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# Replacement of Steel Blade by Composite Blade for Flutter Measurements

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This work summarizes FEM simulations (its setup and purpose) which were made to evaluate performance of a steel blade which is currently used in the facility for flutter measurements. These simulations are also used for an initial design of a CFRP based blade which could replace the original steel blade and therefore allow measurement in the wider range of frequencies.

**Key words:** blade, flutter, CFRP

## Introduction

The blades of turbines are made longer and slender to enhance its efficiency. These long and slender blades, which are operated at supersonic speeds, are prone to the blade flutter. The flutter can cause fatigue failure of the blade. The problem of blade fatigue failures has not yet been fully resolved due to lack of experimental data.

New test facility is under development to solve this problem [1]. The new experimental setup allows investigation of high subsonic flow in a five-blade cascade, where the middle blade undergoes forced sinusoidal oscillation about its centre of gravity. Operation of middle blade at high frequencies is restricted by stresses induced by inertial forces due to oscillations. For advancement of the measurements it would be convenient to increase frequency of forced oscillations.

The idea is to improve the performance of the middle blade by replacement of current steel blade by design based on the CFRP (Carbon Fibre Reinforced Polymer) due to its strength to weight ratio.

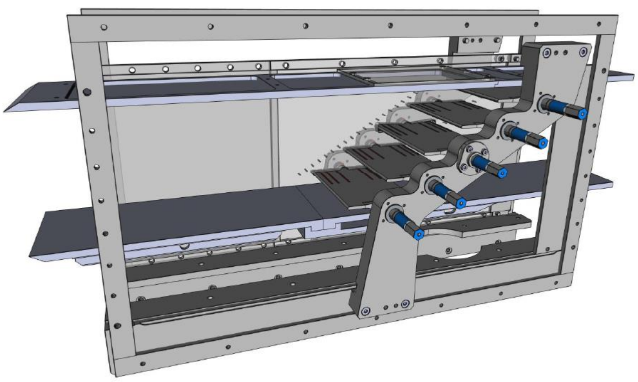

Fig. 1 Experimental test setup.

## Analysis of the Inertial Forces

Firstly, the loading conditions were analyzed. The rotational angle of the blade can be expressed as:

$$\varphi(t) = \varphi_0 sin(2\pi f t)$$

where $\varphi_0$ is angle amplitude, f is oscillation frequency and t is time. And by double time derivation we get maximal angular acceleration.

$$\alpha_{\max} = \varphi_0^2 (2\pi f)^2$$

The value of angular acceleration is then used in the simulations necessary for the design of the composite blade. Simulations are performed in software Ansys 2021 R1.

## Quasistatic Analysis

The quasistatic analysis is simplification which offers fast comparison of designs. The boundary conditions are depicted in the figure 2: two bearing supports, fixed supports in hexagonal shoulder and angular acceleration applied on the whole blade. The design conditions φ0 = 3 deg and f = 200 Hz are considered. The deformed shape of the blade is in the figure 3.

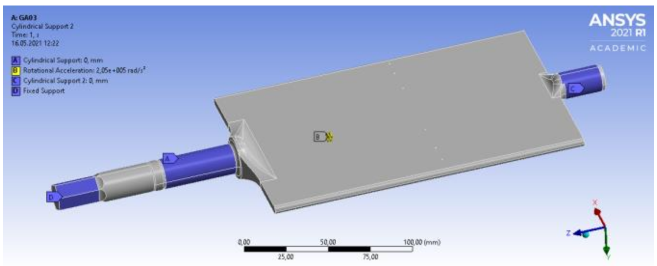


Fig. 2: Boundary conditions for the quasistatic analysis.

