DESIGN AND ANALYSIS OF A SOLID RUNNER FOR A SMALL WIND TURBINE

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In the study presented in this paper, a six blade tubed horizontal axis wind turbine (HAWT) was analysed, taking into account the stiffness of all components, adequately modelled. The natural frequencies and associated modes have been followed for the pristine structure and confronted with those obtained for a damaged one, setting the bases for a sound structural monitoring process. The dynamic behaviour was correlated with that of the rest of the wind power unit, each structural unit being evaluated in a separate study.

KEY WORDS: small wind turbine, tubed solid runner, foam filled blade.

1 INTRODUCTION

Small wind turbines have to run, in most cases, in areas with relatively low wind. The best solution for getting high conversion coefficients in such cases is to use high solidity runners. This type of runners has still to be able to withstand occasionally high wind or gusts. This quite large envelope of atmospheric conditions requires a comprehensive evaluation of the dynamic behaviour of this structure. The assessment of the dynamic behavior is complementing the static structural analysis of the runner loaded by extreme aerodynamic forces.

The solution for the solid runner in this case was a tubed six blade turbine (Figure 1), in hybrid metal- composite variant. The tubed turbine seems to be for the first time considered for a wind turbine, so some advantages apparently linked to such a design will be tested along the development of this project and afterwards, during a series of field trials. Namely, the external cylinder is expected to increase the conversion coefficient, approaching it to the Betz limit (Ragheb M., Ragheb A., 2011), and to contribute to the stabilization on the runner in wind, apart from the tail fin. This cylinder is made from composite materials, while the rest of the structure can be fully metallic or hybrid, upon the manufacturing possibilities existing on place. The runner is placed on a core axle, supported by two bearings and carrying also the direct drive electric generator. The dynamic analysis focuses the cantilever section, ahead of the nearest bearing, and is intended to support inspection techniques which can be in view for the structural health monitoring during the service life of the turbine and adequate related maintenance procedures.

Due to the complex structural architecture of the turbine, the dynamic analysis was performed in two steps: the analysis of a single blade and the analysis of the whole runner, with a simplified model. This technique will be extended for all components of the wind turbine installation, involving the turning platform and the supporting tower. Details of the dynamic analysis of the runner are presented in the subsequent sections.

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2 THE DESIGN

The main idea of the design is a modular. This translated to the whole assembly being first of all easy to transport and easy to manufacture, the greatest part not exceeding a maximum of 3.5 [m]. All the parts were selected such that they are easy to acquire on the market, made of as fewer types of materials as possible and which are not too complicated to work with.

2.1 The outer ring

Discussing each component in part, the first one taken into consideration is the element which distinguishes the runner from the classical one – the outer ring (Figure 1).

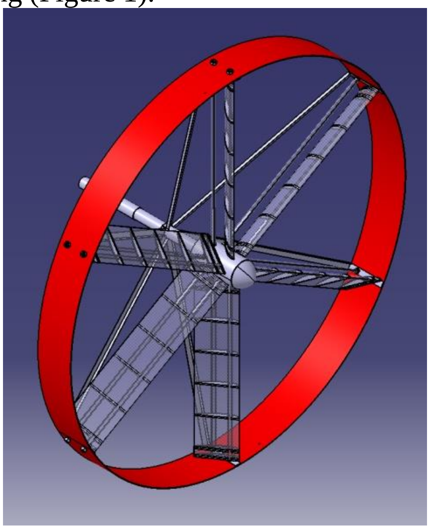

Fig. 1. Highlighted outer ring of the rotor

The main purpose of this ring is to increase the conversion factor. This factor is related to the efficiency of the turbine, which is given by Betz's law, which states that the efficiency can not exceed ~59 [%]. This value was obtained by taking into account quite a few assumptions, one of them being the fact that the direction in which the flux of air would be released from the swept volume of the blades is strictly axial to the turbine. Obviously, in reality it is not the case, since the movement of the blades clearly pushes the air in the radial direction. This is where the outer tube becomes important – the flux of air is forced to follow the axial direction, therefore more energy can be generated, such that the conversion factor is increased.

