TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 57, Issue III, September, 2014

FINITE ELEMENT ANALYSIS TO ESTIMATE THE EFFICIENCY OF A WIND TURBINE ROTOR

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Abstract: *In this article, there are presented few aspects of the research that was made by the authors in the field of Wind Turbine Rotor design. Several variants of turbines were designed, and then analyzed, by using the finite element analysis Ansys program, in order to compare their efficiency and performances. The selected prototypes were manufactured on the SLS equipment - Sinter station 2000, which exists within the Technical University of Cluj-Napoca, Romania. Regarding the efficiency of the rotors, there are a lot of geometrical factors, which influences the power produced by the turbines, like the profile of the rotor blades, the number of the blades, the delay between the blades, etc. On the other hand there are factors that pertain to the rotors manufacturing process or factors that are dependant by the properties of the wind (wind velocity, direction of the wind, etc). All these aspects were taken into account in the designing process of the wind turbine rotor, so as, at the end, the turbine could be easily adapted to our region (Transylvania, Romania).*

Key words: *Selective Laser Sintering, Wind Turbine Rotor, Finite Element Analysis*

1. INTRODUCTION

According to GWEC (Global Wind Energy Council), at the end of year 2011, the total volume of collected energy by the wind farms has reached 238.251 MW/ year. There is a strong competition between the wind farms developed by USA and Germany, as well, each of these two country being leader in this field at a particular time. In the last years, China has become also a strong competitor, due to the massive investments and an existing coherent development plan in this field. According to GWEC reports, the production capacity increases every year with approximately 25 %. Approximately 25 billions € are invested yearly in new wind farms all over the world. This amount of money that is invested in this field proves the dynamic and development capacity of these types of farms in the future, in the entire world (http://www.ewea.org).

As related to the types of wind turbines that exists in the world, we can state that the most used are the ones having vertically axes (Percival et al., 2004). These types of turbines are used on a large scale, due to the fact that basically they are very simple by the constructive point of view, being very easy to manufacture, as well. The Savonius turbines, like the one illustrated in Figure 1, are very used in the developing countries, for example, not because of their efficiency (the running velocity is not too high), but because of the fact that are easy to start even at low values of wind velocity, with no significant influence of wind direction (Aldoss, 1984), (Aldoss & Kotb, 1991).

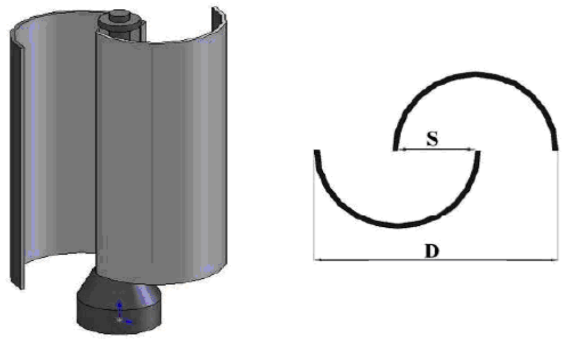

Fig. 1. 3D model of Savonius turbine rotor (example)

Regarding the efficiency of the rotors, there are a lot of geometrical factors, which influences the power produced by the turbines, like the profile of the rotor blades, the number of the blades, the delay between the blades, etc. (Fernando & Modi, 2003). There are several articles that analyze these aspects by the experimental point of view. The power ratio coefficient can be determined, for example by measuring the slewing velocity and the driving moment using two dynamometers attached to every blade of the rotor (Sargolzaei & Kianifar, 2009), There are also some analytically and experimentally methods that takes into account the influence of the rotor profile over the turbine performance. The rotor profile geometry can be optimized by taking into account which is the optimum length of the blade that generates the maximum driving moment and maximum power ratio, in accordance to the wind direction, as well (Altan et al., 2008). There are also some researchers that present modified versions of the Savonius rotors turbine blades that have for example twisted blades (Grinspan et al., 2001). This geometric modification has several advantages by the functioning point of view, such as the reduced pressure over the surface of contact, the decreasing of breaking moments and the capacity of self start-up while running (Grinspan et al., 2003). The power ratio coefficient is significantly improved in this case as compared to the previous versions of turbines that were presented (Fujisawa, 1992), (Huda et al., 1992), (Saha & Rajkumar, 2006).

