한국소음진동공학회 2004년도 추계학술대회논문집, pp. 633~636.

압전 소자를 이용한 항공기용 사각박판에 대한 음향 반응제어

Control of Acoustic Response of A/C Rectangular Plate Using Piezo Electric Material

정도희*· 박신옥**
Dohee Jung, Seenok Park

Key Words : Corner-pinned Plates(코너 지지된 박판), Piezoelectric Actuator(압전소자).

ABSTRACT

Acoustic response control of a corner-pinned plate using piezoelectric wafers was studied, both theoretically and experimentally. Three different sizes of aluminum alloy plates were used and available ball joints were employed to hold the plate at the four corners. The plate with the largest aspect ratio showed the largest and most clear responses to the acoustic excitation in the range of frequencies (0~200Hz), and sound pressure levels (80~100dB) as predicted. The reduction of the acoustic response of the plate by piezoelectric actuator was very significant, more than expected, but abatement of the sound transmission through the plate was only slightly altered by the piezoelectric actuator. This work is an original work extending earlier work with doors excited by acoustic fields. The important difference is the used of ball joints to simulate the joints.

1. Introduction

As aircraft, automobile and other types of vehicles become faster, they make more noise as well as vibration. Noise and vibration can cause a very serious problem for the comfort of the passengers as well as structural fatigue problems [1].

The goal of this research was to reduce the vibration amplitude of a rectangular plate with corner supports caused by acoustic excitation by placing one piezoelectric actuator on the central position which has maximum deflection of plate. There is only a small amount of general literature on the vibration of corner-pinned plates [2, 3].

Three different sized rectangular plate models were used. Vibration control equipment was used to attempt to reduce the acoustic and mechanical responses of the vibrating plate. With these models, the frequencies and bending properties of the corner-pinned plates were calibrated, and finally, the control of the piezoelectric wafer was designed. A comparison of the experimental data with the theoretical results was also made.

2. Theoretical Analysis for the Vibration of a Corner-pinned Rectangular Plate

There are many different methods to get the natural frequencies of the corner-pinned plate vibration. Although the tradition PDE(partial derivative equation) method is valid here, the Rayleigh method was used more extensively here. The motion of rectangular plate us analyzed and then boundary conditions for the corner-pinned plate are be applied to it [4]. The basic equation of motion for a vibrating rectangular plate:

$$\mathrm{D}\nabla^4 w(x,y,t) + \rho_a \frac{\partial^2 w(x,y,t)}{\partial t^2} = 0 \qquad (1)$$

Applying to equation (1) with the boundary conditions of a corner-pinned plate as equation (2), and from the Rayleigh's energy method for the frequency of mode shape 'i' [4], it yields,

* 신영중공업㈜ 연구소
E-mail : dhjung@syhico.com
Tel : (061) 462-3700, Fax : (061) 462-3708

** VOICEPIA

$$
\begin{aligned}
w(0,0,t) &= w(0,0) = 0 \\
w(0,b,t) &= w(0,b) = 0 \\
w(a,0,t) &= w(a,0) = 0 \\
w(a,b,t) &= w(a,b) = 0
\end{aligned} \quad (2)
$$

$$
\omega_n = \frac{\lambda_i^2}{a^2}\sqrt{\frac{D}{\rho_a}} \text{ (cycle/sec) or } f_n = \frac{\omega_n}{2\pi} \text{ (Hz)} \quad (3)
$$

Equation(3) is identical to the exact solution formula except for λ_i^2. The exact solution gives lower values in the lower modes. By establishing a ratio between the Rayleigh solution and the exact solutions, this ratio can be applied to the plate frequency calculated by the Rayleigh method considering ball joint mass and inertia, and piezoelectric mass and inertia to obtain close prediction with test as equation (4).

$$
\omega_n^2 = \frac{U_{plate} + U_{piezo}}{M_{plate} + M_{piezo} + M_{ball-joint}} \quad (4)
$$

3. Experimental Setup

3.1 Corner-Pinned Rectangular Plate Model

The plate model is a thin rectangular plate of aluminum alloy (AL 2024) with a certain homogeneous thickness. Fig. 1 and Fig. 2 show the plate and anechoic box for the experiment.

