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MODAL ANALYSIS OF A SOLID RUNNER FOR SMALL WIND TURBINES

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ABSTRACT

This work compares the modal behaviour of the solid runner proposed for a small wind turbine. Having in view the particular configuration of the runner, the modal behaviour is analysed on the two main structural components: the blades and the structure supporting them. Both structural elements are intended to be made entirely metallic or in a combined metallic/composite architecture. The analysis focuses the natural frequencies and corresponding deformation modes, offering background for the most adequate solutions.

Keywords: Wind turbine runner, modal analysis, metal-composite structure, eigenvalues.

INTRODUCTION

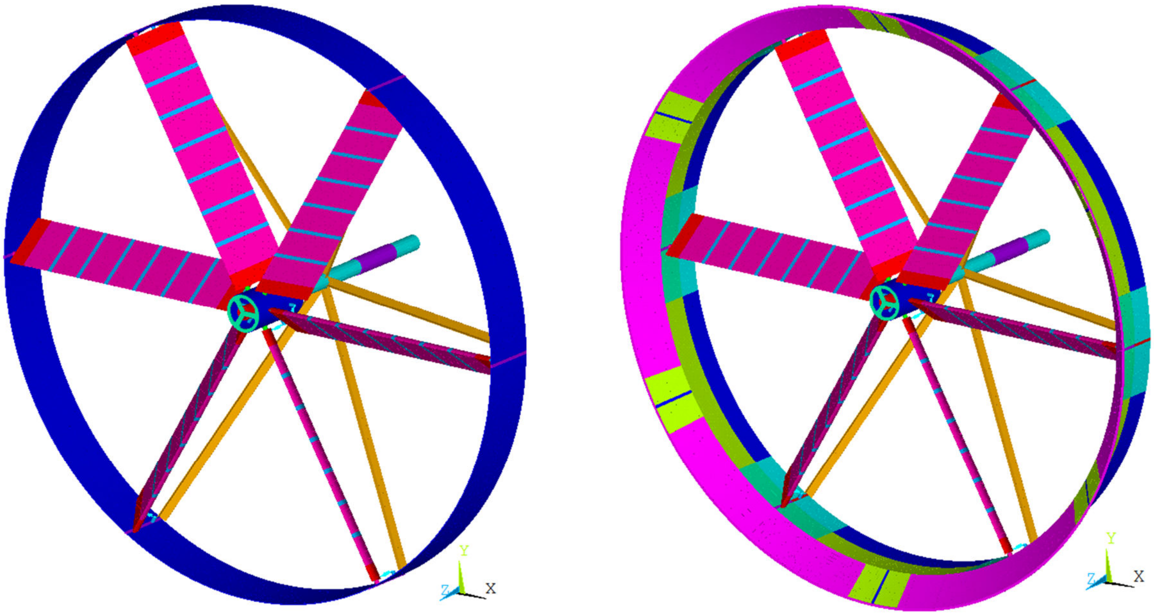
The small Horizontal Axis Wind Turbines (HAWT) are running in many cases in areas with low velocity winds. Solid runners, with increased number of blades are to be used in order to increase energy harvesting efficiency, this design being proposed already in the form of American runner and being revived in recent ones (Islam, 2008). Additional solutions had to be found to further raise the wind energy conversion factor, most moving around the ducted runner configuration. The Diffuser Augmented Wind Turbine (DAWT) was the most widespread (Lilley, 1956) (Gilbert, 1978) (Fletcher, 1980) (Phillips, 2000) (Lubitz, 2014), continuing with the recent turbines equipped with a shrouded diffuser ended with a brim or flange, in different variants, named by some authors the wind lens technology (Ohya, 2010) or flanged diffuser shroud technology (Toshimitsu, 2012) (Owis, 2015). All these design solutions are mainly weighting on the diffuser shape, a particular attention to the intake section of the ducted runner being much less found in the literature (Wang, 2008). Also, all design solutions are presenting aerodynamic performances, claiming boosts in the wind energy conversion efficiency or power output ranging from a reasonable 1.5 to a spectacular 5 factor for the same swept area, while the geometry of the flanged diffusers raise many concerns regarding the structural behaviour in certain service conditions

Our research team proposed a ducted six blade runner, intended to combine both advantages to be exploited in low wind conditions. Apart the aerodynamic study, offering hopes for a consistent increase in the wind energy conversion, the structural analysis was carefully made, in order to ensure safe running conditions and a basis for sound maintenance along an extended reliable service life in more or less isolated places.

