Available online at www.sciencedirect.com
SCIENCE DIRECT
ELSEVIER
Journal of Sound and Vibration 292 (2006) 626–644
JOURNAL OF SOUND AND VIBRATION
www.elsevier.com/locate/jsvi

Free vibration response of two-dimensional magneto-electro-elastic laminated plates

Fernando Ramirez[a,*], Paul R. Heyliger[a], Ernian Pan[b]

[a]*Department of Civil Engineering, Colorado State University, Fort Collins, CO 80523, USA*
[b]*Department of Civil Engineering, University of Akron, Akron, OH 44325, USA*

Received 25 October 2004; received in revised form 20 May 2005; accepted 20 August 2005
Available online 21 October 2005

Abstract

An approximate solution for the free vibration problem of two-dimensional magneto-electro-elastic laminates is presented to determine their fundamental behavior. The laminates are composed of linear homogeneous elastic, piezoelectric, or magnetostrictive layers with perfect bonding between each interface. The solution for the elastic displacements, electric potential, and magnetic potential is obtained by combining a discrete layer approach with the Ritz method. The model developed here is not dependent on specific boundary conditions, and it is presented as an alternative to the exact or analytical approaches which are limited to a very specific set of edge conditions. The natural frequencies and through-thickness modal behavior are computed for simply supported and cantilever laminates. Solutions for the simply supported case are compared with the known exact solution for piezoelectric laminates, and excellent agreement is obtained. The present approach is also validated by comparing the natural frequencies of a two-layer cantilever plate with known analytical solution and with results obtained using commercial finite element software.

1. Introduction

Magneto-electro-elastic laminates show significant interactions between the elastic, electric, and magnetic fields due to the coupled nature of the constitutive equations. These laminates have direct application in sensing and actuating devices, such as damping and control of vibrations in structures. There have been several studies on the electric and mechanical behavior of piezoelectric laminates. Lee [1–4] published a series of papers incorporating the piezoelectric effect into the classical laminate theory. Tzou and Gadre [5] presented the dynamic equations for generalized multi-layered thin shells based on Love's theory and Hamilton's principle. More recently, Heyliger [6] and Heyliger and Brooks [7] presented an exact solution for the static behavior of laminated piezoelectric plates with simple supports. Heyliger and Brooks [8] also obtained the exact solution for the free vibration behavior of piezoelectric plates in cylindrical bending, by extending the free vibration solution of purely elastic simply supported plates to the corresponding piezoelectric case.

*Corresponding author. Tel.: +1 970 4912801.
E-mail address: framirez@engr.colostate.edu (F. Ramirez).

0022-460X/$ - see front matter
doi:10.1016/j.jsv.2005.08.004

Research on the behavior of magneto-electro-elastic laminates is relatively recent. Problems involving magneto-electro-elastic media have been considered by Harshe [9], Nan [10], and Benveniste [11] by developing expressions to determine the effective magnetoelectric effect in composites having piezoelectric and magnetostrictive phases. The exact closed-form solution for three-dimensional simply supported magneto-electro-elastic laminates was presented by Pan [12] based on the quasi-Stroh formalism and the propagator matrix method. Later, Pan and Heyliger [13,14] extended that solution to the corresponding free vibration problem, and to the static cylindrical bending of magneto-electro-elastic laminates. An approximate solution based on a discrete layer model was also obtained by Heyliger and Pan [15] and Heyliger et al. [16] for the cases of two- and three-dimensional magneto-electro-elastic laminates. More recently, Jiang and Ding [17] presented an analytical solution for the study of beams, Lage et al. [18] developed a layerwise mixed finite element model for plates, Buchanan [19] published a comparison between layered and multiphase models for the static and dynamic analysis of magneto-electro-elastic plates, Latheswary et al. [20] studied the dynamic response of moderately thick composite plates.

In this study, the governing equations of motion for two-dimensional linear magneto-electro-elastic laminates are solved using a discrete layer approximate model. Approximations for the three displacements and electric and magnetic potentials are constructed for each homogeneous layer such that the dependence on the in-plane directions and that on the thickness direction of the laminated plate can be separated. This separation allows for breaks in the gradients of the three displacement components and the two potentials across a dissimilar material interface. The free vibration behavior of a single homogeneous piezoelectric layer is studied first to check the present formulation with the known exact solution. The present approach is also validated by comparing the natural frequencies and mode shapes of a two-layer PZT-5A/graphite-epoxy cantilever plate with the analytical solution presented by Vel et al. [21], and with several finite element models. Finally, the natural frequencies, through-thickness modes shapes, and the influence of the piezoelectric and piezomagnetic coefficients on the natural frequencies of a two-layer $BaTiO_3/CoFe_2O_4$ cantilever plate are analyzed.

2. Theory

2.1. Geometry

Laminates are considered with the z-axis out of the laminate plane and the x- and y-axes are the corresponding in-plane axes of the laminate. This is shown in Fig. 1. The laminates are considered to be either very thin or infinitely long in the y-direction and are composed of an arbitrary number of elastic, piezoelectric, or magnetostrictive layers. The laminate has dimensions L_x in the x-direction and has total thickness H, with individual layer thicknesses h_1, h_2, and so on. Layer 1 is the bottom layer of the laminate and layer n is the top layer.

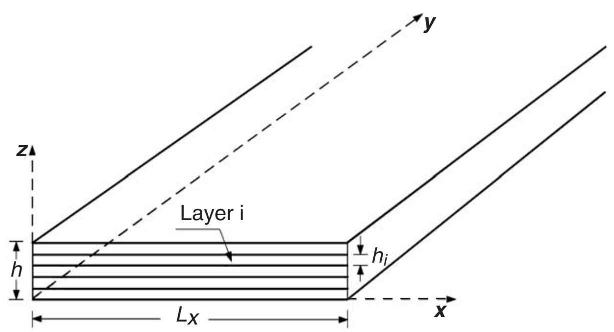

Fig. 1. Laminate geometry.