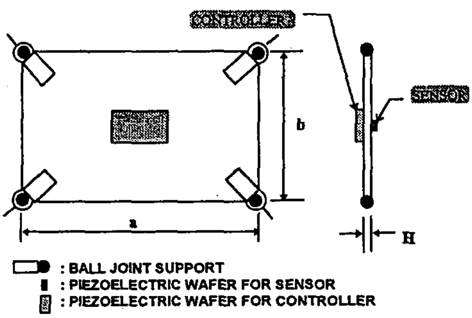

Fig. 1 Corner-pinned aluminum plate with piezoelectric sensor and piezoelectric controller

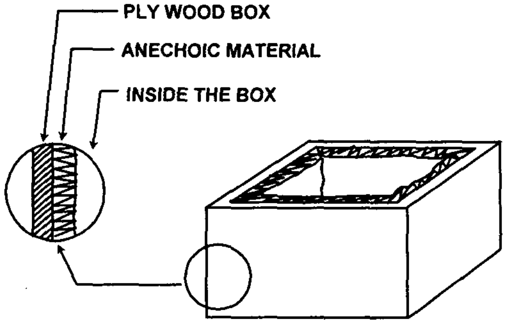

Fig. 2 Anechoic box

3.2 Acoustic Excitation Equipment

The size of anechoic chamber is 30 x 15 x 12 (in^3). The speaker (or driver) provides sound wave levels of 80dB, 90dB and 100dB to the plate. Also, 12 inch dial-wound voice coil type subwoofer speaker was selected to provide a low frequency sound wave of 50 ~ 200Hz because the natural frequency of the corner-pinned plate chosen was in that range. The frequency range of speaker is 26Hz ~ 2.7kHz, and impedance is 8ohm/4ohm. For this reason, low frequency speaker or woofer is used as the acoustic driver as shown in Fig. 3.

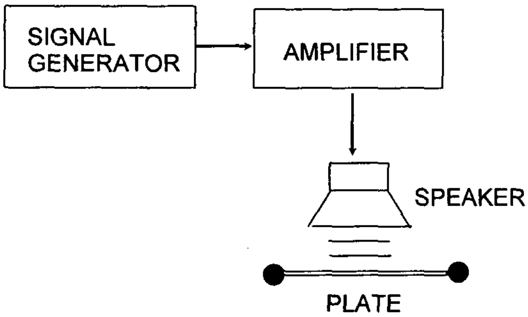

Fig. 3 Acoustic equiptment

3.3 Vibration Control Equipment

The control equipment was intended to abate the vibration of the plate itself and to reduce the transmission of the sound wave through the plate. It consists of three parts: a sensor, a controller, and a piezoelectric actuator as shown Fig. 4. These piezoelectric wafers apply strain by the electric power sent by the controller, and its bending moments are proportional to the amount of the electric power. [4, 5]

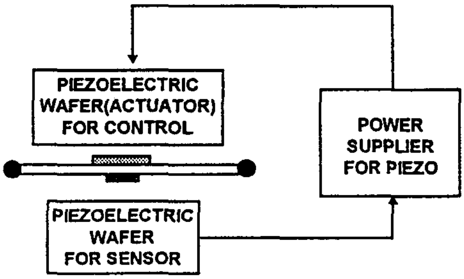

Fig. 4 Three major parts of the control equipment

3.4 Control Method for Reducing the Response of the Plate By Using a Piezoelectric Actuator and Piezoelectric Sensor

For controlling the responses of the corner-pinned plate, a small piece of piezoelectric wafer was used as an actuator. Also, a small piece of piezoelectric wafer was used as a sensor.

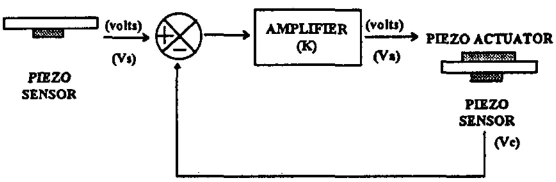

Fig.5 Block diagram for the feedback piezoelectric control concept

The feedback gain of the signal from the piezoelectric sensor to the piezoelectric control wafers is :

$$V_c = \frac{KV_s}{1 + KV_s} \tag{5}$$

4. Results

For the response analysis, the simple mode shape and the Cheng's mode share were used [6]. As shown in the Fig. 6, the plate of the aspect ratio 2.0 gave the most significant responses, and the responses of the plate are not linear to the sound pressure level. They each showed different peaks, but the normalized graphs more closely follow the theoretical analysis.