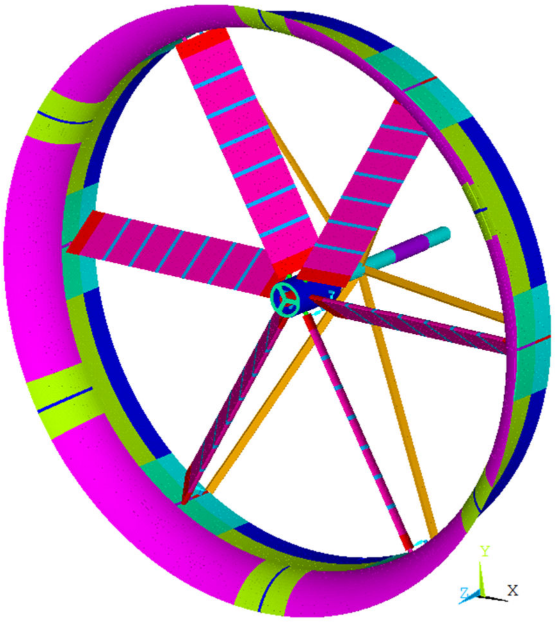
The structural analysis of the turbine runner included static and modal analysis, meant to assess the behaviour of this essential part of the proposed integrated green energy unit facing fluctuating external loads. The results presented in this paper focus the results extracted from the modal analysis concerning the external shell surrounding the runner, in various design variants, a structural part which may create the highest vulnerability for the turbine as a whole.

DESIGN SOLUTIONS AND MODAL ANALYSIS

The design in view for the turbine runner evolved from Variant A, simply cylindrically ducted, through Variant B, having a conical inlet shell, until a final Variant C, with a curved inlet shell (Figure 1).



Variant A Variant B



Variant C

Fig. 1 - Design variants of the ducted turbine runner.

All metallic and mixed composite-metallic structure was considered for the runner. In the second variant, only the radial beams and the blade spar were metallic. The skin and ribs for the blades have been made of fibre reinforced plastics (FRP) and the outer cylinder of thin sandwiches, with FRP skins and coremat® cores. In order to ease the manufacturing, transportation and on site mounting, the over 4 m in diameter turbine was conceived to be made of different parts, easy to mount or dismantle. In turn, such a design created some challenges in the modelling and simulation process, made with the ANSYS code.

RESULTS

The modal analysis of Variant A considered the outer shell alone (Sorohan, 2015), in two configurations: made of a thin sandwich with one coremat® core and made of a thicker sandwich, with two such cores. In both cases, the skins were made of GFRP materials, with an intermediate such layer separating the two cores in the second one, thus resulting a 7 mm thick and a 12 mm thick material, respectively. The first four natural modes and associated frequencies for the thinner sandwich configuration, considered as a reference, are presented in Figure 2.

