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Optimization Formulations for Composite Structures subjected to Compression Loads

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ABSTRACT

In the design of multilayered lightweight composite structures such as wind turbine blades many challenging design problems are involved. Nowadays the blades are high performing structures with lengths of up to 60 meters. In the design of light and cost effective blades it is a necessity that the material utilization is pushed to the limit. A consequence hereof is that the structures are becoming thin-walled and local buckling becomes an issue in compressively loaded regions. The general critical failure mode for these structures in flap-wise bending occurs during a so-called 50 year storm, where the multilayered shell structures may exhibit maximum tip displacement of up about 25% of the length before they fail due to local buckling on the compressive side of the blade. Rational design methods are by this reason necessary in order to improve the structural performance of wind turbine blades further.

One of the major challenges in this field of optimal design of composite structures is development of optimization formulations and rational design methods that account for failure due to compression loads. This means methods that enable us to determine the optimal distribution and orientation of layered material for a fixed geometry.

This work will take its form based on full scale experiments of the static collapse of a 25 meters long wind turbine blade. The experimental results are used as reference for evaluating different finite element analysis approaches in predicting local buckling on a FE shell model within the framework of equivalent single layered theory.

The main objective of the work is formulation and application of different optimization approaches using different types of predictive FE analyses. A 12-meter section from the 25-meter laminated composite main spar in the wind turbine blade is the benchmark for the different optimization formulations. The parametrizations for the optimization are material orientations and layer thicknesses of the fiber reinforced materials in the main spar of the blade. The structural topology of the blade is not changed during optimization. All optimization formulations presented are gradient based approaches solved using mathematical programming techniques.

Two different categories of predictive FE methods for local buckling are presented and their predictive accuracy is compared with results from the static collapse test of the blade.
The first category makes use of linearized buckling analysis, both in its ordinary form and in an extended form. The extended form of linearized buckling analysis initially performs a geometrically nonlinear analysis to a certain load followed by a linearized buckling analysis on the deformed updated geometry in order to predict the buckling load more accurately.
The second category is based on FE geometrically nonlinear analysis. Different local criteria measures, such as relative strain changes, are applied during analysis to predict the point of local buckling.

The optimization formulation regarding the linearized buckling analysis is to maximize the buckling load of the laminated composite structure. This is accomplished by applying a bound formulation where a number of the lowest eigenvalues are considered. In this way the possibility of crossing eigenvalues and creation of multiple eigenvalues is taken into account. The eigenvalue design sensitivity analysis is based on the direct approach, and the non-differentiability of multiple eigenvalues is taken into account, both in the sensitivity analysis and in the optimization formulation. Weight consideration is accomplished by a global mass constraint. See Lund [1] for further details about the design sensitivity analysis and optimization formulation.

Prediction of local buckling during flap-wise loading of the blade model in the geometrically nonlinear analysis is accomplished by different criteria measures. The optimization formulation operates by this reason on a criteria function instead directly on the buckling load. Design sensitivity analysis of the geometrically nonlinear problem is performed using the direct differentiation approach. A bound formulation is exploited assuring differentiable criteria functions. Weight consideration is accomplished by a weight constraint. Preliminary studies in this area have been presented by Overgaard and Lund [2], where a minmax formulation of the strain in the layers was used.

The evaluation parameters for the analysis methods considered are accuracy in comparison to the results from the collapse test of the blade and calculation time. The optimization formulations are evaluated by comparing the results obtained by the different optimization formulations. Finally, the pros and cons between the different optimization formulations are discussed.

REFERENCES

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