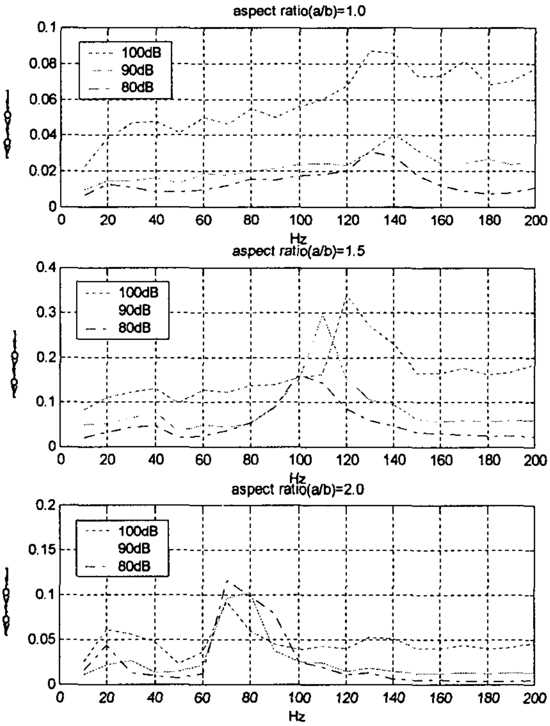

Fig.6 . Comparison of normalized response of piezoelectric sensor to the sound excitation

With the piezoelectric actuator, the responses were lower by about 76% down to about 24% of the original ones. The piezoelectric sensor for the control worked well as a sensor (See Fig.7). The transmission of the sound through the plate was not high, and the reduction improvement with the piezoelectric actuator was only slight. However, more accurate noise measurements are needed to better quantity the effects.

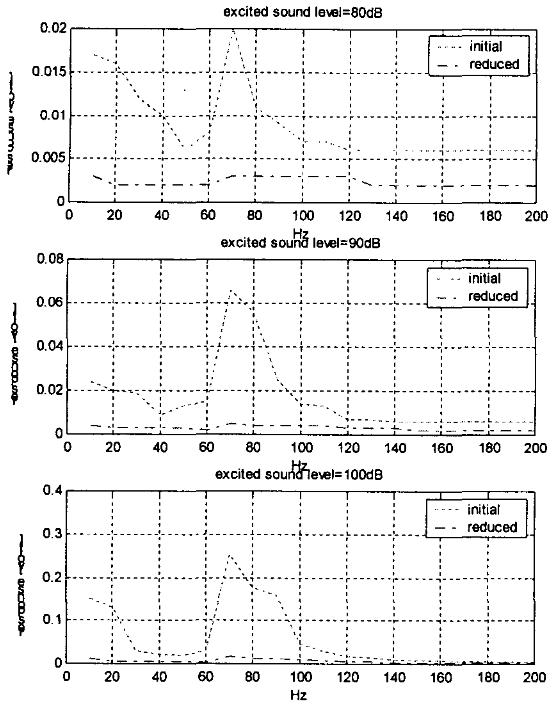

Fig. 7. Comparison of the responses with and without the piezoelectric actuator (aspect ratio = 2.0)

It was measured more closely predicted from the preceding experiments [2] perhaps because they used better measuring equipment. Since the bending responses of the plate of aspect ratio 2.0 is the most significant of the three different sizes of plates, these data and graphs are presented here, while the related date for all aspect ratio is in [6]

5. Conclusions

It was found that a small piezoelectric wafer, used as a motor could snub acoustic response of corner-pinned plates of sizes $5\times5, 5\times7.5, 5\times10(\text{in}\times\text{in})$ and 0.063(in) thickness. The responses were snubbed by around 74% typically at resonance (or some overall averages). While it was hoped that this snubbing action would alter the acoustic transmission somewhat, the results showed that the acoustic transmission was only slightly altered. However, more accurate measuring devices may have conclusively obtained the reduction difference. The wafer was placed only on one side of the plate. Two wafers may have given more reductions. A second, much smaller piezoelectric wafer, was used as a sensor in feedback plate motion to the control system, then to the motor to snub. Attempt to use strain gages were unsuccessful. The strain gage wire leads disbanded, the strain gage became detached, and a variety of these problems led to using the second smaller wafer that worked well.

References

1. E. J. Richards and D. J. Mead, 1968, *Noise and acoustic fatigue in aeronautics*, London, New York, Wiely.
2. S. Akishita and H. Lee, 1990, "Sound Transmission Control by Using Piezo-electric Actuator", AIAA 90-3923.
3. X.-S. Cheng, *Vibrations of rectangular plates supported at corner points*, Tongji University, Shanghai.
4. Kim, J.S. ,1992 " Active vibration control of flexible beam using piezoelectric actuator", Transaction of the Korean Society for Noise and Vibration Engineering", Vol.2, No.3, pp.173~181.
5. Kim, S.J, Yoon K.W. ,1996" Suppression of Sound Radiation from Composite Plate Structures using Piezoelectric Materials", Transaction of the Korean Society for Noise and Vibration Engineering", Vol.6, No.6, pp.781~790.
6. S. Park, 1994, "Techniques for Damping Acoustic and Vibration Responses of Rectangular Corner-pinned Plates Using Piezoelectric Actuators", *M.Sc. thesis of Saint Louis University.*