

Velocity spectrum and blade's deformation of horizontal axis wind turbines

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Abstract: The paper presents the velocity distribution calculated by numerical method in axial relative motion of a viscous and incompressible fluid into the impeller of a horizontal axis wind turbine. Simulations are made for different airflow speeds: 0.5, 1, 3, 4, 5 m/s. The relative vortex on the backside of the blade to the trailing edge, and the vortices increase with the wind speed can be observed from the numerical analysis. Also the translational deformation-the deflection of the wind turbine blades for different values of the wind velocities has been established in this paper. The numerical simulations are made for the following speed values: 5 m/s, 10 m/s and 20 m/s. ANSYS CFD – Fluent was used both to calculate the velocities spectrum and to establish the translational blades deformations. The analyzed wind impeller has small dimensions, a diameter of 2 m and four profiled blades. For this small impeller the translational deformation increases with the wind velocity from 83 to 142 mm. For high wind velocities and large-scale wind turbine impellers, these translational deformations are about several meters, reason to /shut-down the impellers to wind velocities exceeding 25 m/s.

Key Words: axial velocity, wind turbine, blade deflection.

1. INTRODUCTION

The wind turbines play an important role in the renewable energy field, reason to study their mechanical and aerodynamic behaviour, in order to improve their performances.

This article presents the results of the theoretical research in the study of aerodynamic behaviour of the impeller of a small wind turbine, having a diameter of 2 meters and four blades, by simulating different modes of operation, represented by different wind velocities. The aerodynamic modelling and design was made using ANSYS Code, in three dimensional coordinates. The first hypothesis of the theoretical analysis consisted in applying the geometric similarity. Thus, for the considered impeller with four blades, the analysis was made on a section of 90 degrees, containing the blades and the space between two consecutive blades.

The spatial modeling assumptions and theoretical analysis hypothesis involved the translations and rotations (angular deformations) blocked on all three directions at the impeller hub. The theoretical analyse of the aerodynamic behavior of the horizontal axis impeller took into account the airflow pressure and of the centrifugal forces of inertia in the case of three different wind velocities – 5, 10 and 20 m/s. The translational deformation increased with the wind velocity from 83 to 142 mm for this small impeller. For large-scale wind impeller these deformations can reach several meters, being generated both by the

transport velocity u of the impeller and by the air pressure force. So, large impellers are blocked at high wind speeds equal to or exceeding 25m/s. The aerodynamic profile was inspired from similar papers [1],[2],[3],[4],[5],[6]. The propeller geometry has the blade pitch angle to the hub of 10° and maximum blade specific twisting of 35° .

2. VELOCITY SPECTRUM

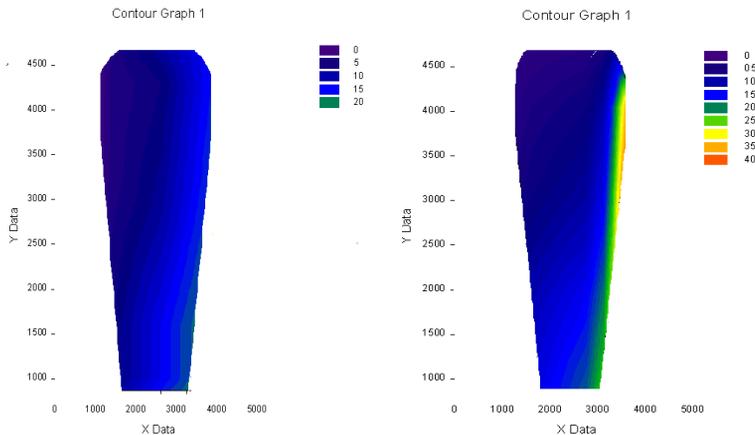
2.1 Modelling hypothesis

In numerical modelling, simplifying hypothesis were made, for example, it is considered that the wind acts directly (perpendicular) to the surface of the blade the velocities induced by the other neighbouring blades are neglected – the slipstream effect and geometrical similarity is applied. The effect of modifying the wind velocities is given by the blade loading with different pressures and different centrifugal forces of inertia. In similar papers [7],[8],[12] the wind turbine aerodynamics is analyzed by the CFD techniques. In order to obtain stable numerical solutions the wind speed v_0 (0,5 m/s, 1 m/s, 2 m/s, 4 m/s and 5 m/s) was kept constant and small Reynolds numbers were used initially. The lifting force given by the air over pressure and the centrifugal force was considered [9],[10]. The pressure on the lifting area is assumed to be perpendicular to each node of the meshed blade. The centrifugal force of inertia is applied at the blades extremity (max. peripheral diameter).

