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Multi-parameter optimization of piezoelectric actuators for multi-mode active vibration control of cylindrical shells

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ABSTRACT

A novel technique for the multi-parameter optimization of distributed piezoelectric actuators is presented in this paper. The proposed method is designed to improve the performance of multi-mode vibration control in cylindrical shells. The optimization parameters of actuator patch configuration include position, size, and tilt angle. The modal control force of tilted orthotropic piezoelectric actuators is derived and the multi-parameter cylindrical shell optimization model is established. The linear quadratic energy index is employed as the optimization criterion. A geometric constraint is proposed to prevent overlap between tilted actuators, which is plugged into a genetic algorithm to search the optimal configuration parameters. A simply-supported closed cylindrical shell with two actuators serves as a case study. The vibration control efficiencies of various parameter sets are evaluated via frequency response and transient response simulations. The results show that the linear quadratic energy indexes of position and size optimization decreased by 14.0% compared to position optimization; those of position and tilt angle optimization decreased by 16.8%; and those of position, size, and tilt angle optimization decreased by 25.9%. It indicates that, adding configuration optimization parameters is an efficient approach to improving the vibration control performance of piezoelectric actuators on shells.

1. Introduction

Circular cylindrical shells have large specific stiffness and high strength which make them useful components in various engineering structures such as energy pipelines, large medical equipment, vehicle cabins, and more. However, they commonly have thin walls, small damping, and close modes. It is necessary to apply multi-mode active vibration control to the cylindrical shell [1] to sufficiently improve structural safety and reliability, as well as to provide enhanced environmental comfort to personnel on the interior of the shell.

The active vibration control of cylindrical shells with distributed piezoelectric material has been investigated by many previous researchers. Tzou et al. [2–4] firstly established the distributed polyvinylidene fluoride (PVDF) actuator dynamics model on the cylindrical shell and explored the effects of different control voltages on damping. Qiu et al. [5] suppressed the vibration and noise of the cylindrical shell in a piece of magnetic resonance image (MRI) equipment by distributed piezoelectric actuators. Jin et al. [6] employed a fuzzy controller based on the genetic algorithm (GA) to control cylindrical shell

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vibration via piezoelectric sensor and actuators (S/As). Zhang et al. [7] studied a cylindrical shell surface partially covered with the multilayer PVDF actuators (LPA) for cylindrical shell active vibration control; Kwak et al. [8,9] established an active vibration control model of macro fiber composite (MFC) actuators and sensors pasted circumferentially and longitudinally on the cylindrical shell, respectively. A sound theoretical foundation for cylindrical shell vibration control with distributed piezoelectric S/As has been established by these researchers. However, the position, size and other parameters of piezoelectric S/As are usually chosen by experience, so the vibration control efficiency cannot be fully optimized [10].

Various optimization techniques have also been attempted for better vibration control performance of distributed piezoelectric actuators on shells. Sun et al. [11] proposed a quasi-modal S/As concept under which the control energy and spillover minimization serve as position and size optimization criteria. Yang et al. [12] considered vibration energy dissipation maximization as an optimization objective and controlled positions, sizes, and feedback gains by GA accordingly. Sohn et al. [13] employed vibration energy minimization as an optimization criterion for three MFC actuators on a hull surface in several specific positions and directions. Biglar et al. [10,15] optimized the positions and orientations of piezoelectric S/As on the isotropic material and functionally graded material (FGM) cylindrical shell by GA for controllability/observability maximization and control spillover minimization [14]. Zhai et al. [1] optimized the actuators positions and thicknesses of finite element model via the simulated annealing algorithm (SAA); Hasheminejad et al. [16] optimized the positions of S/As on a thick cylindrical shell by GA. Various parameters, such as position, size, tilt angle, and thickness, have a certain impact on performance of actuators. However, there is no available technique for the simultaneous optimization of position, size, and tilt angle so far. Piezoelectric patches with tilt angle are commonly modeled via analytical mechanics [10,13,15], the calculation process is relatively complicated.

In this paper, the modal control force of tilted orthotropic piezoelectric actuators is derived based on the theory of piezoelectric shell distributed control [2] and partition integral methodology. A multi-parameter (position, size, tilt angle) optimization model for piezoelectric actuators pasted on the cylindrical shell is established. Four multi-parameter optimization schemes are tested to compare their vibration control performance, including position optimization, position and size optimization, position and tilt angle optimization, and position, size, and tilt angle optimization. A novel geometric constraint is also added into the GA to prevent overlap between tilted actuators.

2. Multi-parameter optimal model of cylindrical shell vibration control

Consider a thin cylindrical shell with tilted piezoelectric film actuators on its outer surface, as shown in Fig. 1. x, ψ, and α_3 form the orthogonal curvilinear coordinate system, where x defines the longitudinal direction, ψ the circumferential direction, and α_3 the transverse direction. “1, 2” are the orthogonal plane coordinates of piezoelectric material; axes 1 and 2 are the first and second principle directions, respectively. The circular cylindrical shell has a length L, radius R, and thickness h. ($x_{i,G}$, $\psi_{i,G}$) denotes the center position of the i-th piezoelectric actuator. w_i^a, l_i^a, h_i^a and β_i are the width, length, thickness, and tilt angle of the i-th piezoelectric actuator, respectively.

2.1. Modal control force

The thickness of the piezoelectric actuators is assumed to be much thinner than that of the cylindrical shell, and the effects of stiffness and mass on the host shell are neglected. Thus, the modal control force of the piezoelectric actuator bonded on the cylindrical shell can be defined as follows [2,4]

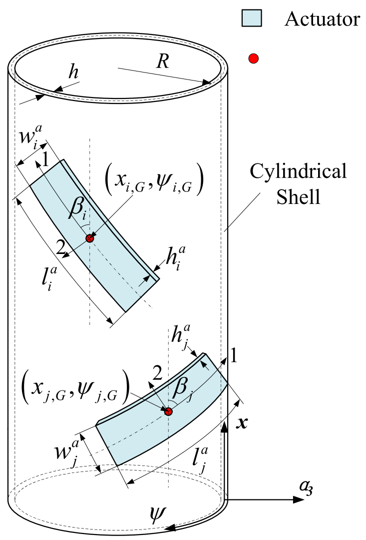

Fig. 1. Cylindrical shell with distributed obliquely pasted piezoelectric actuators.