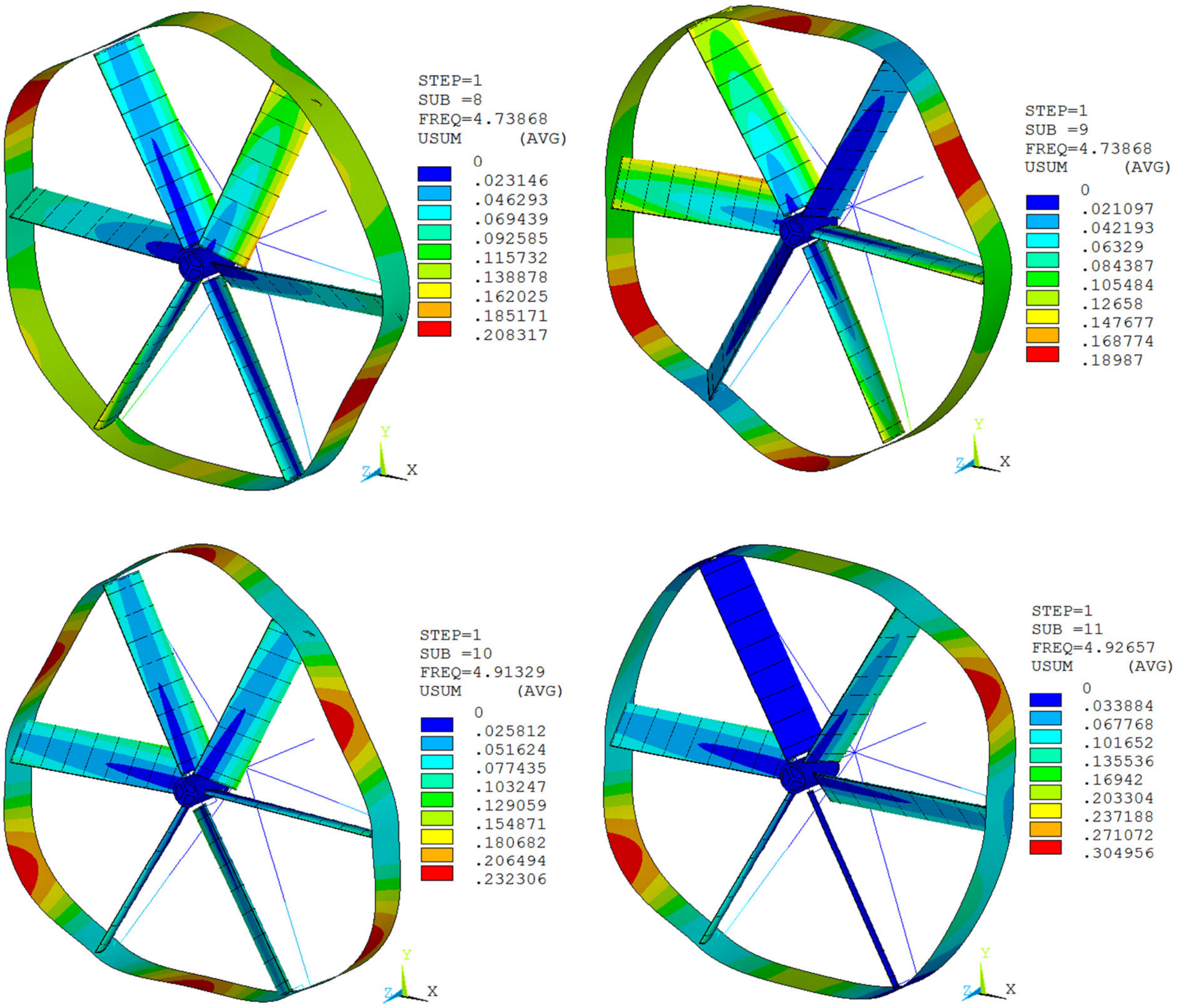


Fig. 2 - First four natural modes for the outer shell of the runner in variant A, made of a thin sandwich material.

Using the thicker sandwich material, with considerably higher stiffness, led to similarly shaped modes, and corresponding frequencies increased with about 20 %.

The models for the other two variants included the whole structure. The inlet shells were made, in both, of 3 mm thick laminates, coming together with some structural adds, in this way smoothing and further stiffening the original duct, used for variant A in the thin sandwich configuration. It has to be retained that in the models used for the simulation of variants B and C, the contribution of the mass of all six blades creates another clear difference.

In Fig. 3 are presented the first four modes in which the outer shell was activated during the modal simulation of variant B.

In Fig. 4 are presented the first similar four modes obtained during the modal simulation of variant C.