As a secondary role, the outer ring also helps keeping the turbine in the direction of the wind. The material it will be made of will most likely be a composite material, but at this point, a possibly metallic configuration isn't excluded. It has to be quite light and resistant. At the connection points with the blade spars, some reinforcements will be present, on both sides of the ring, secured with screws in order to strengthen those sections which will be the most dangerous for this geometry and configuration.

2.2 The axle

The axle (Figure 2) is very important for both the mechanical energy transmission from the rotor to the generator as well as the support of the rotor itself. The proposed idea at this point is to have it made from one single piece, due to the fact that it's both safer (no wielding points or other stress concentrators that may appear depending on the technological solution of attaching two distinct parts) and economical.

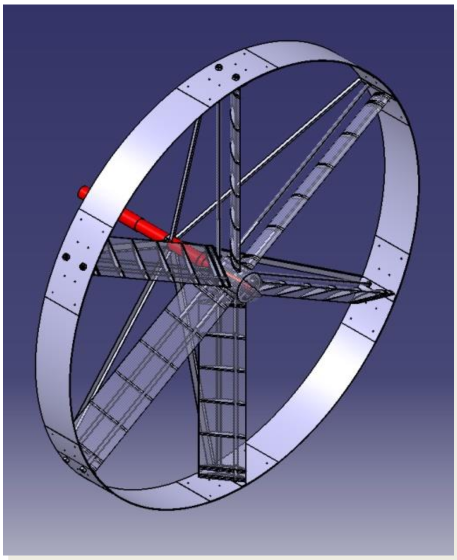

Fig. 2. Highlighted axle of the rotor

At the rotor's end, it will have some cut-off sections in which the elements assisting the connection between the blade spars and the axle will rest. Those sections will have to be carefully studied during the static test. Also, the end will be covered by an inner cylinder and a cone which mask the whole fixing mechanism in the center, as well as two lids (on both ends of the cylinder) which assists in transmitting the moment from the cylinder surrounding the axle to the axle itself.

2.3 The inner cylinder

The inner cylinder (Figure 3) is made out of steel as well. Its role is mainly to strengthen the structure as well as to provide the support for the blades' lower end. It will be fixed onto its position by both the end part and the cone specified earlier, as well as the blade spars which penetrate it in 12 points.

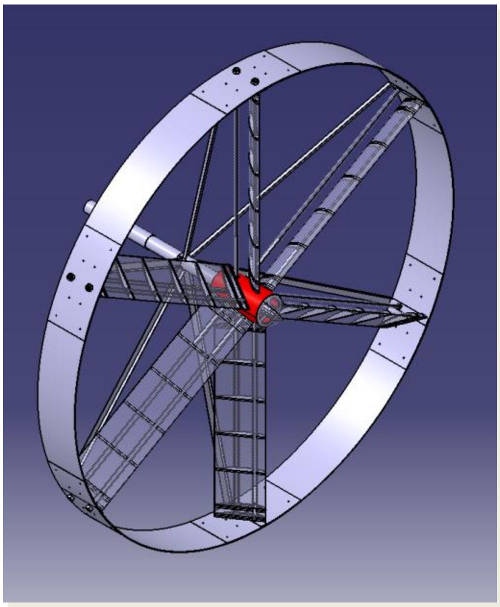

Fig. 3. Highlighted inner cylinder of the rotor

2.4 The blade spars

The 12 spars (Figure 4) are made out of steel, and based on their location they provide either support for the blades (and outer ring) or increase the overall solidity of the assembly by eliminating the possibility of the appearance of a parallelogram effect due to the geometry. They are also useful for the system of blade angle limiting system, which has yet to be designed at this point. Inside them, at the lower end, some connection parts will be inserted, in order to assist the mechanical energy transmission from the blades to the axle.

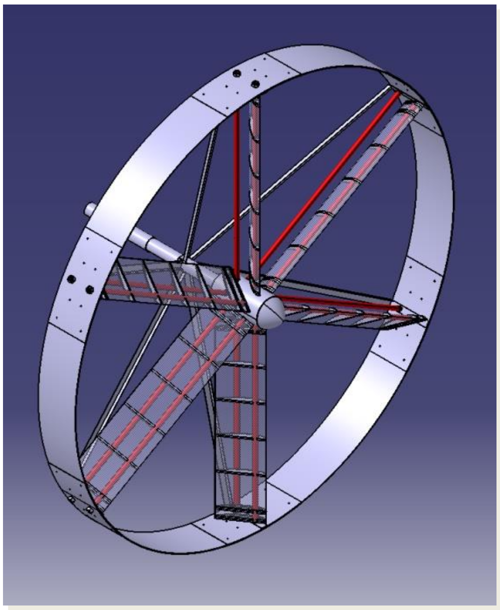

Fig. 4. Highlighted spars of the rotor

2.5 The axle

The last basic elements discussed for the overall design of the rotor are the blades (Figure 5). They are responsible for the conversion of energy from the kinetic form, coming from the wind, to the mechanical form used to generate electricity.

