TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 65, Issue Special IV, December, 2022

3D POSITIONING DEVICE FOR SIMULATING THE OPERATION OF WIND SYSTEMS

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Abstract: *In the paper, the authors present an experimental stand for simulating the operation of two types of wind turbines (with vertical axis - VAWT and horizontal axis - HAWT). The experimental stand allows the generation of the numerically controlled current flow on 3 axes so that the experimental model is as close as possible to the real model. The six experimental models of wind turbines proposed for the study were made using Rapid Prototyping technologies. The paper aims to determine the most efficient profile of wind turbines, for the same current flow, given the efforts of specialists to find new approaches to obtaining renewable energy.*

Key words: *Additive manufacturing, fused deposition modelling, green energy, 3D positioning device, rapid prototyping, wind systems*

1. INTRODUCTION

Renewable energy comes from natural resources that are constantly renewing themselves in relatively short time frames. Currently, the functioning of the world economy relies mostly on energy from non-renewable resources (coal, oil, natural gas). Factors such as greenhouse gas emissions that favour global warming, pollution, acid rain, all due to the use of these conventional resources, but also alarm bells that draw attention to the fact that oil – the main source of fuels for transport – is about to be depleted, have triggered a process of significant investments at the global level to value renewable energy resources. Renewable energy sources can be grouped into five categories: solar, wind, aquatic, geothermal and biomass. The category "aquatic sources" includes energy obtained from rivers and oceans. All these sources of energy, except the geothermal ones, exist because of the sun's energy. Biomass is made up of vegetal substances, which have absorbed some of the solar energy following photosynthesis. Rivers feed on rains, the latter occur due to evaporations on the surface of oceans and lakes, under the influence of solar heat. The wind is formed as a result of the uneven heating of the Earth's surface by the Sun. Geothermal energy is the energy of underground heat.

The main advantage of wind energy is the zero emission of pollutants and greenhouse gases, due to the fact that no fuels are burned, no waste is produced and the costs per unit of energy produced are reduced. Unlike nuclear power plants, for example, where decommissioning costs can be several times higher than the plant's costs, in the case of wind generators, the costs of decommissioning, at the end of the normal period of operation, are minimal and can be fully recycled [1-2, 4-8].

The main disadvantages are: the relatively limited energy resource, the inconstancy due to the variation in wind speed and the small number of possible locations [1-2, 4-8].

2. MATERIALS AND METHODS

Due to the differentiated heating of the Earth's atmosphere by the sun as well as due to the Coriolis force associated with the rotational motion of the Earth, large movements of the air masses occur, which leads to the classification of wind energy as an indirect form of solar energy. It goes without saying, therefore, that the distribution of wind energy is uneven from one region to another. Analyzing the movement of air currents vertically, the speed of air currents gradually increases with height, until they stabilize at an altitude that can reach up to about 2000 m.

Due to the frictional forces and the geometric unevenness of the land and various constructions, near the Earth's surface the speed decreases significantly. The factor z_0 [m] of terrain roughness is taken into account, which represents the theoretical height up to which the wind speed is zero. Figure 1 shows roughness factor values for various types of land and buildings.

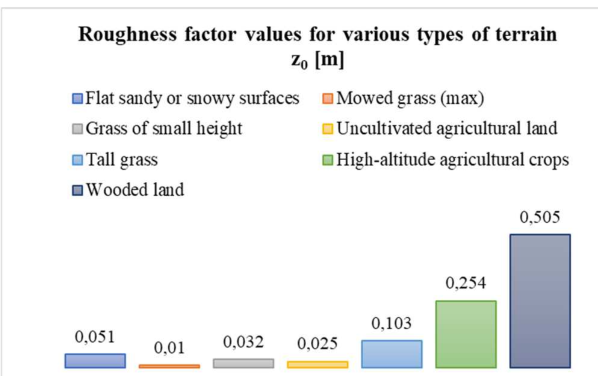

Fig. 1. Roughness factor values for various types of terrain

In the case of localities, suburbs or cities this factor exceeds the value of 1 and can reach even up to 4.