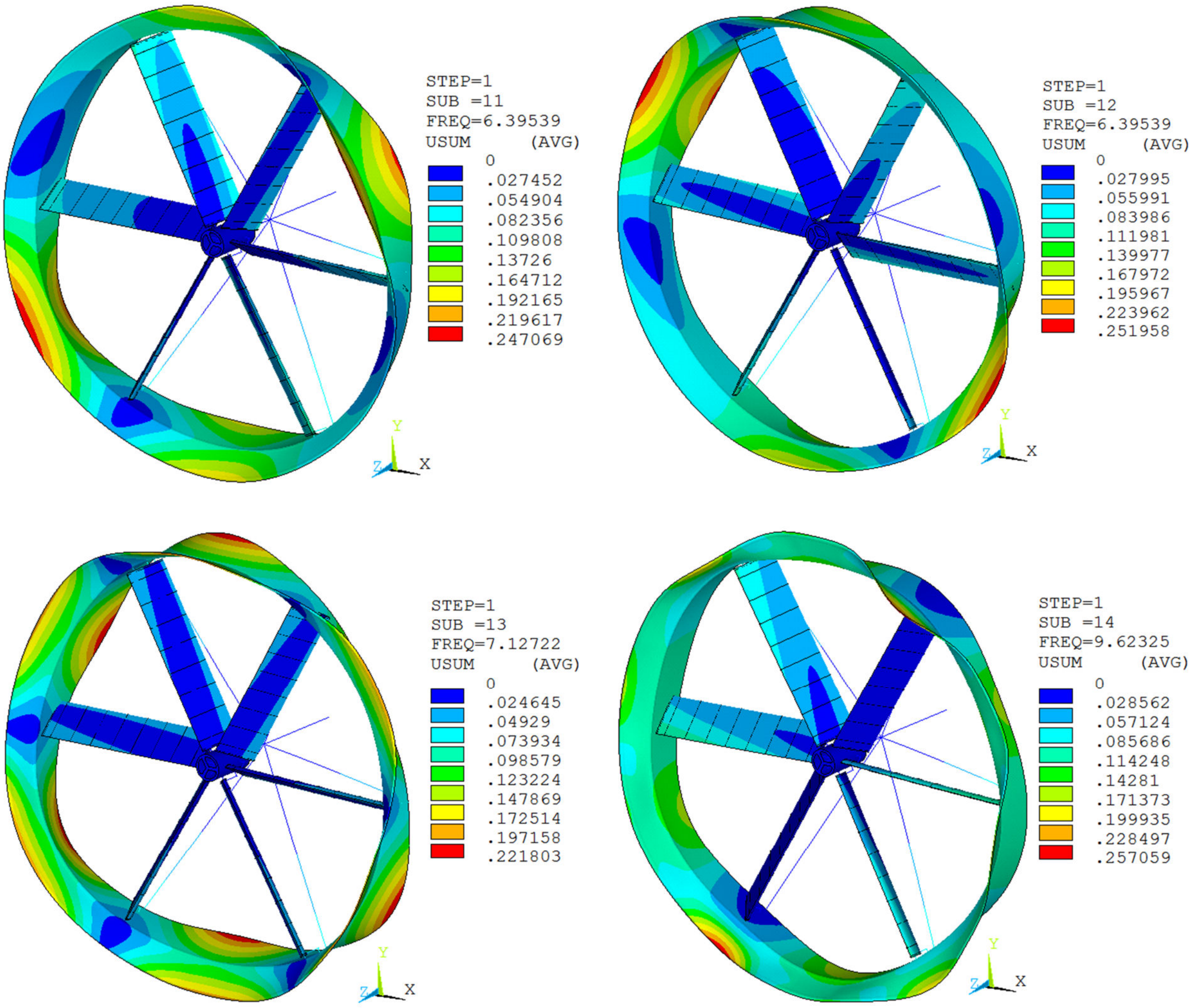


Fig. 3 - First four natural modes for the outer shell of the runner in variant B.

CONCLUSION

The modal analysis of the three design variants considered for the small wind turbine outlined one important fact: the modal behaviour of the outer shell ducting the blades is conservative in the first four modes, with similarly looking mode shapes and associated frequencies, with little influence on the side of the shell configuration. The modes can permute, like modes 3 and 1, for variants B and C, respectively. The frequencies keep in the rather low range domain, between 5 and 8 Hz, which is still over the frequency corresponding to the maximum estimated rotational speed of 200 rot/min.