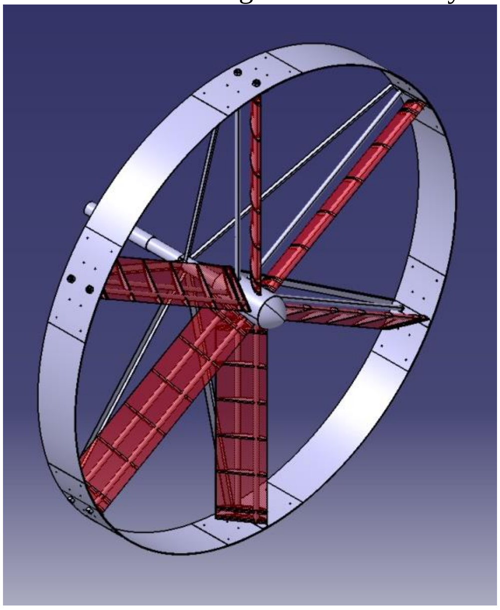

Fig. 5. Highlighted blades of the rotor

The aerodynamic profile for these blades is RAF6. The blade model was built in a rather detailed way, considering all the structural elements: spar, ribs and skin, in a whole metallic variant. In one structural variant, the ribs and the skin are made of duralumin sheets. Having in view the small thickness of the skin, another variant in which the blade is filled with polyurethane foam for better keeping the geometry of the airfoil in all loading conditions is considered too. The outer shell will most likely be made out of CFRP (carbon fibre reinforced polymer) for the case of foam-filled geometry. At the upper and lower end, a second layer will be placed in order to strengthen those sections, taking into account the fact that the only contact between the blade construction and the rest of the rotor will take place through the soft-metal spacers (most likely bronze) which are found between the blade's spar and the inner steel pipe.

3 THE METHOD

For the FE model of the blade, thin SHELL181 elements were used for the skin, ribs and for the spar, while for the filling foam, SOLID185 elements were used. (Figure 6)

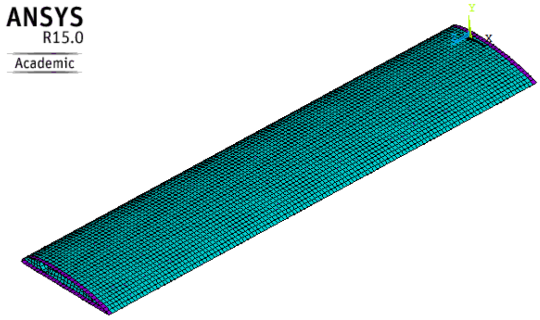

Fig. 6. The FE model of a single blade

The runner was modeled in a simplified way in order to better put in evidence the basic natural modes. The composite outer cylinder was modeled with thin shell elements and the metallic radial beams linking it to the turbine shaft and the shaft itself were modeled with beam elements (Figure 7).

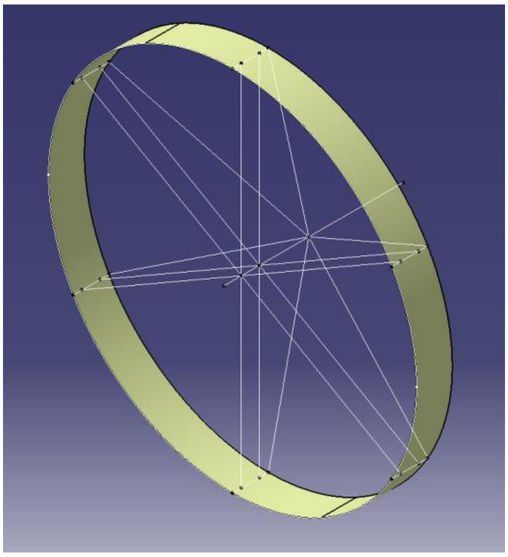

Fig. 7. Simplified rotor model

The materials and their properties considered in the FE models were assigned as presented in Table 1.

