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Active damping of laminated cylindrical shells conveying fluid using 1–3 piezoelectric composites

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ABSTRACT

In this paper, the performance of the active constrained layer damping (ACLD) treatment for active control of thin laminated cylindrical shells conveying fluid has been investigated. The constraining layer of the ACLD treatment has been considered to be made of vertically or obliquely reinforced 1–3 piezoelectric composite (PZC) materials. A three-dimensional finite element model has been developed for the laminated shells integrated with the patches of ACLD treatment to describe the coupled hydroelastic behavior of the shells. Velocity feedback control law has been implemented to activate the patches. Symmetric and antisymmetric cross-ply and antisymmetric angle-ply shells have been considered for evaluating the numerical results. Emphasis has also been placed on investigating the effect of the variation of the piezoelectric fiber orientation angle in the PZC constraining layer on the performance of the patches.

1. Introduction

Extensive research on the active control of light weight flexible structures using piezoelectric materials as distributed actuators and sensors has been carried out during the past several years [1–16]. When the piezoelectric distributed actuators and sensors, being activated with proper control effort, are either mounted on or embedded into the host flexible light weight structures, the resulting structures attain self-controlling and self-sensing capabilities. Such flexible structures having built-in mechanism for self-controlling and self-sensing capabilities are customarily called as “smart structures”. Most of the work on smart structures dealt with the distributed actuators made of the existing monolithic piezoelectric materials. The magnitudes of the piezoelectric coefficients of the existing monolithic piezoelectric materials are very small. Hence, the distributed actuators made of these materials need large control voltage for satisfactory control of smart structures. The further research on the efficient use of these low-control authority monolithic piezoelectric materials led to the development of the active constrained layer damping (ACLD) treatment [17]. The ACLD treatment consists of a constraining layer made of the piezoelectric materials and a constrained viscoelastic layer. The flexural vibration control by the constrained layer damping treatment is attributed to the dissipation of energy in the constrained viscoelastic layer due to its transverse shear deformations. The constraining layer of the activated ACLD treatment increases the transverse shear deformations of the viscoelastic constrained layer over its passive counterpart resulting in improved damping of the host structures. The control effort necessary for causing transverse shear deformations in the low-stiff constrained viscoelastic layer of the ACLD treatment is compatible with the low-control authority of the monolithic piezoelectric materials. Hence, the piezoelectric materials perform much better to attenuate the vibrations of smart structures when they are used for the constraining layer of the ACLD treatment than when they are directly bonded to the flexible host structures. If the constraining piezoelectric layer of the ACLD treatment is not activated with control voltage, the treatment causes passive constrained layer damping of the smart structure. Thus, the ACLD treatment provides the attributes of both passive and active damping simultaneously when under operation and creates an inbuilt fail-safe mechanism. Since its inception, extensive research has been carried out to investigate the performance of the ACLD treatment for active damping of smart structures [18–25].

Piezoelectric composite (PZC) materials have been emerged as the new class of smart composite materials. Such PZC materials are composed of piezoelectric fiber reinforcements and epoxy matrix. These PZC materials provide wide range of effective material properties, good conformability and strength integrity [26]. Among the various PZC materials studied by the researchers, the vertically and obliquely reinforced 1–3 PZC materials are commercially available [27] and are being effectively used for under water transducers, medical imaging applications and high frequency ultrasonic transducers [26]. The constructional feature of a lamina made of vertically reinforced 1–3 PZC material is that the piezoelectric fibers are vertically aligned across the thickness of the lamina while the fibers are poled along their length. In case of the obliquely

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reinforced 1–3 PZC, the piezoelectric fibers are obliquely aligned across the thickness of the lamina. These composites are characterized by improved mechanical performance, electromechanical coupling characteristics and acoustic impedance matching over the existing monolithic piezoelectric materials [26]. Research on PZC materials is mainly concerned with the micromechanical analysis of these materials [28–34]. Recently, Ray and his coworkers [35–37] investigated the performance of these 1–3 PZC materials for active damping of linear and nonlinear vibrations of composite beams, plates and shells.

Cylindrical shells conveying fluid are widely used as engineering applications and are prone to undergoing vibrations. Research on such coupled problems is mainly concerned with the dynamic analysis, buckling analysis and stability analysis of shells conveying flowing fluid. For example, Païdoussis and Dense [38] investigated the flutter of thin cylindrical shells conveying fluid. Chen and Rosenberg [39] analyzed the free vibrations of cylindrical shells conveying fluid. Natural frequencies and critical velocities of laminated circular cylindrical shells with fixed–fixed ends conveying fluid were studied by Chang and Chiou [40]. Amabili et al. [41] analyzed the nonlinear dynamics and stability of simply supported circular cylindrical shells conveying fluid using semi-analytical finite element method. Kadoli and Ganesan [42] carried out free vibrations and buckling analysis of composite cylindrical shells conveying hot fluid. Seo et al. [43] performed a finite element analysis to study the frequency response of cylindrical shells conveying fluid. Bochkarev and Matveenko [44] investigated the influence of boundary conditions on the dynamic behavior cylindrical shells conveying fluid. Ugurlu and Ergin [45] also carried out a hydroelastic analysis to investigate the effects of different end conditions on the dynamic response of thin circular cylindrical shells containing flowing fluid. Recently, Sheng and Wang [46] investigated the dynamic characteristics of fluid-conveying functionally graded cylindrical shells.

