

COMPUTATIONAL MODELING OF A MULTI-LAYERED PIEZO-COMPOSITE BEAM MADE UP OF MFC

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In this work, an attempt has been made to study the response of an electrically loaded structure made up of various piezo-composite lamina with same overall geometry, bonded together in an arbitrary lay-up to determine the behavior of the composite laminate under various mechanical and electrical loading conditions. Based on geometry and input electrical load, such a laminate is capable of generating any arbitrary kind of dynamic structural profile and at the same time being light weight, hence finds various applications in the aerospace industry. The problem is considered as a design problem and various parametric studies are performed subsequently using asymptotic procedures, which can give closed-form solutions. For the simplest case, stacked layers are made up of a piezo-electric material, Macro Fiber Composite (MFC) which is commercially available from Smart Material Corp. [1], a linear 3-D electromechanical constitutive law is incorporated and the theoretical formulation is constructed using a beam kind of model. MFC is popular for its great flexibility, surface conformability, excellent actuation properties ($d_{33} = 460$ pc/N) and are quoted as being capable of a maximum strain of $1800 \mu\epsilon$. M8528-P1 and M8528-F1 are chosen as constituent lamina in the piezo-composite actuator. Such an actuator may find its applications in numerous fields ranging from flapping wing or morphing wing MAVs, UAVs, aircraft control surface, vibration control of helicopter rotor blades or aircraft rudder, satellite booms and so on. After the invention of MFC by NASA in 1996 and commercialization by Smart Material Corp. in 2002, it has evolved a lot in terms of design, properties and effectiveness. Also lots of customizable variants of MFCs are available from the manufacturer. Keeping in mind the actuation authority provided by MFCs, it is difficult to analyze such a complex coupled nonlinear behavior using conventional ad-hoc beam theories or other engineering beam theories which are based on some truncation schemes or small strain approximations.

The Variational Asymptotic Method (VAM) coupled with geometrically exact kinematics form a powerful tool for analyzing such complex nonlinear phenomena as shown previously by many in the literature [3 - 7] for various challenging problems like initially twisted

helicopter rotor blades modeling, matrix crack propagation in a composite, modeling of hyper elastic plates and various multi-physics problems. VAM can be developed into a computationally efficient and accurate tool to find the 1-D strain energy by approximating 3-D strain energy as closely as possible. The behavior of an elastic body is completely understood by its energy. To obtain the 1-D behavior as is typical in a beam analysis, this energy must be integrated over the cross-sectional area to get the 1-D energy. To perform this simplification, VAM makes use of thickness to width, width to length, width multiplied by initial twist and strain as small parameters embedded in the problem definition and provides a way to approach the exact solution asymptotically. In this work, above mentioned electromechanical problem is modeled using VAM which breaks down the 3-D elasticity problem into two parts, namely a 2-D non-linear cross-sectional analysis and a 1-D non-linear analysis, along the reference curve. The recovery relations obtained as a by-product in the cross-sectional analysis earlier are used to obtain 3-D stresses, displacements and velocity contours. The expressions of sectional forces and moments as obtained from cross-sectional analysis in closed-form show the electro-mechanical coupling and relative contribution of electric field in individual layers of the piezo-composite laminate. The spatial and temporal constitutive law as obtained from the cross-sectional analysis are substituted into 1-D fully intrinsic, geometrically exact equilibrium equations of motion and 1-D intrinsic kinematical equations to solve for all 1-D generalized variables as function of time and an along the reference curve co-ordinate, x_1 .

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