Acta Mechanica Solida Sinica, Vol. 28, No. 1, February, 2015 ISSN 0894-9166
Published by AMSS Press, Wuhan, China

VIBRATION AND SOUND RADIATION OF AN ASYMMETRIC LAMINATED PLATE IN THERMAL ENVIRONMENTS**

Wei Li **Yueming Li***

(*State Key Laboratory for Strength and Vibration of Mechanical Structures, Xi'an Jiaotong University, Xi'an* 710049, *China*)

Received 7 January 2013, revision received 22 January 2014

ABSTRACT Analytical studies on the vibration and sound radiation characteristics of an asymmetric laminated rectangular plate are carried out in this paper. Theoretical formulations, in which the effects of thermal environments are taken into account, are derived for the vibration and sound radiation based on both first-order shear deformation plate theory and Rayleigh integral. It is found that the natural frequencies, the resonant amplitudes of vibration response and the sound pressure level decrease with the temperature rising. The natural frequencies of asymmetric plates are smaller than those of symmetric plates and the velocity responses of asymmetric plates are larger than those of symmetric plates.

KEY WORDS asymmetric laminated plate, thermal environments, FSDPT, vibration, sound radiation

I. INTRODUCTION

Laminated plates are widely used in the field of aerospace, such as the aerocraft structures, which usually suffer serious aerodynamic heating in service. Thermal stresses caused by thermal environment change may induce buckling and influence dynamic characteristics.

A number of analytical and numerical solutions have been given for free vibration and buckling problems of composite laminates and sandwich plates. Reddy and Khdeir[1] studied the buckling and free vibration behavior of cross-ply rectangular composite laminates under different boundary conditions by analytical and finite element solutions of the classical, first-order, and third-order laminate theories. It is concluded that the shear deformation laminate theory is able to accurately predict the behavior of composite laminates, whereas the classical laminate theory over-predicts natural frequencies and buckling loads. In Ref.[2], exact solutions were presented for the free vibration of symmetrically laminated composite beams with first-order shear deformation and rotary inertia considered in analysis. Asghar et al.[3] used Reddy's layer-wise theory to conduct free vibration analysis of laminated plates. Kant and Swaminathan[4] analyzed the free vibration of composite laminates and sandwich plates based on a higher-order refined theory, which accounted for the effects of transverse shear deformation, transverse normal strain/stress and nonlinear variation of in-plane displacements with respect to the thickness coordinate. Ganapathi and Makhecha[5] presented an accurate higher-order theory using the finite element procedure for the free vibration analysis of multi-layered thick composite plates. Liew

* Corresponding author. E-mail: liyueming@mail.xjtu.edu.cn

** Project supported by the National Natural Science Foundation of China (Nos. 11321062, 91016008 and 91216107).

et al.[6] adopted the first-order shear deformation theory for predicting the free vibration behavior of moderately thick symmetrically laminated composite plates. Shooshtari and Razavi[7] gave a closed form answer analytically to linear and nonlinear free vibrations of composites based on the first-order shear deformation theory.

With respect to the influence of the temperature, Fauconneau and Marangoni[8] investigated the effect of a constant thermal gradient on the transverse vibrational frequencies of a simply supported rectangular plate. Prabhu and Dhanaraj[9] analyzed the thermal buckling of laminated composite plates using FEM based on the first-order shear deformation theory. Free and forced vibration analyses for initially stressed functionally graded plates in a thermal environment were presented in Ref.[10]. Matsunaga[11] presented a two-dimensional global higher-order deformation theory for the free vibration and stability problems of angle-ply laminated composites subjected to thermal loading. Pradeep and Ganesan[12] studied the free vibration and damping characteristics of plates consisting of composite stiff-layers and an isotropic viscoelastic core under thermal loads using FEM. A decoupled thermo-mechanical analysis was made using the finite element method[13]. In the study, a four-side clamped plate with constant temperature throughout the plate domain was analyzed for thermal buckling, frequency and damping behavior, and the variation trends of these characteristics against temperature were indicated as well. Jeyaraj et al.[14] presented numerical studies on the vibration and acoustic response characteristics of a composite plate in a thermal environment considering the inherent material damping property of the composite material based on the classical laminated plate theory and coupled FEM/BEM technique. The influence of thermal environments on the dynamic response and acoustic characteristics were investigated in Ref.[15], in which theoretical expressions were derived first for the vibration and acoustic radiation of a simply supported rectangular thin plate by considering the membrane forces induced by thermal environment change. It is reported in Refs.[16] and [17] that structural topology optimization has been carried out to minimize the radiated acoustic power and structural dynamic compliance in a thermal environment .

In the present work, the analytical vibration solution of an asymmetric laminated plate in a thermal environment is solved by employing the first-order shear deformation plate theory (FSDPT), in which shear deformation and rotary inertia are involved, and then the sound radiation characteristics of the laminated plates are obtained using Rayleigh integral analytically. The variation of natural frequencies and sound radiation characteristics with temperature has been studied. Validation studies are also done and a good agreement with numerical solutions calculated by commercial software is achieved.

II. FORMULATIONS

The displacement fields based on the FSDPT of the laminated plate (Fig.1) are given by

$$\begin{aligned} u(x,y,z,t) &= u^0(x,y,t) + z\varphi_x(x,y,t) \\ v(x,y,z,t) &= v^0(x,y,t) + z\varphi_y(x,y,t) \\ w(x,y,z,t) &= w(x,y,t) \end{aligned} \tag{1}$$

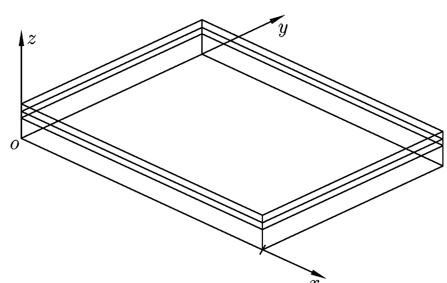

Fig. 1. Laminated plate.

where u, v and w are the displacements along x, y and z directions with x and y on the plane of the plate and z along the thickness direction, and φ_x, φ_y are the rotations of a transverse normal about the y- and x-axes. All of the letters with ^{0} stand for the value of mid-surface.