The specific boundary conditions for the axial wind turbines take into account the impeller type which is a four twisted blades wind turbine impeller with pitch angle at the hub of 15 degrees [11], [13]. The velocities have three components: the absolute wind velocity v , the tangential velocity u and the relative velocity w creating the lift force, the maximal couple and generating maximal power from the airflow. The blades are limited at the shaft by a cylindrical hub with the radius $r_b = 0, 1$, and with the radius $r_p = 1$ at the peripheral area, limited by a metallic sheet (as a casing) $v_c = 0$. We considered the boundary conditions for the impeller walls $v_r = w$, in both the input and output section. [6], [9], [10], [11].

2.2 Numerical solutions for axial velocity distribution

Figure 1 shows examples of the relative velocities spectrum for the air flow in axial wind turbines, for different wind velocities: 0,5 m/s, 1 m/s, 3 m/s, 4 m/s and 5 m/s. A maximum concentration values for the axial velocities is observed on backside of the blade. The calculation speed and the computer performance have allowed a finer network of 100000 nodes.



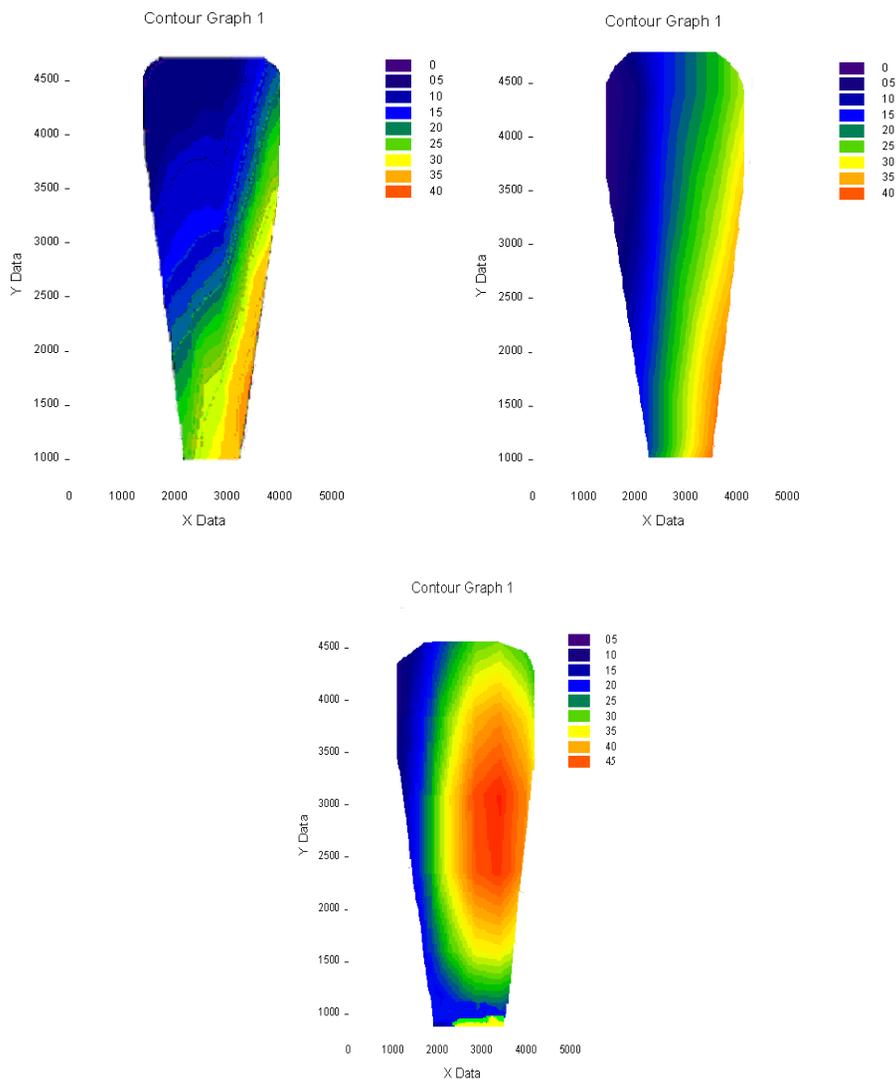


Fig. 1 Velocities spectrum in axial relative motion, for wind speeds of 0,5 m/s, 1 m/s , 3 m/s, 4 m/s and 5 m/s

From the numerical results it can be seen the distribution of the axial velocity, the generation of the relative vortex on the backside of the blade - on the trailing edge, and the vortices increase with the wind speed. Stable solutions were obtained for small airflow velocities (1 – 5 m/s) and small Reynolds numbers. The horizontal axis wind turbine with diameter of two meters starts up at the wind velocity of 0, 5 m/s when the analyzed rotor overcomes the inertia.