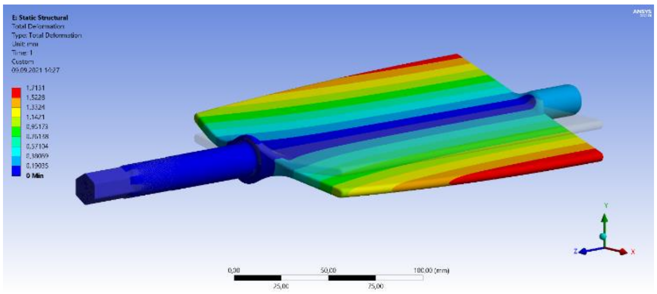

Fig. 3: Deformed shape from quasistatic analysis.

## Transient Analysis

Transient analysis represents reality much more credibly but they are computationally expensive. The inertial forces are considered in transient analysis and the damping has to be specified. The damping of the blade is property of the material, geometry and constraints. Damping will be measured for the steel blade by experimental modal analysis. For the composite blade is the process: manufacturing of the first stage of CFRP blade -> experimental modal analysis to get damping -> transient analysis -> evaluation of the failure criteria -> redesign of the blade?

## Modal Analysis

The modal analysis has to be performed to avoid resonance. The operating frequency of forced oscillation should be far enough from first torsional eigenfrequency. Therefore, the eigenfrequencies are analyzed. The boundary conditions are similar to the quasistatic analysis – two bearing supports and fixed support in the hexagonal shoulder.

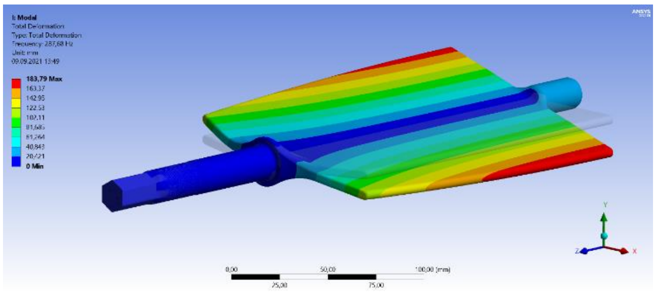

Fig. 4: First torsional eigenmode.

## Computational Fluid Dynamics

The blades in the wind tunnel are also loaded by aerodynamical forces. The influence of the aerodnamical forces was investigated [2]. It was found that for the steel blade are the aerodynamical moments an order of magnitude lower than moment caused by inertia. Therefore, for the initial design of the composite blade is the aerodynamical loading not considered.

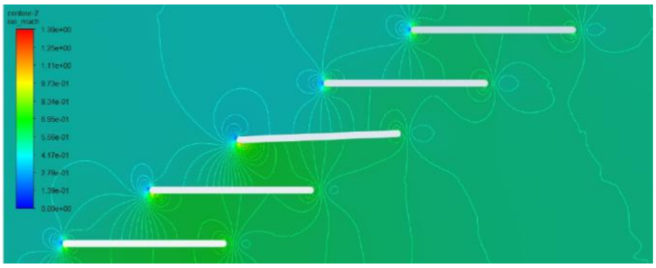

Fig. 5: CFD analysis of the steel blade.

## Results

Results for the steel blade and current CFRP design are presented in the table 1. Vertical displacement and first eigenfrequency are evaluated.

Table 1: Current results.

| | Steel | CFRP |
|---|---|---|
| $u_y$ [mm] | 1,93 | 1,15 |
| $f_1$ [Hz] | 287 | 357 |

## Conclusion

Several structural and CFD analysis were made for evaluation of performance of the steel blade and for design of the CFRP blade. The simulations show that the replacement of steel blade by CFRP blade is convenient and feasible.

## Acknowledgement

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## Reference

[1] Lepicovsky, J., Šidlof, P., Šimurda, D., Stěpán, M., Luxa, M., 2020. New Test Facility for Forced Blade Flutter Research. Proceedings of the Power System Engineering 2020, Plzeň, Czech Republic.

[2] Vomáčko, V., Šidlof, P., Šimurda, D. and Hála, J., CFD analysis of flow in a blade cascade deformed due to forced torsional vibration. Proceedings of the Topical Problems of Fluid Mechanics 2021, Czech Republic