Table 1. Materials and properties

Materials /Properties	**E [MPa]**	**v**	**Parts**
Steel	2.1e5	0.3	Blade spars, radial straight and inclined beams, turbine shaft
Dural	7.2e4	0.33	Blade skin, ribs
Sandwich composite	5e3	0.33	Outer ring
Polyurethane foam	20	0.4	Blade filling
Thin CFRP	5e4	0.3	Blade skin

4 THE RESULTS

4.1 Blade results - comparison

The modal analysis was performed for the two FE models, in two structural configurations for each. The 1st and 4th vibration modes and associated frequencies, corresponding to both structural variants of the blade are illustrated in Figures 8 and 9, respectively Figures 10 and 11.

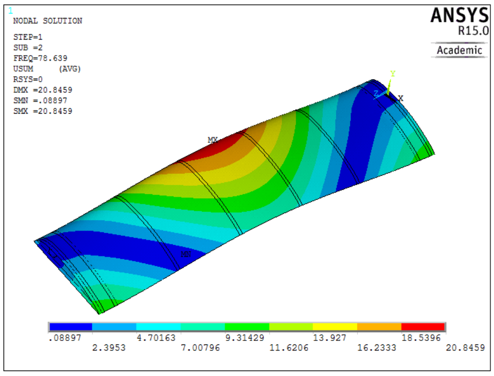

Fig. 8. First mode of vibration – foam filled

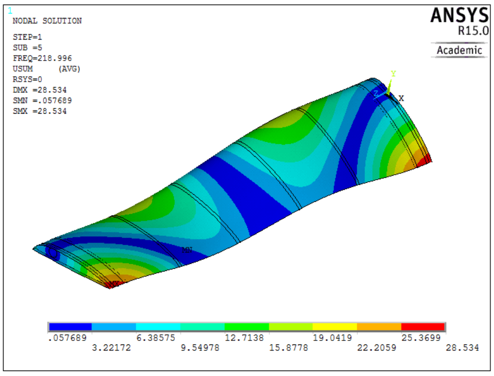

Fig. 9. Fourth mode of vibration – foam filled

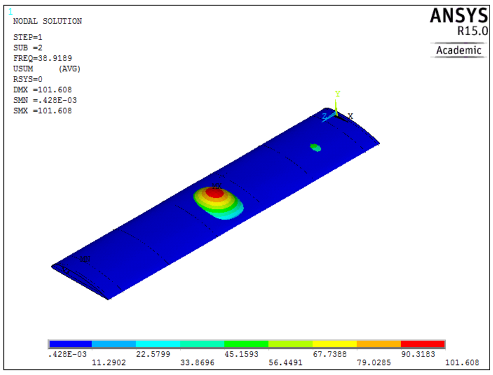

Fig. 10. First mode of vibration – metallic configuration

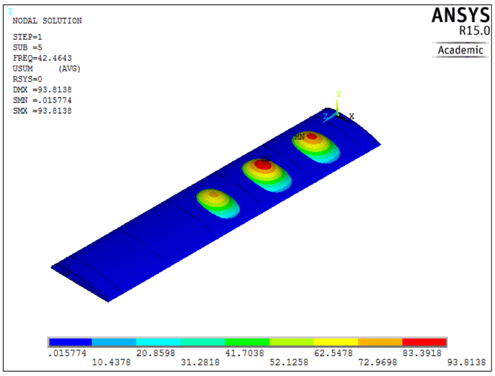

Fig. 11. Fourth mode of vibration – metallic

At the first glance, one can see that the blade in all metallic configuration exhibits first local modes, at considerable lower frequencies, which are denied to the blade in composite skin-foam filling configuration, considerably stiffer. This makes the decision of the final configuration that will be used way easier from the point of view of performance – it is obvious that the foam filled one is better.

