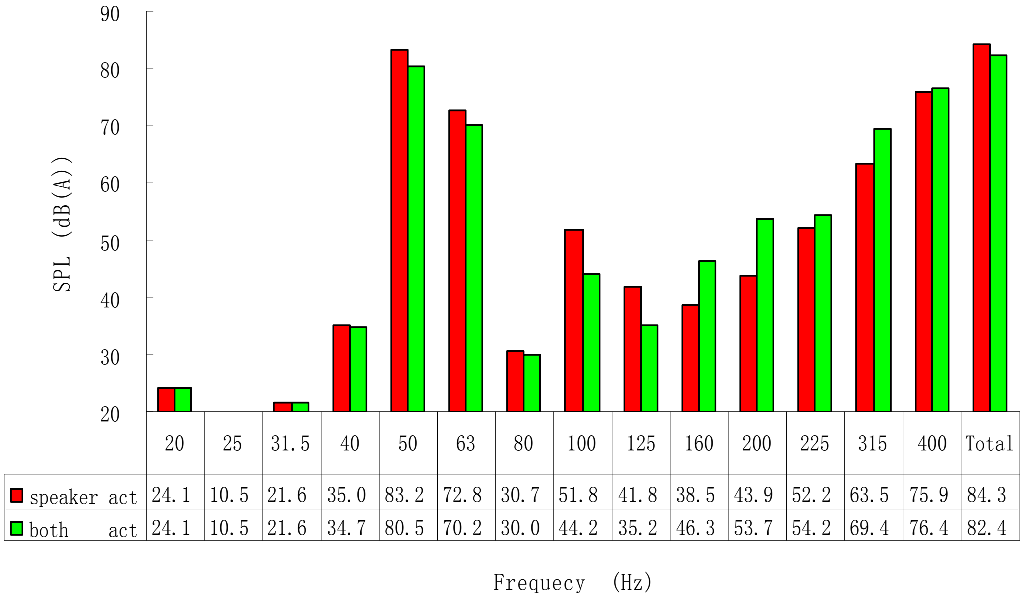


Figure 4.1: The vibration level experiment result



	20	25	31.5	40	50	63	80	100	125	160	200	225	315	400	Total
🟥 speaker act	24.1	10.5	21.6	35.0	83.2	72.8	30.7	51.8	41.8	38.5	43.9	52.2	63.5	75.9	84.3
🟩 both act	24.1	10.5	21.6	34.7	80.5	70.2	30.0	44.2	35.2	46.3	53.7	54.2	69.4	76.4	82.4

Figure 4.2: The 1/3 octave experiment result

6. CONCLUSION

The paper used the subspace method to identify the acoustic system. With direct control and LMS method to simulate the enclosure plate vibration, and also do experiment to verify the simulation result, it found that not only the vibration reduced, but also the noise also reduced. Future, more experiment and multiple frequencies are going to be researched.

REFERENCES

[1] Elliott S J, Nelson P A, Stothers I M and Boucher C C, “In-flight experiments on the control of propeller-induced cabin noise,” *J. Sound Vibration.* **140** 219-238(1990)

[2] Fuller C R, Hansen c h and snyder S D “Active control of sound radiation from a vibrating rectangular panel by sound sources and vibration inputs: an experiment comparison,” *J. Sound Vibration.* **145** 195-215(1991)

[3] Kinsler L E, Frey A R, Coppens A B and Sanders J V “Fundamentals of acoustics 3rd edn,” (Wiley, New York, 1982).

[4] Poh S, Baz A and Balachandran B, “Experiment adaptive control of sound radiation from a panel into an acoustic cavity using active constrained layer damping,” *Smart Mater. Struct.* **5** 649-659(1996)

[5] Nijsse G, Verhaegen M, Schutter De B, Westwick D and Doelman N, “State space modeling in multiple active control systems,” *Proceedings of active 1999.Floridida.* 909-920(1999)

[6] P. Van Overschee, B. De Moor, “Subspace Identification for Linear Systems: Theory, Implementation, Applications, (Kluwer Academic Publishers, Boston 1996).

[7] M. Viberg, “Subspace-based methods for the identification of linear time-invariant systems”, *Automatica 31. 1835–1851(1995).*

[8] Nestorovic T, Lefevre J, Ringwelski S and Gabbert U, “Finite element and subspace identification approaches to model development of a smart acoustic box with experimental verification,” *Proceedings of world academy of science, 2007 Prague* 315-320(2007)

[9] Clark R L, Fuller C R, “Experiments on active control of structurally radiated sound using multiple piezoceramic actuators,” *J. Acoust. Soc. Am.* **35** 3313–3320(1992)

[10] Lee J C, Chen J C, “Active control of sound radiation from rectangular plates using multiple piezoelectric actuators,” *Applied Acoustics* **57** 327-343(1999)