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Study on Transmission Loss in Smart Panel Using Piezoelectric Shunt

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ABSTRACT

In this paper, admittance is introduced to represent electro-mechanical characteristics of piezoelectric structures and to predict the performance of piezoelectric shunt system. Finite element method is used to obtain numerical admittance. In order to illuminate the effect of noise reduction in the shunt system, two experimental setups were constructed. One is for matching the resonant shunt damping. The other is a standard test setup according to SAE J1400 used to measure the transmission loss for the smart panel with shunt circuit. Shunt performance and noise reduction of smart panel are realized by these two experiments.

1. INTRODUCTION

Noise radiating from vibrating structures is a vital problem in the field of engineering and many efforts have been investigated to solve the problem. Since passive piezoelectric shunt system is simple, compactness and low cost compared with active damping technology and also has advantages of wide bandwidth in vibration reduction and robust temperature characteristics compared with traditional passive damping technology using viscoelastic materials, passive shunt damping technique using piezoelectric ceramic patches with shunt circuit is investigated in this paper [1-3].

The piezoelectric shunt damping is a technology that the mechanical energy in structure is transferred to electrical energy through the piezoelectric ceramic patches bonded on the structure and the transferred electrical energy is dissipated by heat through resistor in shunt circuit attached to the structure [2, 3]. Generally, piezoelectric shunt system consists of host plate on which piezoelectric ceramic patches are bonded and electric shunt circuit networked to the piezoelectric ceramic patches. In order to dissipate external vibration or acoustical energy efficiently, piezoelectric structure must be constructed to generate more charges on the surface of piezoelectric ceramic patches bonded on the host structure. Shunt circuit must be tuned to the resonances to be suppressed and dissipate the vibration energy at resonance into heat. Most researches have been concentrated on piezoelectric shunt circuit such as development of efficient shunt circuit [4-6].

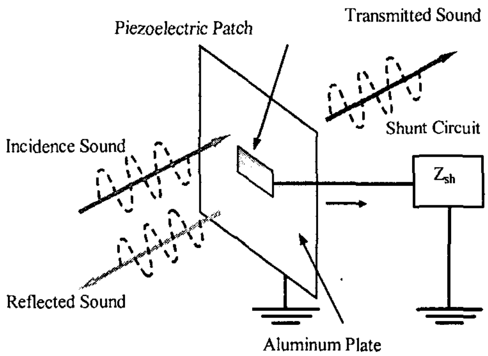

Figure 1. Schematic diagram of piezoelectric structure

Two smart panels (configured as Fig. 1) are compared through numerical analysis and experiment to show the correlation of the results for the design. In the process of experiment, two test setups and methods are investigated including resonance shunt and transmission loss. Therefore, vibration and noise reduction are evaluated.

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2. NUMERICAL ANALYSIS

The finite element methods were used for two ways, the first is to find the strong radiation modes of the smart panel through modal analysis. The second is to calculate the admittances of the smart panel. The admittances at natural frequencies will be used as the objective function to postulate the optimal model in the light of Taguchi method.

The basic resonant shunt circuit consists of a series inductor–resistor R–L circuit paralleled with the inherent capacitance of the PZT, it creates a damped electrical resonance. The resonance can be tuned so that the PZT acts as a tuned vibration energy absorber [7]. The electrical resonance of the circuit can be calculated by the inherent capacitance and the inductance in the shunt circuit, as in Eq. (1).

$$\omega_e = \frac{1}{\sqrt{LC_0}} \quad (1)$$

Here, C_0 describes an inherent dielectric capacity of piezoelectric patch. The synthetic inductor in the shunt circuit was used in order to tune the resonance since it can be shifted a little in the real application. The inductance is calculated using Eq. (2).

$$L = \frac{R_1 R_3 R_4}{R_2} C_1 \quad (2)$$

The resistor, R_2 can be adjusted to change the synthetic inductance, but R_1, R_3, R_4, and C_1 are fixed. According this, one can find the proper electrical resonance.

3. SETUP OF THE EXPERIMENTAL SYSTEM

In order to correlate the results of numerical analysis, two experimental systems were constructed to examine the shunt performance and noise reduction through switching on/off the shunt circuit. Initial and optimal model were used for comparison. The initial model size is 300mmX300mmX0.5mm, with PZT patch 100mmX50mmX0.5mm and the optimal model size is the same host plate size with PZT patch 100mmX100mmX0.5mm.