All these aspects were taken into account at the Technical University of Cluj-Napoca, for several variants of turbines that were designed, and analyzed afterwards, by using the finite element analysis program Ansys, in order to compare their efficiency and performances.

2. FINITE ELEMENT ANALYSIS TO ESTIMATE THE EFFICIENCY AND PERFORMANCE OF A WIND TURBINE ROTOR

In order to estimate the efficiency and performance of the wind turbine rotor illustrated in Figure 2, by using the finite element analysis method, the 3D CAD model has been designed using SolidWorks 2011 program.

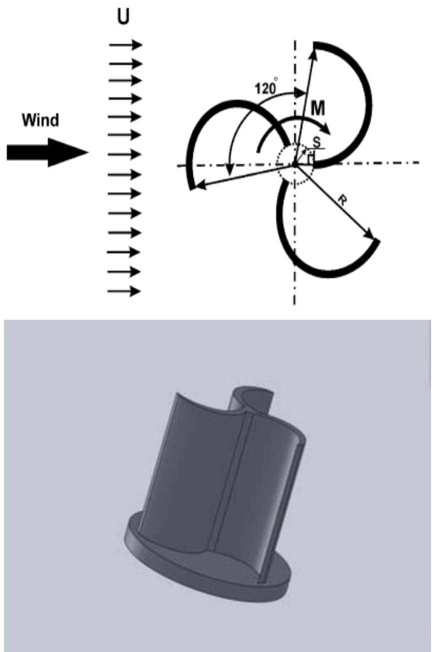

Fig. 2. 3D model of the wind turbine rotor (SolidWorks 2011)

As it is possible to observe from the schematic drawing presented in Figure 2, the most important dimensions are the angle between blades, that must be 120°, the blade radius R=35 mm and the diameter of the main swivel pin S=5 mm. The disc from the inferior side of the part offers a good stability of the rotor in functioning, by increasing its weight in this way. As related to the overall size of the part, it has been limited to a cylinder of Ø 110 x 100, in order to decrease the number of calculus that are needed during the finite element analysis and due to the size limits given by the SLS equipment.

As related to the finite element analysis (FEA), after importing the 3D model into the Ansys FEA program, there were needed few initial operations to be made, that consisted basically in the designing of a solid body around the part and the mesh generation as illustrated in Figure 3. A mesh with 260.893 nods and 1.421.646 elements has been generated.

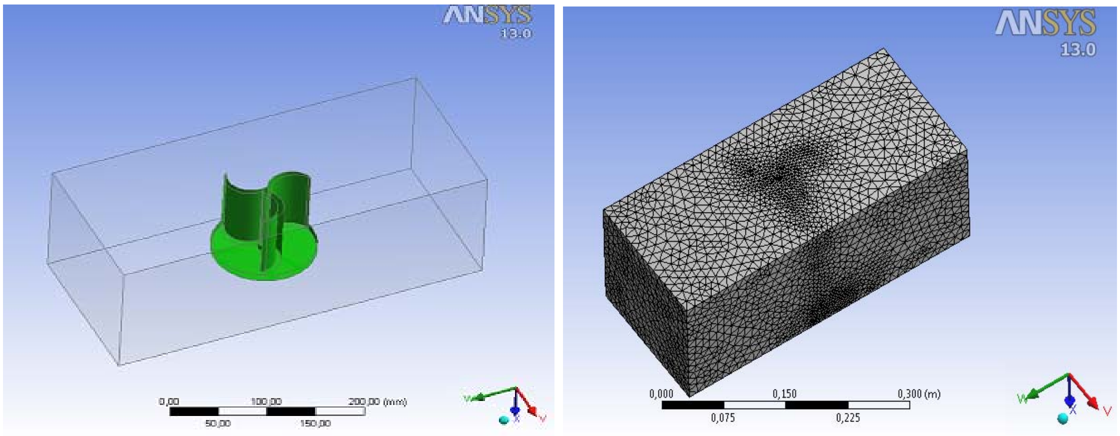

Fig. 3. The solid body that has been generated around the rotor and the mesh (Ansys)

