ACTIVE SOUND RADIATION CONTROL OF CYLINDRICAL STRUCTURES USING PIEZOELECTRIC ACTUATORS

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1. INTRODUCTION

The placement of control actuators in an active noise control system can significantly affect the control performance. Considering the high cost of active control experiments, the optimal design of the physical control system is essential to ensure the efficiency of an active noise control system before it is implemented.

In simple cases like the sound radiation from plates into a free field, the optimal position of the actuators could be determined using sound radiation analysis and modal analysis. However, for a complex enclosure, it would be a wise choice to find the optimal positions of actuators using some optimal approach, because of the inherent complexity of structural acoustic coupling.

Due to their advantages over the gradient-based approach of being robust and highly efficient in dealing with complex multi-model nonlinear problems, Genetic Algorithms (GAs) have been recognized by many researchers as a promising tool in the optimal design of active noise and vibration control systems. However, most of the reported work focused more on the GAs than on the design of the ASAC system itself, and PZT actuators were simplified to be point forces. Obviously, the control effect of PZT actuators is different from that of point forces. The fact that PZT actuators generate distributed effects on the structure over the covered area makes the problem of optimal placement design more critical.

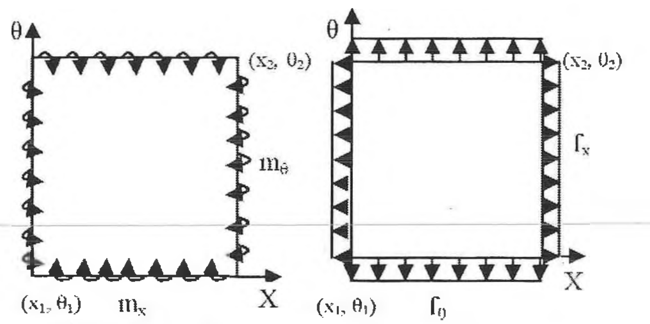
In this paper, the location optimization of PZT actuators in an ASAC system of a cylindrical shell with an internal floor partition is investigated using Genetic Algorithms. The primary physical model was previously developed to simulate the sound field inside an aircraft cabin. In the present work, the effect of PZT actuators was added to the model through a bending model and an in-plane force model [1]. The control performances of both models were assessed and compared. Considering the requirement of practical application of ASAC, the optimal configuration of control system obtained at a single frequency was also tested over the low frequency range below 500Hz.

2. METHOD

2.1 Models of PZT

Two analytical models of PZT actuators (i.e., bending and in-plane force models [1]) were employed here to simulate the effect of PZT actuators attached on opposite sides of the cylinder wall. The bending model simulates the effect of two actuators operating out of phase, which produces an axial stress distribution varying linearly through the thickness of the cylinder wall and creates bending about the middle surface of the cylinder. The loading produced on the cylinder by the bending model is approximated by a line moment distribution acting on the perimeter of the piezoelectric patch area (Figure 1 (a)).

With the in-plane force model, the actuators are assumed to operate in-phase. When this model is implemented on a flat plate, only in-plane displacements are produced. In the case of a cylinder, however, bending displacement is also induced by the in-plane deformation due to the curvature effects intrinsic to shells. Hence, it is possible to employ this model in the ASAC of a cylindrical structure. The in-plane loading can be simulated by a line force distribution on the perimeter of the patch area (Figure 1 (b)).



(a) Bending model (b) In-plane force model
Figure 1: Model of PZT actuators

2.2 Placement optimization of PZT actuators

The vibroacoustic model of the investigated structure was presented in detail in the previous work [2]. In the optimization of the actuator placement using Genetic Algorithms, the reduction of the acoustic potential energy, given by the difference between the acoustic potential energy level before and after control, was employed as the evaluation function to achieve the global control of the interior sound field. For a given configuration of actuator placement, the optimal control input was determined using the quadratic optimization approach minimizing the acoustic potential energy in the enclosure.

