COMPLIANT MECHANISM DESIGN FOR ADAPTIVE TRAILING EDGE FLAPS

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Summery Using a trailing edge flap actively on a wind turbine wing can eliminate the fluctuation in the wind field and thereby reduce the overall load response of the turbine. This work aims at finding the optimal compliant mechanism that controls the flap. Topology optimization is used with a geometrically nonlinear finite element formulation. The optimization problem is formulated as a minimization of the summed error between the desired point and the actual points.

INTRODUCTION

It has been wind turbine developers dream for a long time to be able to eliminate the fast fluctuations in the wind fields that the turbines experiences. This can lead to lower overall loads and less fluctuating loads on the turbine components and thereby longer life time expectancy. This work is a part of a project that aims to uncover the potential of reducing fluctuating loads by actively using a trailing edge flap on the wind turbine wings.
The goal of this work is to find the optimal compliant mechanism that can provide the shape of the flap that is proscribed by the aerodynamic and aeroelastic calculations. This is done by using the topology optimization method (for an overview of the method see M. P. Bendsøe and O. Sigmund) with a geometrically nonlinear finite element method (FEM) as used in Buhl *et al.* and Pedersen *et al.*
The topology optimization method has been used in a wide range of applications from MicroEletricMechanicalSystems to designing satellites (see M. P. Bendsøe and O. Sigmund). However, it is mostly used as a "first step starting guess" in the design phase since the outer perimeter can be coarse. Experience with designing compliant mechanisms using topology optimization show that the resulting topology often consists of rigid beams connected by hinge type areas (see Pedersen *et al.*). Within this project the found optimized compliant mechanism will be "translated" into a rigid body mechanism and thereafter tested and optimized using multibody mechanism design. The present paper will, however, concentrate on the topology optimization of the actuating mechanism for the flap.

THE OPTIMIZATION PROBLEM

The optimal topology should in the final configuration consist of only solid and void elements which ensured by the SIMP-model (again look in M. P. Bendsøe and O. Sigmund for further details). To remove the checkerboard problem the standard filter technique discussed in M. P. Bendsøe and O. Sigmund is used. A continuation approach is used on the filter radius such that the possibility of ending in a local minimum is less likely.
A set of points describing the outer shape of the flap in actuated configuration is given from the aerodynamic and aeroelastic calculations. Another set of point on the actual outer perimeter must coincide with the given set of points. This is done by formulating the optimization problem as a minimization of the summed squared error between the two sets of points in the deformed configuration.
The optimization problem has like most standard topology optimization problems with mechanism design constraint on the input displacement and a volume constraint.
The objective function for this optimization problem can be written as

$$\left.\begin{array}{rl} \min\limits_{\boldsymbol{\rho}} : & \Phi = \sum_{m=1}^{M} \left(u_{out,m} - u^*_{out,m}\right)^2 \\ \text{subject to} : & \boldsymbol{v}^T \boldsymbol{\rho} \leq V^*, \\ : & u_{in} \leq U^*_{in}, \\ : & \mathbf{0} < \boldsymbol{\rho}_{min} \leq \boldsymbol{\rho} \leq \mathbf{1} \end{array}\right\} \quad (1)$$

where $u_{out,m}$ is the actual position of the m^{th} point on the perimeter, $u^*_{out,m}$ is the m^{th} desired point, M is the number of point in total, v is the volume of an element, V^* is the volume constraint, ρ is the density of an element, u_{in} is the actual displacement in input point and U^*_{in} is the constraint of the input point. The design variable has the upper bound of one while the lower bound for ρ is $\rho_{\min}$.

EXAMPLE

In Figure 1 the design domain is shown for the following example. The design domain is supported on the lower and upper fourths of the right edge. The actuator is placed in the middle of the right edge. The flap contour is set to be fixed solid material while the material outside the flap is set to be fixed void.

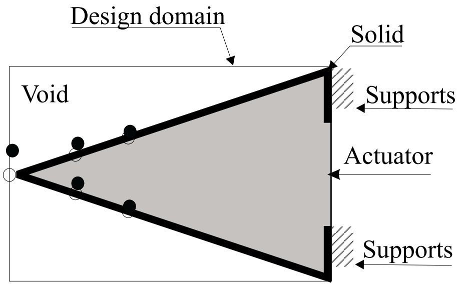

Figure 1. A conceptual layout of the design domain.

The gray color in Figure 1 represents the area where the mechanism can be formed. The flap should follow 5 given point marked with solid circles in Figure 1. The points on the flap (marked with hollow circles) should in the deformed configuration coincide with the solid circles.

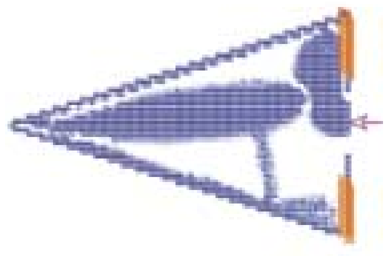

Figure 2. The optimized flap mechanism in undeformed configuration.

The optimization problem was solved in 712 iterations and error is less than 10^{-6}. The internal mechanism is a simple rod delivering all its actuation to the out corner of wedge.

CONCLUSIONS

The topology optimization problem of finding the optimal mechanism, to make the trailing edge of a blade follow a given shape, has been solved. The optimization problem was written as an error function where a number of points on the flap should go through the same number of given points. The error between the two sets of points are minimized. The optimization problem was solved with an acceptable error in 712 iterations.

FURTHER WORK

The work presented here is a small part of the steps in finding the optimal mechanism for the trailing edge flap. More work is done with more advanced optimization problems. The optimal mechanism has gone through a postprocessing and the actual mechanism will be built.

REFERENCES

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