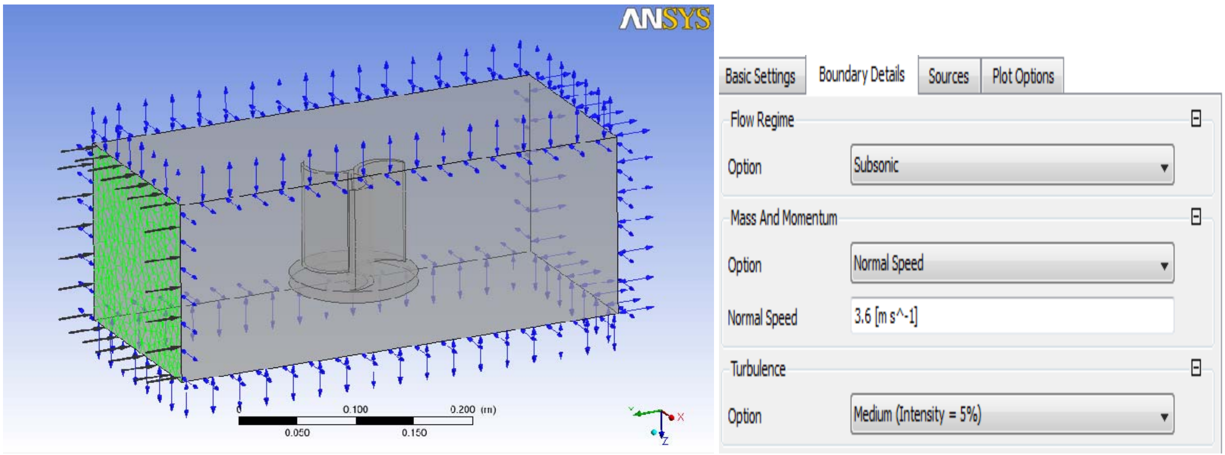

Fig. 4. The constraints applied over the solid body (Ansys)

The next important step of the FEA consisted in the constraints establishment, such as locking the solid body movement constraints and the specification of the wind velocity and the pressure inside the solid, as illustrated in Figure 4. Three particular cases were analyzed.

The wind velocity has been set-up, having a value of 3.6 m/s, 9 m/s and 12 m/s accordingly. The pressure inside the solid body has been set-up on 0 Pa, due to the fact that the main focus of the finite element analysis was to determine which are the pressure and the velocity that are applied in the rotor region, without introducing any supplementary constraints. The value of 3.6 m/s for the wind velocity has been selected, by taking into account the mean of the reported values of the wind velocity for Transylvania region from Romania. The values of 9 m/s and 12 m/s were taken into consideration, in order to analyze the stability of the rotor for higher wind velocity values and the power developed in these cases, as well.

The last stage consisted in running of the analysis. An important conclusion of the made analysis was that the scanning velocity in the rotor area would be decreased as compared to the initial value of velocity of the wind. For example, in the case when the wind velocity is set-up at a value of 12 m/s, the maximum velocity in the rotor area will be decreased to a value between 5-7 m/s, as illustrated in Figure 5. Not only the velocity is influenced in this case, but also the pressure applied on the propeller surface. If the wind velocity is increased, the pressure applied on the propeller surface will be increased, as well.

