Free Vibration Bahaviour of Fiber Metal Laminates, Hybrid Composites, and Functionally Graded Beams using Finite Element Analysis

Harshan Ravishankar

Department of Mechanical Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, Amrita University, India

Revathi Rengarajan

Department of Mechanical and Aerospace Engineering, The Ohio State University, Columbus, Ohio, USA

Kaliyannan Devarajan

Department of Mechanical Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, Amrita University, India

Bharath Kaimal

Department of Automotive Systems Engineering, The University of Michigan-Dearborn, Dearborn, USA

(Received 25 August 2014; accepted 16 February 2016)

In this study, the free vibration analysis of rotating and non-rotating fiber metal laminate (FML) beams, hybrid composite beams (HCB), and functionally graded beams (FGB) are investigated. FML beams are high-performance hybrid structures based on alternating stacked arrangements of fiber-reinforced plastic (FRP) plies and metal alloy layers. Hybrid composite beams are materials that are made by adding two different fibers. Functionally graded beams are new materials that are designed to achieve a functional performance with gradually variable properties in one or more directions. The effects of different metal alloys, composite fibers, and different aspect ratios and angular velocities on the free vibration analysis of FML beams are studied. The effects of different angular velocities and different aspect ratios of rotating and non-rotating hybrid composite beams are also investigated. Finally, the effects of different angular velocities and different material distributions, namely the power law, exponential distribution, and Mori Tanaka's scheme on the free vibration analysis of FGB, are also invesigated.

1. INTRODUCTION

Fiber metal laminates, hybrid composites, and functionally gradient beams are often used in engineering applications. Rotating FML, HCB, and FGB are especially used in helicopter and wind turbine blades. FML are hybrid structures consisting of different metal sheets and FRP composite layers such as glass, aramid, and carbon fibers. One of the most important objectives of their production is to combine the good impact resistance of the metals with the light weight characteristic of FRP. A combination of two or more various types of fibers in a single plastic gives a hybrid composite and it is mainly used in the aerospace industry. Sometimes, a ceramic layer or steel material may be bonded to the surface of other metallic structures and act as a thermal barrier in a high temperature environment. The sudden change in the material properties across the bonded region produces a stress jump and may further give rise to delamination or cracking of the interface. One way to overcome this shortcoming is to employ an FGB beam in which the material properties vary continuously and thereby possess noticeable advantages over homogeneous and layered materials in maintaining the integrity of the structure.

In order to design these types of structures, their dynamic analysis needs to be investigated. The dynamic analysis characteristics of rotating FML, HCB, and FGB beams differ from those of non-rotating structures. The centrifugal inertial force due to the rotational motion causes the increment of the bending stiffness of the structure, which naturally results in the variation of natural frequencies. Sinmazcelik et al.[1] explained and reviewed the different types bonding and different testing methods on different FML. Huang et al., proposed a discrete method for the analysis of flap-wise bending vibration of rectangular plates using Dirac's delta function.[2] The effects of the positions of point supports, the variable thickness, the aspect ratio, and the boundary conditions on the frequencies were studied. Hashemi et al. studied the effect of different parameters, including the aspect ratio, thickness ratio, hub radius ratio, and rotation speed on the natural frequencies of rotating thick plates by using the Mindlin-Reissner plate theory along with second order strain-displacement assumptions that were applied for plate modeling.[3] The Kane dynamic method was employed for the derivation of nonlinear governing equations of motion, which included the Coriolis effects and the couplings between in-plane and out of plane deformations. The free vibration of rotating tapered cantilever Bernoulli-Euler beams with linearly varying rectangular cross-section was studied by Ozdemir and Kaya by using differential a transform method.[4] For rotating Euler beams at high angular velocities, Huang et