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New results in active and passive control of sound transmission through double wall structures

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Abstract

This paper presents an overview of recent results concerning active and passive control of sound transmission through double wall structures. First, the analytical simulations are presented for the active control of sound transmission through double wall structures. These are based on a coupling structural-acoustic modal model using piezoelectric materials and loudspeaker/microphones as actuator/sensors. The numerical results show the potential for employing piezoelectric sensor/actuators to improve sound transmission loss. In addition, some useful conclusions are obtained. When, for example, a volume velocity sensor is applied to a radiating plate, sound transmission loss will improve significantly, no matter what type of actuators (i.e. loudspeakers or PZT actuators on either plate) are used. With a loudspeaker/microphone configuration should be avoided for same thickness double wall structures, etc. Furthermore, current research activities on the control of sound transmission through double wall structures also include an arrangement of Helmholtz resonators (HRs) placed within the wall cavity for the passive control of sound transmission through a double wall structure. The current research goal is to find optimal parameters of HRs (damping ratio, numbers, natural frequency, etc.) in order to maximize the improvement of the transmission loss over a specified frequency range. An analytical model of fully coupled structural-acoustic-HRs within a double wall structure is established. Results indicate that tuning the HRs to the mass–air–mass resonance frequency does not guarantee the best possible improvement of the sound transmission loss. Using the frequency averaged sound transmission loss as the cost function to optimize the natural frequency of the HRs is a more effective method to find the HRs tuning frequency for maximizing the improvement of the transmission loss. The aim of this paper is to illustrate the potential of the active control approach using smart piezoelectric materials and different control actuators (i.e. loudspeakers in the cavity, PZT actuators applied to one of the plates) to improve the transmission loss through double wall structures. Additionally, new results on tuning and placement of HRs are presented. Both of these are based upon a refined model of the systems and offer good physical insight into the active and passive control of sound transmission through double wall structures.

Keywords: Double wall structure; Active noise and noise transmission control; Piezoelectric; Helmholtz resonator; Transmission loss

1. Introduction

A significant amount of research has been performed to develop control technologies for suppressing the interior noise of the fuselage. The advances have come about thanks to the competitive market and increasing customer demand as well as an awareness for improved comfort environments. Double wall structures provide good noise insulation from the exterior of an aircraft fuselage to the interior noise field. However, the acoustic performance of the double wall structure deteriorates rapidly at low frequency around the mass–air–mass resonance (double structures resonance), where it can be even became worse than that of a single plate. In an effort to reduce the levels of vibration and interior noise of enclosures, many techniques have been developed. These can be broadly classified into active control and passive control methods.

One possible solution is by means of active control methods. Over the past decades, with the advances in smart materials and increasing power of digital computers, active control has emerged as a viable technology to solve the problem of low frequency noise radiated from structures. Active control falls into two categories: active noise control (ANC) using a secondary acoustic source to cancel unwanted sounds and active structural acoustic control (ASAC) utilizing a variety of actuators applied directly to the structure for reducing the sound power radiated from the structure.

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There has been a great deal of analytical and experimental research on active control of sound transmission through double wall structures, and significant progress was obtained in both the ANC system [8,13,14] and the ASAC system [1,13]. For example, in Ref. [13], a modal model is derived from the partial differential equations of the subsystems. Furthermore a thorough understanding of control theory, potential actuators and sensors, and possible complications encountered with active sound or vibration control is provided. Ref. [1] developed a state space model for double glazed window with control loudspeakers within the cavity between the plates; then, four different controllers (two feedforward and two feedback control strategies) were implemented and compared.

Another possible solution is to use passive control or semi-active control methods. For example, it is possible to apply an arrangement of optimally tuned Helmholtz resonators (HRs) to increase the acoustical damping level inside the cavity between the double plates. The HR is one of the most common devices for passive control of noise at low frequencies. Fahy [3] first investigated the interaction between a single HR and an acoustic mode in an enclosure. Mason and Fahy [12] proposed to control sound transmission through an infinite double plate using HRs. Mao and Pietrzko [9] developed a fully coupling structural-acoustic-HRs system for double wall structures by the modal coupling method. In this work the optimally tuned natural frequency and damping ratio of HRs are discussed in detail.