3.1 Optimal tuning test setup for smart panel

Actually, the resonance of the smart panel will be shifted a little in real application, therefore it is very important to find the optimal inductance and resistance for the shunt circuit. The setup for this purpose is shown in Fig. 2. A PZT patch (50mmX50mmX0.5mm) for actuating bonded on the center place of one side of the panel, an accelerometer (Charge Accelerometer Type 4374, B&K) attached on the surface of the PZT patch for sensing bonded on the other side of the smart panel. Tuning the value of resistor R_2, the real resonance of the shunt circuit can be found. Tuning the value of load resistor R_5, the optimal damping can be achieved. The testing devices includes PORTABLE FFT ANALYZER CF-3200 manufactured by ONO SAKK company.

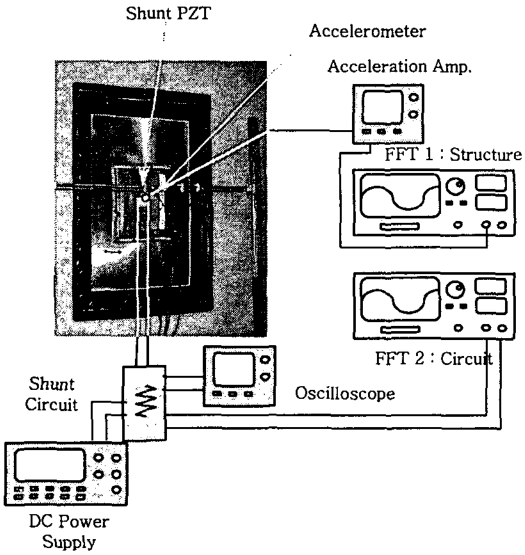


Figure 2. Experimental setup for shunt damping

3.2 Acoustical effect test setup for smart panel

To test the performance of the smart panel with shunt circuit about noise reduction and transmission loss, a standard facility was built according to SAE J1400. The schematic is shown in Fig 3. The transmission loss test facility includes two adjacent rooms, a reverberation room and a semi-anechoic reception room. A test window is located between the two rooms where smart panels are clamped for testing. Sine sweep plane wave is generated through the loudspeakers in the reverberation room, and the sound pressures, which is reflected and transmitted through the window, are measured by microphones in the reverberation room and the reception room. The testing devices include sound signal amplifier (Inter VI PA-4000 PUBLIC ADDRESS AMPLFIER) for magnifying the source signal and 3560-B-040 FFT analyzer made by B&K company.

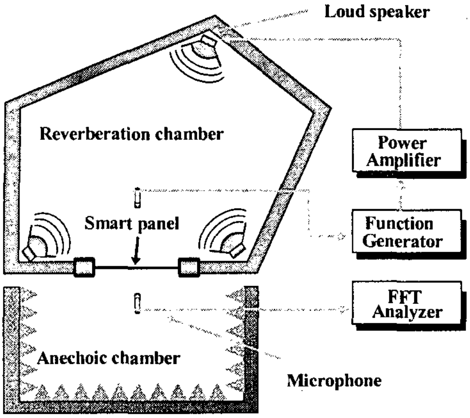


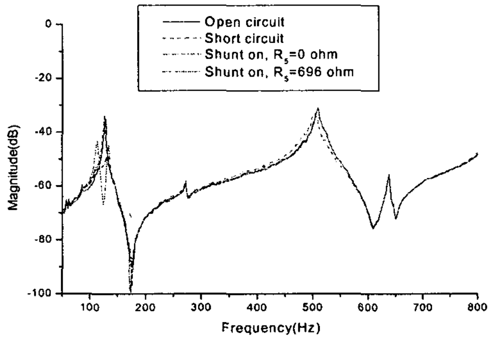
Figure 3. A schematic diagram for transmission loss test

4. RESULTS AND DISCUSSION

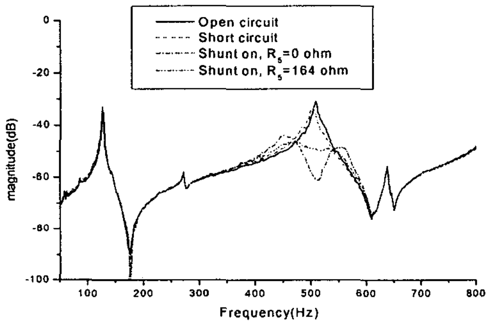
After the numerical analysis, the initial model and optimal model are selected to correlate the numerical and experimental results.