3. TRANSLATIONAL DEFORMATION OF THE BLADES

The theoretical analyze of the aerodynamic behavior of the impeller of horizontal axis wind turbine takes into account the airflow pressure and the centrifugal forces of inertia in the case of three different wind velocities – 5, 10 and 20 m/s. The tangential wind velocity pushes the blade forward, the air pressure pushes the blade backward thus a permanent deflection resulting at high wind velocities. Translational deformation increased with the wind velocity

from 83 at 5 m/s, to 108 mm for 10 m/s and to 142 mm for 20 m/s. These deformations are specific to the wind turbine impeller having 2 m in diameter and four blades. Figures 2, 3, and 4 present these numerical and graphical translational deformations.

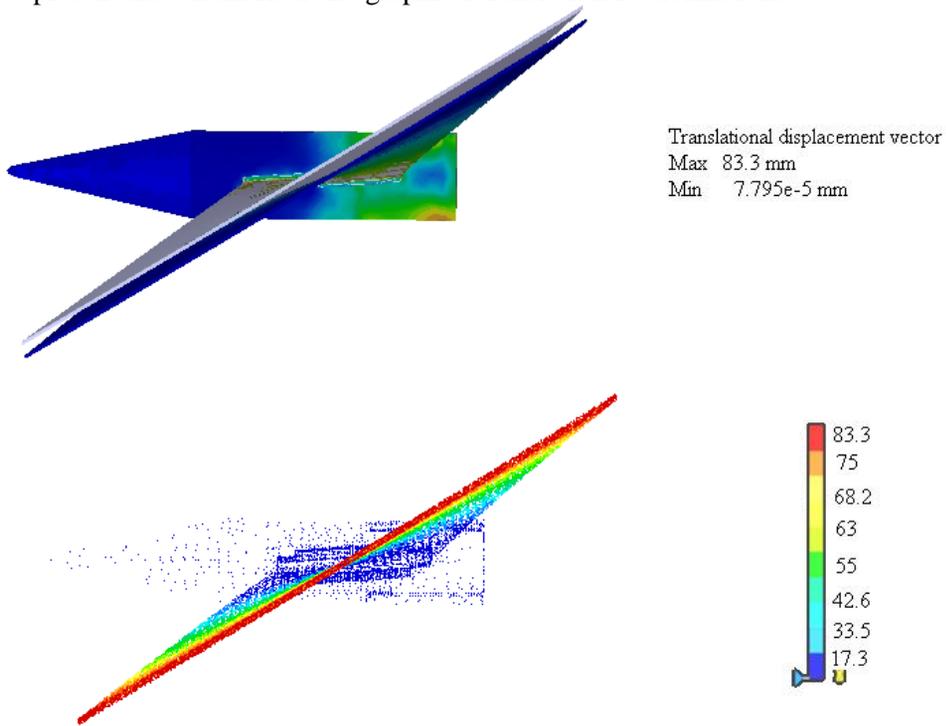


Fig. 2 Translational deformations for 5 m/s airflow velocity

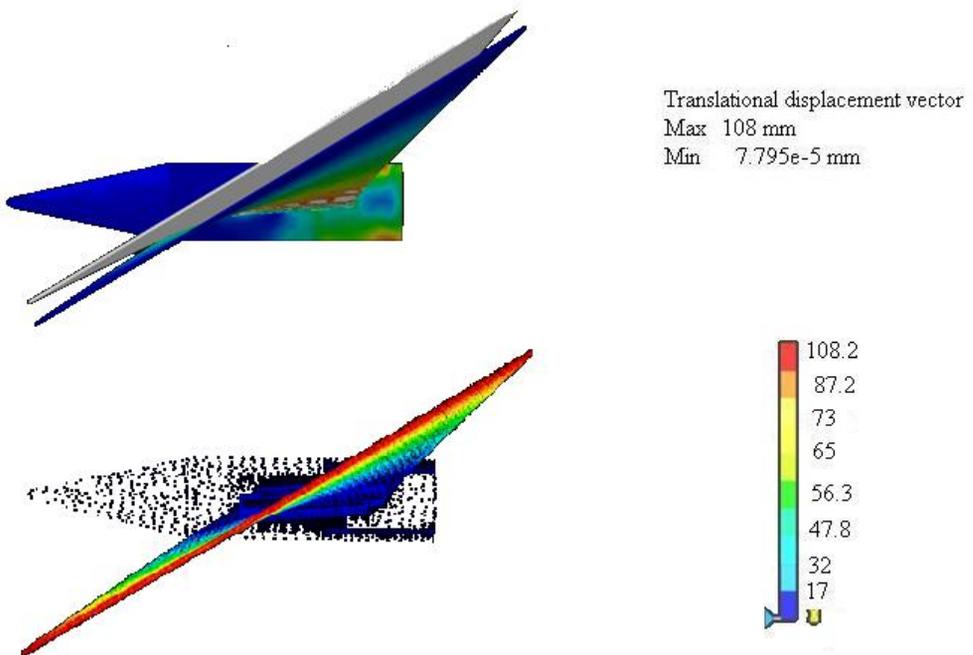


Fig. 3 Translational deformations for 10 m/s airflow velocity

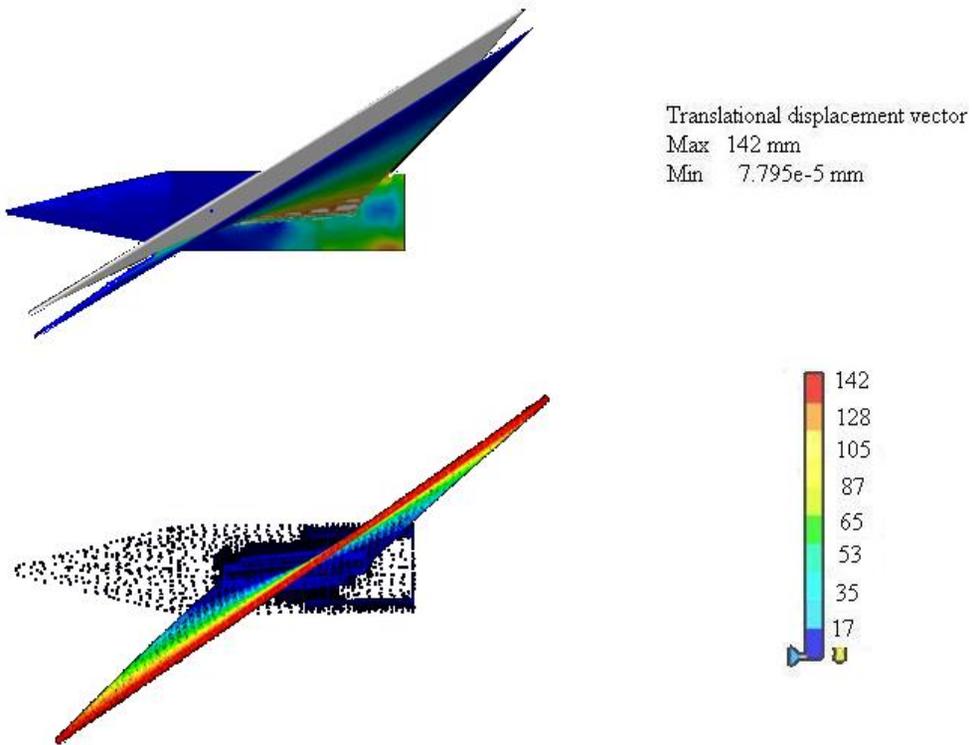


Fig. 4 Translational deformations for 20 m/s airflow velocity

For large-scale wind impellers these deformations can reach several meters, being generated both by the transport velocity u of the rotor and by the airflow pressure (6-7 m for the impeller with a diameter of 90 m). Therefore, large impellers are blocked at high wind speeds—equal to or exceeding 25 m/s.

4. CONCLUSION

In this paper it was studied an impeller of a horizontal axis wind turbine having 2 m in diameter and four blades. To extract the maximum power from the airflow, this studied impeller has a pitch angle of 10° and twisted blades. The aerodynamic modelling and design was made using ANSYS Code, in three dimensional coordinates.

Using the numerical analyze, the relative axial velocities spectrum was obtained for different wind velocities. The relative vortices on the backside of the blade - on the trailing edge and the vortices increase with the wind speed were highlighted.

The translational displacements of the blades / maximal deflection for three wind velocities, 5, 10 and 20 m/s were also studied, to establish the aerodynamic behaviour of the blades of HAWT.

The translational deformation increased with the wind velocity from 83 at 5 m/s, to 108 mm for 10 m/s and to 142 mm for 20 m/s. For large-scale wind impeller and high wind velocity, these translational deformations have several meters, reason to shut-down the rotor at over 25 m/s airflow velocity.

The results of this study are useful to correct the design of the impeller of the horizontal axis wind turbine.

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