Active control of vibrations of cylindrical shells conveying fluid should be an important issue and has not yet been addressed. In this paper, authors intend to investigate the active constrained layer damping (ACLD) of circular laminated composite cylindrical shells conveying fluid. For such investigation, three-dimensional analysis of ACLD of laminated cylindrical composite shells integrated with the patches of ACLD treatment and coupled with flowing fluid has been carried out by the finite element method. The constraining layer of the ACLD treatment is considered to be made of the vertically or obliquely reinforced 1–3 PZC materials. Particular emphasis has been placed on investigating the effect of variation of piezoelectric fiber orientation on the performance of the ACLD patches.

2. Finite element model of smart shell conveying fluid

In this section, a finite element model of smart laminated cylindrical composite shells conveying fluid has been developed governing the coupled fluid–structural interaction. Fig. 1a shows a schematic diagram of thin laminated cylindrical composite shell made up of N number of orthotropic layers conveying the flowing fluid. Each ply of the shell is made of homogeneous, orthotropic, linearly elastic material and the layers are assumed to be perfectly bonded together. The length, the average circumferential length, the thickness and the average radius of the shell are denoted by a, b, h, and R, respectively. The top surface of the shell is integrated

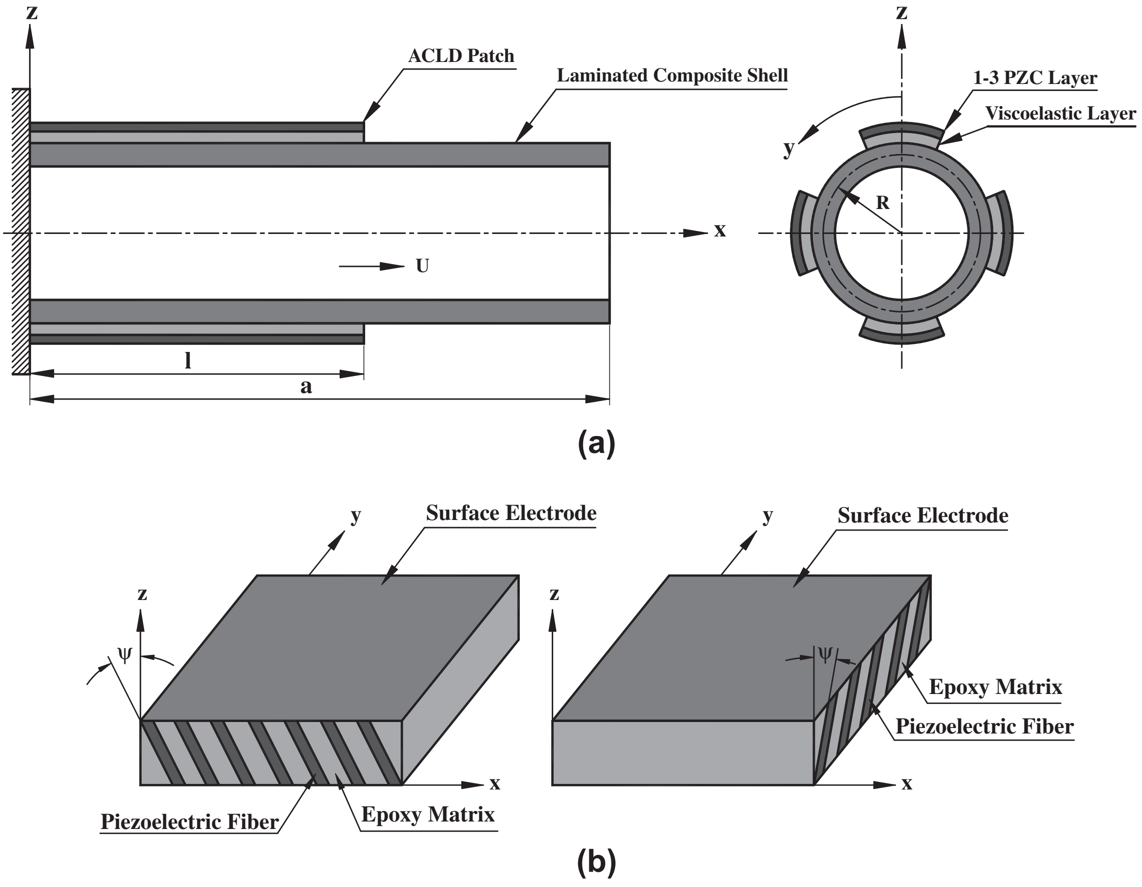

Fig. 1. Schematic diagrams of laminated shell integrated with four patches of ACLD treatment: (a) laminated shell with patches and (b) 1–3 PZC constraining layer.