4.1 Shunt damping test

In terms of natural frequencies in the experiment, the first and fifth modes were selected as the resonance in the shunt circuit which need tuning to find best shunt damping. Figure 4 shows frequency response function (FRF) of the initial model.under switching on/off shunt damping circuit. For initial model, the tested results are observed according to four testing conditions. At open and short circuit with shunt off, the resonance is shifted a little due to piezoelectric softening effect. After tuning $R_2 = 120\Omega$ with shunt on, the first mode is matched when the load resistor is $R_5 = 0\Omega$, which represents the under damping state. Tuning the load resistor $R_5 = 696\Omega$ through fixing R_2, the optimal damping can be observed and 16 dB vibration reduction is achieved. For the fifth mode, it shows $R_2 = 200\Omega$, $R_5 = 0\Omega$ which specified the under damping state as well as $R_5 = 164\Omega$ specified the optimal damping. The 18 dB vibration reduction is achieved. By means of the same testing process in the optimal model, the optimal damping is $R_2 = 240\Omega$ and $R_5 = 463\Omega$ for the first mode and 20dB vibration reduction is achieved. For the fifth mode, the optimal damping is $R_2 = 418\Omega$ and $R_5 = 100\Omega$. Vibration reduction of 22dB is achieved. Consequently, under the optimal tuning process, the optimal model proposed good damping effect comparing to the initial model.



(a) First mode



(b) Fifth mode

Figure 4. The shunt damping effects of initial model

4.2 Transmission loss test

Transmission loss is determined using equation [8].

$$TL = MNR + 10\log10(A/S\alpha) \qquad (3)$$

where TL is the transmission loss of the panel, MNR is the measured noise reduction between the reverberation room and reception chamber under sine sweep wave exciting. $S\alpha$ is the Sabine absorption of the reception room, and A is the area of the test window. The expression $10\log10(A/S\alpha)$ is constant for any test panel with the same area. Therefore, it can be replaced with a constant correction factor,(CF), Eq. (3) is changed to

$$TL = MNR - CF \qquad (4)$$

In order to determine this correction factor for the test window, a flexible test panel was made out of 1mm-thick barrier material to clamp into the test window to calibrate the environment noise level. The transmission loss of the barrier material is directly calculated from the mass-law equation:

$$TL_{calc}(dB) = 20\log10(W) + 20\log10(f) - 47.2 \quad (5)$$

where TL_{calc} is the theoretical transmission loss, W is the weight density of the flexible test panel, and f is the center frequency of the third-octave measurement band. The CF is determined as

$$CF = MNR - TL_{calc} \quad (6)$$

The initial model and the optimal mode with shunt circuit are tested. The sine sweep wave was used to excite the test panel from 1-1250Hz. The test results are shown in Figs. 5 and 6. From the figures, the transmission loss of initial model increased 2dB for the first mode and 5dB for the fifth mode. However, the transmission loss of optimal model increased 3dB for the first mode and 8dB for the fifth mode. As result, smart panel of optimal configuration with shunt circuit switch-on can increase more transmission loss comparing to the shunt switch-off.

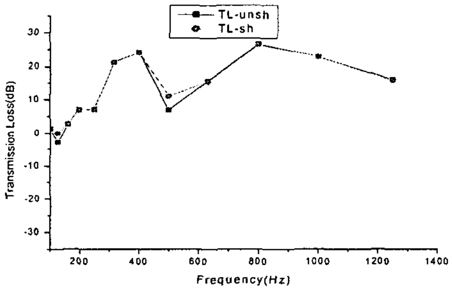


Figure 5. Transmission loss of the initial model

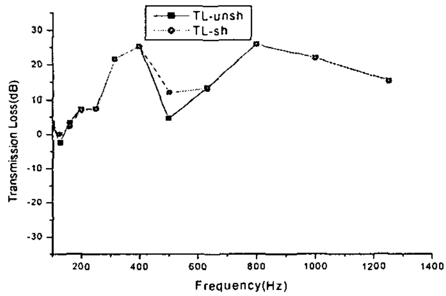


Figure 6. Transmission loss of the optimal model

5. CONCLUSIONS

In this paper, the admittance is used as the performance index in the design of smart panel. The resonant shunt circuit is networked with the main structure to improve the shunt performances. Using optimal configuration obtained from Taguchi method, two experiments were executed to verify vibration reduction and noise reduction. The shunt damping is improved as 25 % in first mode and 22 % in fifth mode compared to the initial configuration. Transmission loss test for the initial model and optimal model showed the transmission loss can be increased 50 % for the first mode and 30 % for the fifth mode.

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