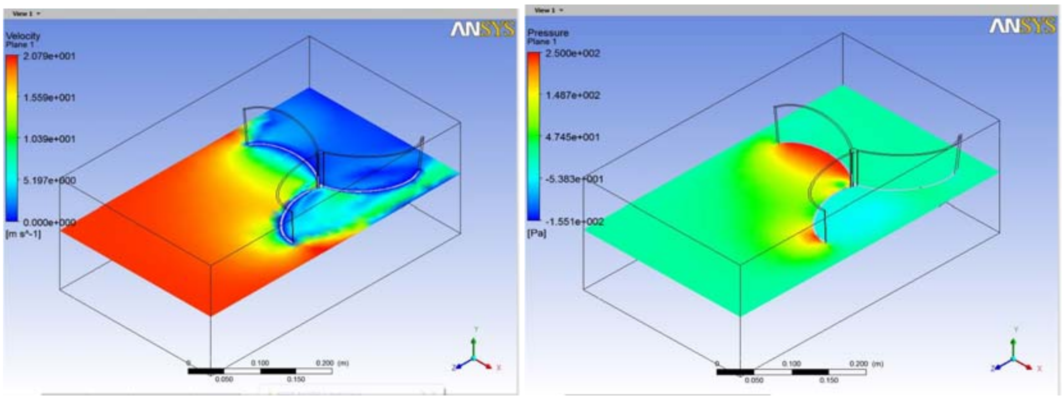

Fig. 5. The velocity and the resulted pressure in the blades area as estimated by Ansys

There is also another important conclusion that can be stated, related to the pressure distribution over the rotor blades, as illustrated in Figure 6.

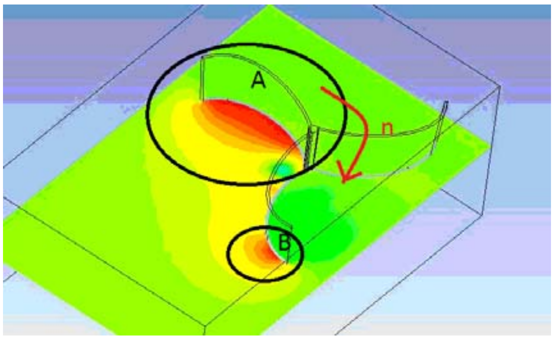

Fig. 6. Pressure distribution over the blades (Ansys)

As it is possible to observe from Figure 6, the rotation sense is from left to the right, with the rotary speed n. The detail marked with A in the figure represents the area were the pressure distribution is positive, in the sense that the efficiency of the turbine is significantly increased in this way, because the pressure is applied in the same direction to the rotation sense. The detail marked with B in the figure represents the area were the pressure distribution is negative, due to the fact that there are being applied pressures in the opposite sense, trying to break down the rotor while running. In order to have an efficient functioning of the rotor, it is obligatory that the value of the pressure being applied on the surface of the rotor blade in the A area will be higher as compared to the ones being applied in the B area. In this way, the power ratio will be significantly increased, as well.

In order to determine the power ratio, several calculus needs to be made, as presented below:

-Calculus of the forces F applied on every blade, using formula:

$$F = A * p \text{ [N]} \qquad (1)$$

where A is the blade area in [mm^2] and p is the pressure being applied on the area, in [Pa];
-Calculus of the moments M that are applied for the calculated forces, on every blade, using formula:

$$M = F * l \text{ [N*mm]} \qquad (2)$$

where l is the distance between the applying force point to the propeller rotor axis, in [mm];
-Calculus of the resulted moment M_{res}, using formula:

$$M_{res} = M_{positive} - M_{negative} \text{ [N*mm]} \qquad (3)$$

where $M_{positive}$ is the moment calculated for the A area (Figure 6), and $M_{negative}$ is the moment calculated for the B area (Figure 6), in [N*mm];
-Calculus of the power ratio coefficient, P, using formula:

$$P = \frac{\pi * M_{res} * n}{30 \cdot 10^6} \text{ [kW]} \qquad (4)$$

where n – is the rotary speed in [rot/min].

The power ratio coefficient will be maximum if the value of M_{res} will be maximum and the rotary speed of the wind turbine will be maximum, as well. The rotary speed n can be easily calculated using formula:

$$n = \frac{1000 \cdot V}{\pi \cdot D} \text{ [rot/min]} \quad (5)$$

where V represents the maximum velocity in the blade area, in [mm/min] and D represents the blade rotor diameter, in [mm].

3. WIND TURBINE ROTOR MANUFACTURED BY SLS

In accordance to the results obtained within the finite element analysis that were made, the best three variants of wind turbine rotors were manufactured from Polyamide PA6 material, using the Sinterstation 2000 equipment at the Technical University of Cluj-Napoca, Romania (see Figure 7). The technological parameters that were used within the SLS manufacturing process (laser power, scanning speed, building temperature, layer thickness) are briefly presented in Table 1.