Also, z_0 can be calculated directly if measurements of the wind speed at two different heights are made simultaneously and the following law applies:

$$lnz_0 = \frac{v_1 \cdot lnz_2 - v_2 \cdot lnz_1}{v_1 - v_2} \quad (1)$$

where v_1 and v_2 represent the measured wind speeds at heights z_1 and z_2 respectively [1].
In order to capitalize on the wind resource, it is of interest to know the variation of the wind speed up to a maximum height of 150 m in relation to the land surface. The law of speed variation is defined by the relation:

$$v_1 = v_2 \cdot \left(\frac{z_1}{z_2}\right)^a \quad (2)$$

Constant *a* is Hellman's exponent and depends on the stability of the air, the type of land surface, the time of day and the season, the temperature and roughness of the surface. Some examples of the values of Hellman's exponent are shown in figure 2. Its value can be calculated with the following logarítmica relationship:

$$a = 0{,}096 * lnz_0 + 0{,}016 * (lnz_0)^2 + 0{,}24 \quad (3)$$

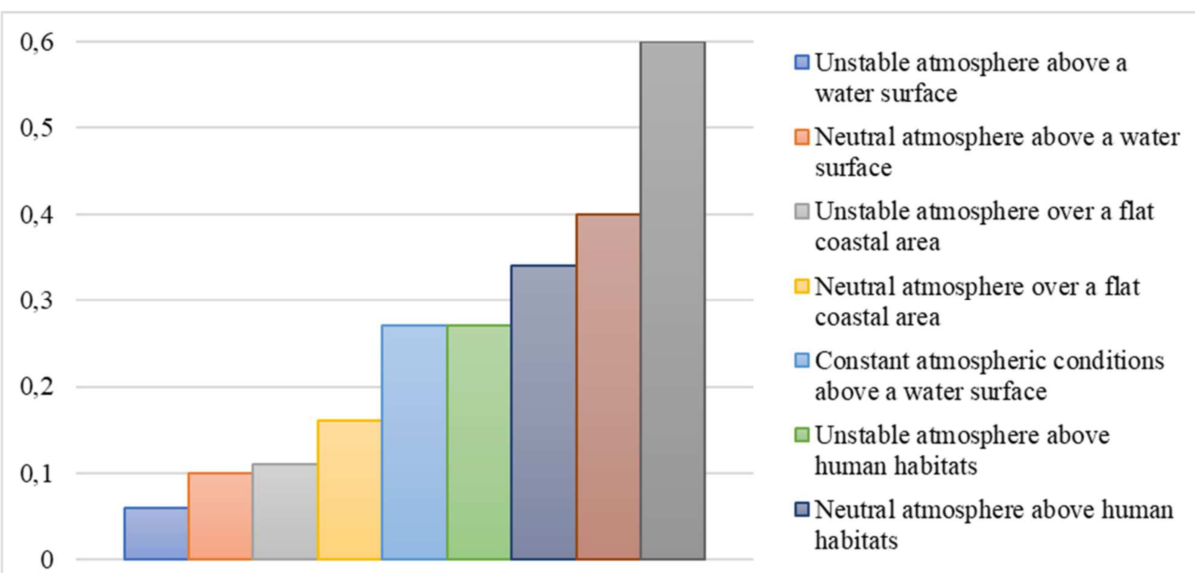

Fig. 2. Example values of Hellman's exponent for different cases

Depending on the orientation of the rotor axis, the turbines can be with horizontal axis and vertical axis. The models with horizontal axis are the most widespread, in turn being classified by the location of the system in relation to the wind (Fig. 3).

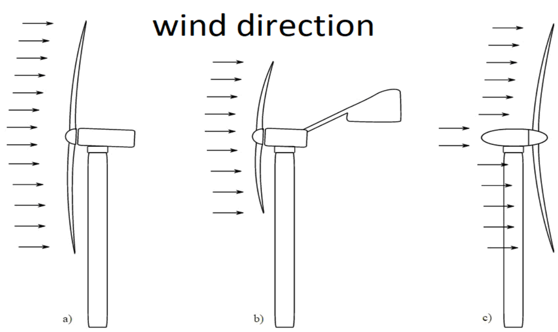

Fig. 3. – (a) upstream location with active orientation system; (b) upstream location with a passive orientation system; (c) downstream location [9]

It is necessary that the stiffness of the blades is higher in order to avoid contact with the tower by bending under the action of air currents. There is also a need for a wind direction orientation system.