4.2 Outer ring results - comparison

The modal analysis was performed for two FE models differentiated by a variation in the thickness of the outer cylinder: 7 [mm] for the first case (Figures 12 and 13) and 12 [mm] for the second case (Figures 14 and 15). In these figures are presented two sets of the first and fourth vibration modes and associated frequencies obtained, for both values of the thickness. The natural modes and corresponding frequencies are very well alike, the only difference being an upwards translation of the associated frequencies with about 2 Hz for the turbine equipped with a thicker outer cylinder. The rest of the structure remains unshaken in the range of these quite low frequencies, proving a considerable higher stiffness in comparison with the outer cylinder.

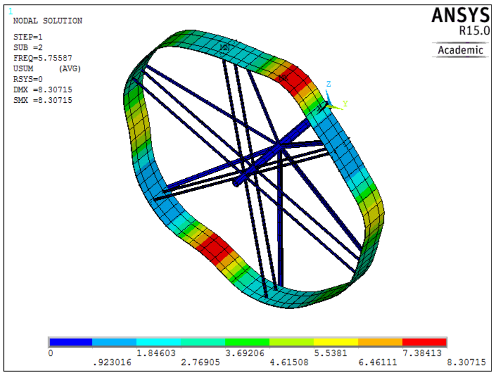

Fig. 12. First mode of vibration – 7 [mm]

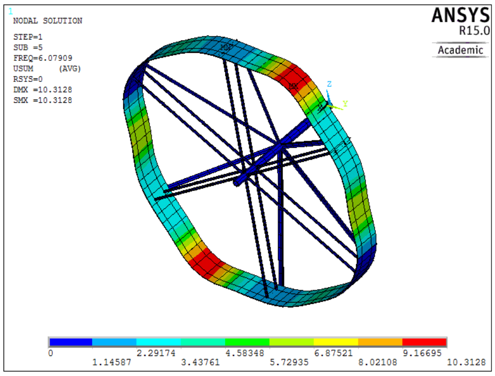

Fig. 13. Fourth mode of vibration – 7 [mm]

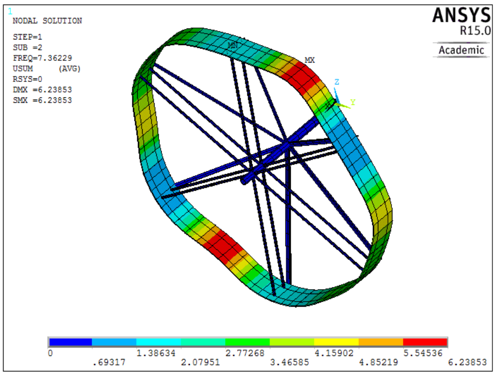

Fig. 14. First mode of vibration – 12 [mm]

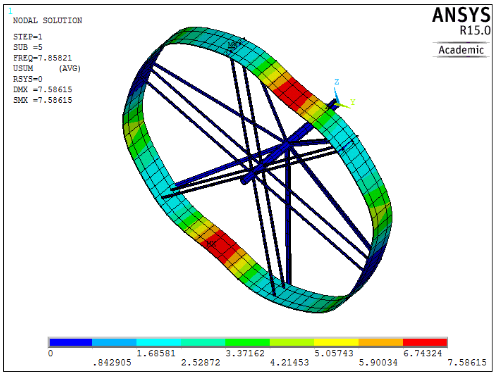

Fig. 9. Fourth mode of vibration – foam filled

5 CONCLUSIONS

The studies performed so far on the virtual models offer valuable information which allows the estimation of the range in which various sections of the structure may vibrate. Regarding the runner, it is quite clear that only the outer cylinder may exhibit vibrations which can be excited by cyclic loads occurring during the turbine functioning, mainly aerodynamic. These vibrations will not interfere with those of the other structural elements of the runner in the forecasted domain of quasi-cyclic external loads. Eventually, the dynamic behaviour of the structure will be compared with these results.

The next step will consist in cross-checking the fulfillment of static and dynamic requirements for every structural element. Then, the effects of various scenarios of damaged elements on the behaviour of the structure will be analyzed, with proposal of repair technologies. This approach will be conducted in line with the studies conducted in (Constantin, Anghel, Găvan & Sorohan, 2008 & 2011) with continuously more demanding regulations concerning reliability of wind turbines during their service life (Friedmann, Mayer, Koch & Siebel, 2011)

6 ACKNOWLEDGEMENTS

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