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Active and Passive Control of Shell Modal Vibration and Acoustic Radiation

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There has recently been significant interest in reducing structural noise and vibration using small piezoelectric actuator patches surface bonded to a vibrating structure. Typically, piezoceramics (such as PZT) are used for actuation because of their large force output capabilities. However, because of its rigidity, PZT cannot typically be used on curved surfaces like shells. For such applications, macro-fiber composite (MFC) piezoelectric actuators—which use PZT as the actuation element but which are flexible—are more suitable [1]. This method—using an actuator to introduce a control input to the system—is termed an “active” method. Another method of structural acoustic and vibration reduction is the use of passive constrained layer damping (PCLD) patches [2]. These patches (which are typically small relative to the vibrating structure) consist of a viscoelastic layer surface-bonded to the structure, and a rigid constraining layer bonded to the viscoelastic layer. Elastic deformations of the substructure result in shear deformation of the viscoelastic layer and significant energy dissipation [2]. Such treatments are deemed “passive” methods. Both methods have been found to be effective in reducing sound and vibration from structures, especially when the patch location is optimized (a frequency dependent process) [2-3]. Both methods also have their respective limitations. For instance, passive reduction is typically not as significant as active reduction; however passive methods generally act in a broadband sense. Active methods can typically target only single frequencies at a time, and can result in unwanted modal spillover [3]. Furthermore, controller stability is always an issue with active control methods.

More recently, a combination of active and passive methods, termed “hybrid” method, has been investigated, with the goal of retaining maximum benefits from each method. For example, an ideal hybrid method would provide significant reduction for broadband and single-frequency excitation in a highly stable and cost effective package. A state-of-the-art review by Benjeddou [4] detailed various hybrid methods. Some include both active and passive patches on the same structure, while others include “active constrained layer damping” (ACLD) in which the constraining layer of a traditional passive patch is replaced with an actuator to induce further shear deformation. The review concludes that the literature is sparse on hybrid methods applied to shell structures. Such structures are of particular interest to aerospace and automotive industry because many components (e.g. helicopter cabin, automotive driveline, etc.) can be modeled by vibrating thin-walled shells.

Our experimental results show that a single MFC actuator surface bonded to a shell structure is capable of significant noise reduction. Experiments are performed in an anechoic chamber with disturbance input in the form of an electrodynamic shaker (Fig. 1). The structure used is a thin cylindrical aluminum shell of the following dimensions: length = 457 mm, outer diameter = 152 mm, and thickness = 2.2 mm. Excitation is harmonic at approximately 1250 Hz, corresponding to the (2, 2) mode of the shell (Fig. 2).

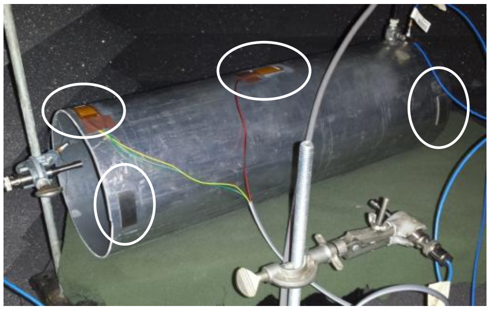

Figure 1. Experimental setup with active and passive patches

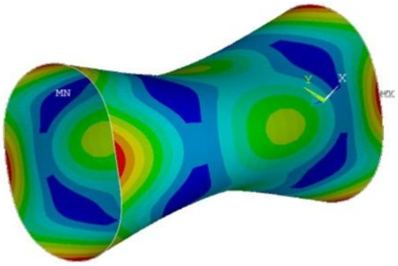

Figure 2. Mode (2, 2) of a cylindrical shell

Modal index (m, n) corresponds to the m-th axial mode and the n-th circumferential mode. User-in-the-loop feedback is used to determine the optimal amplitude and phase for the control signal (Fig. 3). A sound pressure level reduction of approximately 35 dB is observed (Fig. 4)

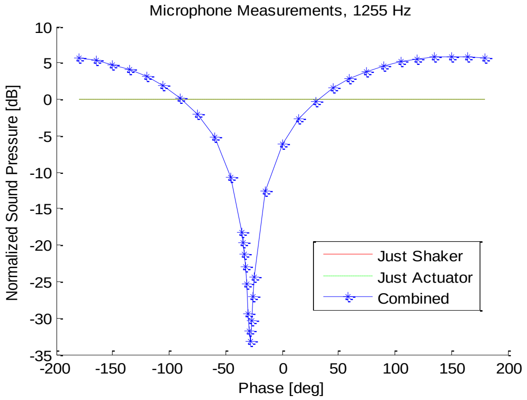

Figure 1. Active reduction vs. control signal phase

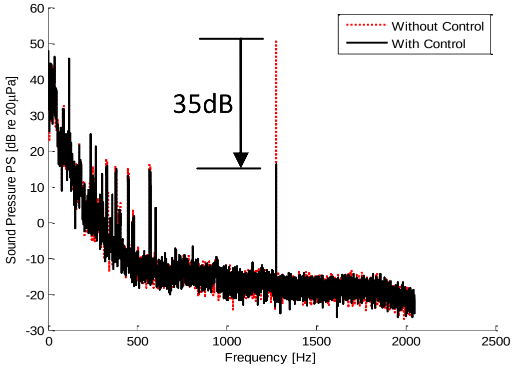

Figure 2. Sound pressure spectrum with active control

Similar experiments were performed with additional passive damping applied to the shell (for the hybrid method). Preliminary findings show that such a hybrid method can provide additional reduction beyond either active or passive methods alone, as evident from Table 1. Here, the insertion loss is defined as:

$$IL[dB] = 10\log 10\left(\frac{\psi^2_{untreated}}{\psi^2_{treated}}\right) \tag{1}$$

Table 1. Measured insertion losses (IL) for a shell with alternate reduction methods for the (2, 2) shell mode

Reduction Method	Acceleration IL [dB]	Acoustic IL [dB]
Passive	10	10
Active	44	35
Hybrid	67	44

Analytical and computational models based on modal expansion [3] and Rayleigh-Ritz method [2] as well as a commercial finite element method are used to support the experimental findings and to objectively determine optimal placement for active patches. Finally, applications for this research include ground vehicles (hybrid and electric vehicles with mid-to-high frequency noise sources), aircrafts/rotorcrafts (for radiated sound from cabin walls), and submarines.

Acknowledgments

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