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3. RESULTS

The investigated structure and the coordinate system are shown in Figure 2. In simulations reported hereafter, the disturbances were assumed to be point forces; and control actions were provided by PZT actuators. Clearance distance between the disturbance and the control actuator of 0.05m in the longitudinal direction and 10 degrees in the circumferential direction was imposed to avoid placing a control actuator too close to or even overlapping a disturbance force. A complex case involving 10 disturbance forces with random amplitudes and phases and 4 PZT actuators was investigated. The size of the actuators is 0.05m x 0.02m covering a sector angle of 4°.

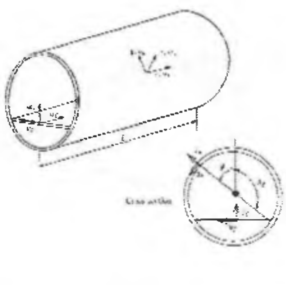
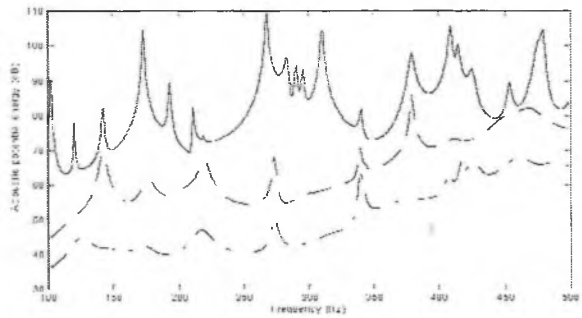


Figure 2: Schematic diagram of investigated structure

PZT actuators were assumed to operate as a bending model and an in-plane model, respectively. Optimization was carried out at the acoustic resonant frequency of 283.7 Hz. The reduction of the acoustic energy with the optimal PZT actuators operating as a bending model was up to 41.66 dB. As the PZT actuators operate as an in-plane force model, the reduction of the acoustic potential energy reached 53.56 dB, which is 11.9 dB more than that obtained in the case of a bending model.

The above result was obtained for one single frequency. Therefore, it is no surprise that the optimal configuration performs well. If it is only effective at one single frequency, a control system would be highly limited in a practical application. Therefore, it would be interesting to verify whether the optimal configuration obtained could also be effective for other frequencies. To this end, the control performance of the same control system was tested in the frequency range below 500 Hz (Figure 3). Since there are no other resonant frequencies below 100 Hz, the frequency range examined was set from 100 Hz to 500 Hz. From Figure 3, one can observe that there is significant sound attenuation over the whole frequency range of interest, whether the PZT actuators operate as a bending model or an in-plane force model. This overall performance could be explained by the structural coupling analysis of the investigated structure [3], which showed that, in this frequency range, the sound field is mainly contributed by a limited number of structural modes with high radiation ability. Therefore, one could predict that the ASAC control system designed at one acoustic resonant frequency could also be effective over the low frequency range under 500 Hz.

From Figure 3, it can also be observed that, over the whole frequency range of interest, the in-plane force model has much better control performance than the bending model. The typical difference between the two configurations oscillates between 10 and 15 dB. This observation can be easily understood. In fact, due to the strong membrane effect, the in-plane motion of the shell is strongly coupled to the out-of-plane motion at low frequencies. When PZT actuators are attached to the surface of a cylindrical shell, the generated in-plane force could produce a more favorable distribution of the low order circumferential modes of the investigated structure and hence couples much more efficiently with the low order interior cavity modes than does the bending model.



Before control ------Control with bending model
-·-·-·-Control with in-plane force model
Figure 3: Control performance of optimal PZT actuators

4. DISCUSSION

This study demonstrated the encouraging performance of PZT actuators in active control of interior noise after placement optimization over the low frequency range under 500 Hz, as well as at the single design frequency. In terms of PZT actuators attached on a cylindrical surface, the in-plane force model has much better control performance than the bending model.

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