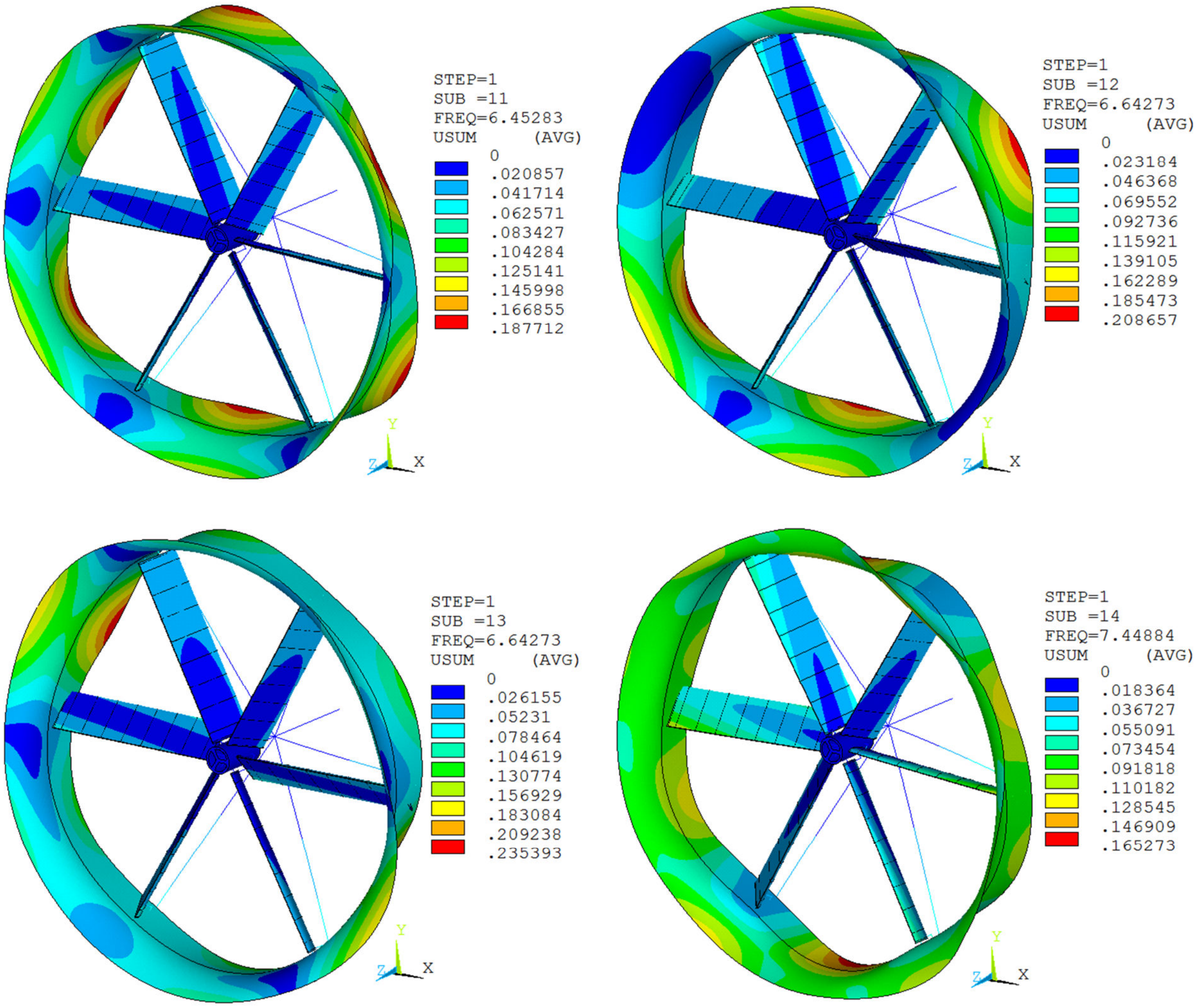


Fig. 4 - First four natural modes for the outer shell of the runner in variant C.

The lack of sensitivity of the modal behaviour of the outer ring face to the structural design leads to a confortable dissociated static structural analysis, which has to respond to the critical cases considered for the whole envelope of environmental in-service conditions in view.

On another hand, careful monitoring has to be made concerning the coupled modes and the conditions favouring such modes. For example, the torsional mode activating both the outer ring and the blades, exhibited at the very low frequency in conditions of blocked turbine axle (Fig. 5), may become dangerous in certain running conditions, having in view the actual direct drive generator characteristics or conditions of emergency runner braking.

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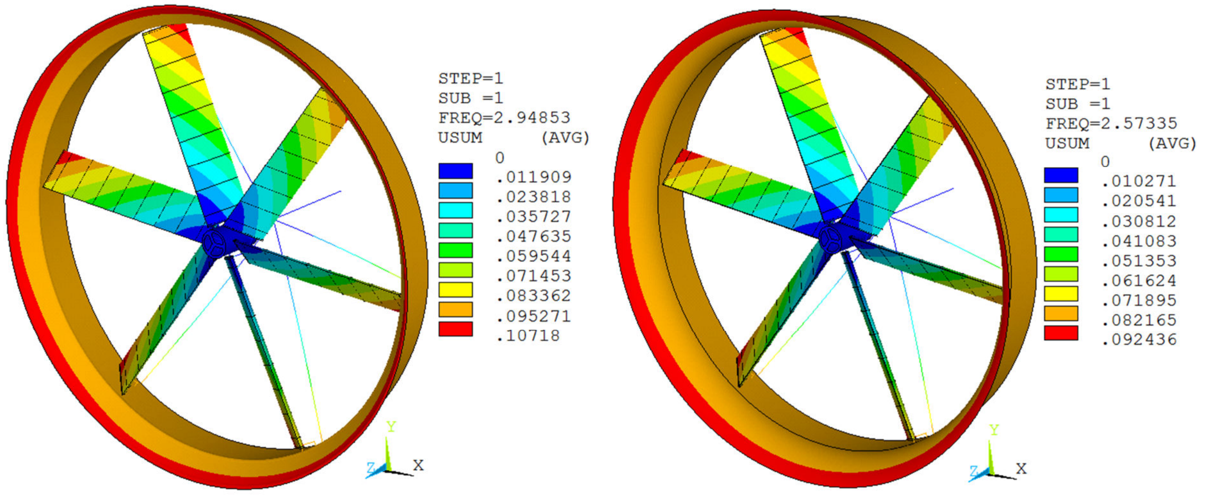

Fig. 5 - Torsional vibration mode implying the inlet shell and the blades, for variants B (left) and C (right).

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