In general, previous work on the active control of sound transmission through the double wall structures employs microphones or accelerometers as sensors. If microphones are used as the pressure sensor, microphones in the far field normally perform better than those located within the cavity. However, positioning microphone in the far field is often impractical to implement. In most recent research, microphones located in the cavity were used as discrete pressure sensors so that the control system can be made more compact and the acoustical path between the exciting source and sensor less sensitive to environmental changes.

As opposed to discrete pressure and velocity measurement, distributed piezoelectric materials sensors (i.e. PVDF) are often used in numerical/experimental studies for single plate cases [10,11,15]. Piezoelectric sensors have the inherent advantage of integrating over their surface area, which leads to potentially more robust implementations than acceleration sensors. Piezoelectric sensors have attracted ever greater attention in recent years.

The aim of the paper presented here is twofold. Firstly, the potential of the active control approach using piezoelectric materials as actuator/sensors is illustrated. The numerical control performances with different control actuators (i.e. loudspeakers in the cavity, PZT actuators applied to one of the panes) and sensors (microphones, symmetrical rectangular PVDF patches and volume velocity PVDF sensor) are studied and compared. Furthermore, physical insight into active control of sound transmission through the double wall structures is achieved.

As a second aim, it is sought to control sound transmission through double wall structures using optimally tuned HRs. An analytical model of fully coupled structural-acoustic-HRs inside a double wall partition is presented and the closed form solution for the cavity pressure with HRs is established. The optimal parameters of HRs (damping ratio, numbers, natural frequency, etc.) maximizing the improvement of the sound transmission loss of HRs is then discussed.

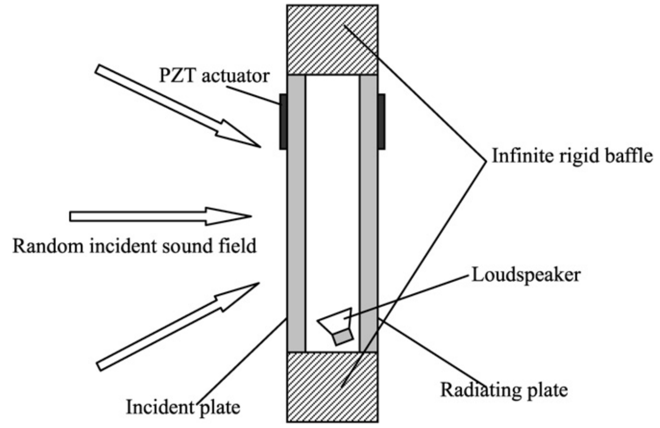

Fig. 1. Double plate structure with different actuators.

2. System modeling for active control

Fig. 1 shows a model describing the mechanical behavior of a double wall structure. Two plates (plane, parallel, same finite size with length L_x and width L_y), denoted by incident plate and radiating plate, are located in a rigid framework and baffled in an infinite rigid wall. The incident plate is set to be at $z = 0$ and the radiating plate at $z = L_z$. The radiated acoustic field of the double plate structure is assumed to be an acoustic free field.

Assume that the double wall structure is excited by a random indent acoustic wave (diffuse field). There are K_p control acoustic sources in the cavity, K_i control PZT actuators on the incident plate and K_r control PZT actuators on the radiating plate. These PZT actuators consist of two co-located PZT patches (on each side of the plates) wired out of phase to produce pure bending in the structure. The acoustical field of the cavity can be described as a homogeneous wave equation as follows:

$$\nabla^2 p - \frac{1}{c_o^2}\frac{\partial^2 p}{\partial t^2} = -\rho_o \sum_{k=1}^{K_p} \frac{\partial Q_{\mathrm{con},k}}{\partial t} \tag{1}$$

with boundary conditions

$$\frac{\partial p}{\partial \vec{n}} = \begin{cases} \rho_o \frac{\partial^2 w^i}{\partial t^2} & \text{on incident plate } (z = 0) \\ -\rho_o \frac{\partial^2 w^r}{\partial t^2} & \text{on radiating plate } (z = L_z) \\ 0 & \text{otherwise} \end{cases}$$

where ρ_o and c_o are the density and sound speed of the air, respectively. p is the sound pressure in cavity, $Q_{\mathrm{con},k}$ is the kth acoustic source strength at location $\boldsymbol{r}_k$ in the cavity. w^i and w^r are the displacements of the incident plate and radiating plates, respectively.

Assume that the stiffness and mass of the PZT actuators added onto the plates are negligible. The vibration of the in-