Table 1.
Technological parameters used within the SLS manufacturing process

Laser power [W]	Scanning speed [mm/s]	Building temperature [°C]	Layer thickness [µm]
5	1257	170	100


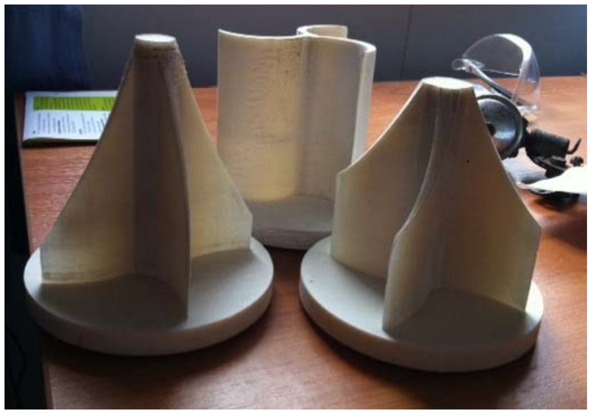

Fig. 7. The wind turbine rotors manufactured using the Sinterstation 2000 equipment (at the Technical University of Cluj-Napoca, Romania)

4. CONCLUSIONS

In conclusion of our research, we could state that the finite element analysis program Ansys has proved to be a very useful tool, in order to design the wind turbine rotor with a higher efficiency and a higher performance, as well. Several variants of wind turbine rotors were designed, by taking into account the geometrical factors that has a significant influence over the power produced by the turbines, such as the profile of the rotor blades, the number of the blades, the delay between the blades, etc. On the other hand, as it was proved by the finite element analysis that was done, there are other factors that have a significant influence over the wind rotor performances, such as the wind velocity or the pressure being applied on the surface of every blade. The power ratio coefficient will be maximum, if the value of resulted moment M_{res} will be maximum and the rotary speed of the wind turbine will be maximum, as well, at the end. The best three variants of wind turbine rotors were manufactured from Polyamide PA6 material, using the Sinter station 2000 equipment, and will be experimentally tested also, in the near future, at the Technical University of Cluj-Napoca, Romania.

5. ACKNOWLEDGEMENTS

This paper was supported by the European Social Fund through POSDRU Program, DMI 1.5, ID 137516 PARTING.

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Analiza cu elemente finite in vederea estimarii eficientei rotorului unei turbine eoliene

Rezumat: In cadrul acestui articol sunt prezentate cateva aspecte importante legate de cercetarile care au fost efectuate de catre autori in domeniul proiectarii si fabricarii rotoarelor pentru turbine eoliene in cadrul Universitatii Tehnice din Cluj-Napoca. In acest sens mai multe variante de astfel de turbine au fost proiectate cu ajutorul programului SolidWorks, fiind analizate ulterior prin metoda analizei cu elemente finite cu ajutorul programului Ansys in vederea realizarii compararii acestora din punct de vedere al eficientei si perfomantelor pe care aceste turbine le ofera. Prototipurile selectate au fost fabricate prin sinterizare selective cu laser cu ajutorul echipamentului Sinterstation 2000 care exista in cadrul Centrului de Fabricatie Rapida Inovativa de la Universitatea Tehnica din Cluj-Napoca, Romania. In ceea ce priveste eficienta acestor turbine, exista o serie de parametri geometrici care influenteaza puterea realizata de acestea, cum ar fi profilul geometric al palelor de rotor, numarul palelor, etc. Pe de alta parte insa exista o serie de factori ce tin de procesul de fabricatie al rotoarelor sau care sunt strans legate de proprietatile vantului (viteza vantului, directia vantului, etc). Toate aceste aspecte au fost luate in calcul in cadrul procesului de proiectare al rotorului turbinei eoliene, astfel incat varianta conceputa si realizata in final sa poata fi adaptata cu usurinta regiunii noastre din Transilvania, Romania.

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