Journal of Sound and Vibration 413 (2018) 173–190

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

Dynamic properties and damping predictions for laminated plates: High order theories – Timoshenko beam

Bohdan Diveyev [a], Solomija Konyk [a], Malcolm J. Crocker [b, *]

[a] Lviv National Polytechnic University, St. Bandera str. 12, 79013, Lviv, Ukraine
[b] Mechanical Engineering Department, Auburn University, Auburn, AL 36849, USA

ARTICLE INFO

Article history:
Received 19 April 2017
Received in revised form 6 October 2017
Accepted 10 October 2017

Keywords:
Vibration
Damping
Composite laminated beams and plates

ABSTRACT

The main aim of this study is to predict the elastic and damping properties of composite laminated plates. This problem has an exact elasticity solution for simple uniform bending and transverse loading conditions. This paper presents a new stress analysis method for the accurate determination of the detailed stress distributions in laminated plates subjected to cylindrical bending. Some approximate methods for the stress state predictions for laminated plates are presented here. The present method is adaptive and does not rely on strong assumptions about the model of the plate. The theoretical model described here incorporates deformations of each sheet of the lamina, which account for the effects of transverse shear deformation, transverse normal strain-stress and nonlinear variation of displacements with respect to the thickness coordinate. Predictions of the dynamic and damping values of laminated plates for various geometrical, mechanical and fastening properties are presented. Comparison with the Timoshenko beam theory is systematically made for analytical and approximation variants.

1. Introduction

Noise and vibration are of concern with many mechanical systems including: industrial machines, home appliances, surface vehicle transportation systems, aerospace systems, and building structures. Many such mechanical system components are comprised of beam and plate like elements and the vibration of such systems is the focus of several detailed recent studies [1–6]. The vibration of beam and plate structural systems can be reduced by the use of passive damping, once the system parameters, such as dynamic stiffness of the plate or beam, have been identified. This is the subject of the research described in the present paper. In some cases of forced vibration, the passive damping that can be provided is insufficient and the use of active damping has become attractive [7]. Active damping is mostly only used with high first cost items such as automobiles and aircraft, since it is still too expensive to use with low cost items such a household appliances.

Structures composed of laminated materials are among the most important systems used in modern engineering and, especially, in the automobile and aerospace industries. Aircraft such as the Airbus A340 and Boeing 787 Dreamliner make extensive use of laminated composite materials. Such lightweight and highly reinforced structures are also being used increasingly in civil, mechanical and transportation engineering applications.

* Corresponding author.
E-mail address: crockmj@auburn.edu (M.J. Crocker).

https://doi.org/10.1016/j.jsv.2017.10.017
0022-460X/

Nomenclature

$[A]$ system matrix
$a(k,k), a_P(k,k), a_{PP}(k,k), b(k,k), b_P(k,k), b_{PP}(k,k), ab(k,k), ab_P(k,k), ba_P(k,k)$ the matrices $[A_1^X]$ … terms
$[A_1],[A_2],[A_d],[A_{uu}],[A_{uw}],[A_{ww}],[A_{mu}],[A_{mw}]$ system matrix sub-matrices
$[A_{12}],[A_{21}],[A_{22}]\ldots,[A_{NN}]$ sub-matrices (for N-layered beam)
$[A_1^X],[A_{1P}^X],[A_{1PP}^X],[B_1^X],[B_{1P}^X],[B_{1P}^X],[AB_1^X],[APB_1^X],\ldots[ABP_1^X]$ the length functions product matrices
A vibration amplitude (in dB)
c_1, c_2 constants in the analytical displacement terms
c_{ij} weight coefficients of normal displacement approximations
C_{xx}, C_{xz}, C_{zz} Hooke's law modulus
$[C]$ damping matrix
d_{ij} weight coefficients of normal displacement approximations
g_{ij} weight coefficients of normal displacement approximations
e_{ij} weight coefficients of normal displacement approximations
E Young's modulus
E_i Young's modulus of (i) beam layer
E_T Timoshenko beam Young's modulus
$E_T\ I$ bending stiffness of beam
f_i eigenfrequencies
f_{ij} weight coefficients of normal displacement approximations
f_{Si} Euler beam eigenfrequencies
G shear modulus
G_T Timoshenko beam shear modulus
H_p one-half of the thickness of a lamina
$H^{(n)}$ one-half of the thickness of a $(1) + \ldots +(n)$ sheets of lamina
K rigidity of beam fastening
$[K]$ stiffness matrix
$[K_i]$ stiffness matrix of (i) beam layer
m_{ij} weight coefficients of normal displacement approximations
M bending moment
$[M]$ mass matrix
n_{ij} weight coefficients of normal displacement approximations
N_f number of eigen-frequency
N_X, N_Z numbers of approximations along the x,z axis
NS numerical scheme
O the set of parameters $\nu_1, \nu_2, \ldots, \nu_{N_C}$
P external force vector
q_{ij} weight coefficients of normal displacement approximations
$[q_i]$ vector of displacement in (i) beam-layer
Q shear force
S, S^* primary assumptions for transverse stress
U displacement along the x-axis
$u_{ik}^e, \overline{u}_{ik}^e, u_{ik}^d, \overline{u}_{ik}^d$ set of core and face sheets displacement components and amplitudes along the x-axis
U, U^e, U^d displacement vector of sandwich, of sandwich core, sandwich face sheets
v displacement along the y-axis
w displacement along the z-axis
$w_{ik}^e, \overline{w}_{ik}^e, w_{ik}^d, \overline{w}_{ik}^d$ set of core and face sheets displacement component and amplitudes along the z-axis
$\alpha, \alpha_1, \alpha_2$ constants in analytical stresses terms
ε_{xx} normal deformation along the x-axis
ε_{nn} normal deformation along the z-axis
$\varphi(z)$ unknown term in tangential displacement
$\varphi_i(x)$ longitudinal coordinate functions for u
$\gamma_i(x)$ longitudinal coordinate functions for w
γ_{xz} shear deformation in the xz plane
η middle beam damping parameters
$\eta_1, \eta_2, \ldots, \eta_{N_R}$ layer damping parameters
η_Σ total damping of sandwich