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OPTIMAL DESIGN OF LAMINATED COMPOSITE BEAMS WITH MASS, STIFFNESS, AND FREQUENCY CONSTRAINTS

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Abstract

A novel framework is presented for optimal design of laminated composite beams based on a high-fidelity beam model and multimaterial topology optimization techniques. Results are presented for the simultaneous three-dimensional topology and laminate optimization of beams subjected to mass, stiffness and frequency constraints. The framework is applicable to the optimal design of a large class of long slender structures, e.g., wind turbine rotor blades.

The structural response of the beam is analyzed based on a beam model combining both high accuracy and efficiency, two paramount aspects in optimal design frameworks. The model is obtained in two steps. The stiffness and mass properties of a series of representative cross sections along the length of the beam are analyzed first using BECAS – BEam Cross section Analysis Software (Blasques & Lazarov, 2011). BECAS is an open-source finite element based tool which is able to accurately estimate effects stemming from material inhomogeneity and anisotropy for cross sections of arbitrary geometry. The cross section properties are then integrated along the length to generate the beam finite element stiffness and mass matrices used in the analysis of the global beam response. Based on the resulting cross section forces and moments, BECAS is also able to determine the three-dimensional stress and strain at any point in the cross section. Results are presented where the global (displacement and natural frequencies) and local (stresses and strains) beam responses are shown to match very closely those obtained using computationally much more expensive solid and shell finite element models.

The optimal design problem is solved using multimaterial topology optimization techniques. The design variables are associated with the volume fractions of different candidate materials at each element of the cross section finite element mesh. These may be different (anisotropic) materials or the same material oriented in different directions, .e.g., carbon fiber laminates oriented in different directions. An extension to multiple anisotropic materials of the typical density filtering technique is used to avoid mesh dependency and checker-boards. The optimal design problem is solved using the robust and efficient sequential quadratic programming algorithm, SNOPT (Gill et al, 2002).

This framework has been employed by Blasques & Stolpe (2012) for optimal design of beams of constant cross section with constraints on mass, stiffness, and shear and mass center position. The previous problem formulation is augmented here to include frequency constraints. The results show that it is possible to simultaneously optimize the three dimensional structural topology and laminate properties of the laminated composite beams to control frequency placement and satisfy different constraints on stiffness and cross section properties. Furthermore, the results suggest that the framework has a strong potential in addressing optimal design problems combining a large number of design variables and complex multiphysics constraints, e.g., optimal design of wind turbine blades with aeroelastic constraints.

References

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