Systems with downstream location, when the tower and the nacelle have the first contact with the wind, then the rotor with blades. Unlike the upstream models, the flexibility of the blades may be greater and the orientation system is not required as the nacelle-rotor assembly is self-orienting. These advantages translate into a lower value of the initial investment. On the other hand, however, due to turbulence and loss of wind speed when interacting with the nacelle and the tower, these systems have a lower efficiency. Also, both turbulence and pressure losses behind the tower lead to sudden and periodic variations of the loads in the blades, which require increased resistance to fatigue.

The turbine blades can be made of fiberglass, wood, steel, aluminum or titanium and are up to four, there is also a model with a single blade and a counterweight instead of the paired blade. This particular solution offers the advantage of a lower price. However, among the commercial versions, the cheapest is the two-bladed one, but like the one-bladed model, their noise level is higher. Four-blade rotors are well balanced but have a high mass and lower cost-related efficiency. The compromise solution currently widely used is the three-blade rotor.

The wind turbine converts the kinetic energy of the air flow that crosses the rotor-baled area into mechanical energy and then, with the help of the generator, into electrical energy. The air flow yields only a part of the kinetic energy the rest of the energy is consumed in order for the air to leave the flow-turbine interaction zone.

In Fig. 4 it is schematically presented an air flow with the initial velocity v_0, which crosses the circular area A_0 and interacts with the rotor of the turbine with the baled area A_1. In section A_1, the airflow meets a resistance, the pressure increases, and the velocity decreases to v_1. By succumbing some of the energy, the airflow leaves the turbine at a speed of v_2 less than v_1. Since the air mass passing through sections A_0, A_1 and A_2 remains constant and the speed has decreased, it follows that $A_2>A_1>A_0$, in other words, the effect of distorting the air flow that runs through the turbine rotor occurs, forming a funnel [2].

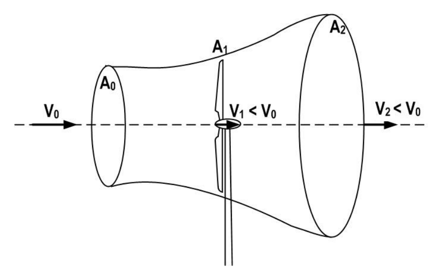

Fig. 4. The effect produced by the wind turbine on an air flow [2]

From this point of view, figure 5 presents the most widespread concepts that exist today.

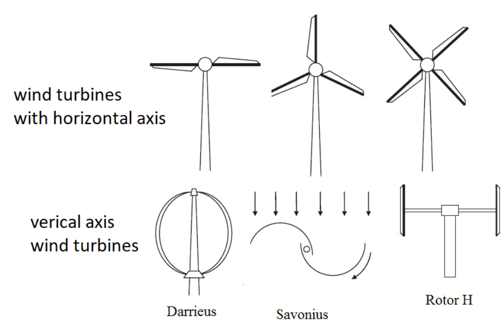

Fig. 5. Types of wind turbines, according to the orientation of the rotor axis: the upper row – with horizontal axis; lower row – with vertical axis [2, 10-11]

The construction of vertical axis turbines is simpler, given that both the transmission and the generator can be located at ground level. Also, most of the constructive variants involve the placement of a rotor support bearing at ground level. These characteristics are reflected in easier maintenance compared to horizontal axis turbines. Another advantage is that a wind orientation system is not required, as it works regardless of its direction, which recommends them to be used in areas with frequent variations in wind direction [1-2, 4-5].

In the paper are presented different types of constructions of wind turbines with vertical and horizontal axis, made on Delta 3D printers and Cartesian 3D printers [3].

The Darrieus turbine is characterized by the C-shaped palettes, which have the ends attached to the axis at the top and bottom of it. As variants of this concept can be found H rotor turbines with vertically arranged blades (Gyromill turbines), straight or helical. A specific advantage of these turbines is that the peripheral speed of the blades is higher than the wind speed, even compared to horizontal axis turbines, which makes them suitable for power generation applications. The Savonius turbine has a very simple construction that consists of two half-cylinders arranged in the shape of the letter S, with a space for passing air between them [1-2, 4-5].

Fig. 6. Different types of wind turbines with horizontal and vertical axis, made on 3D printers

Fig. 7 shows the constructive principle of these turbines and the main dimensions, including the overlap S between the two semi-cylinders and their diameter d, as well as the angle of attack α. Unlike the other types, the operation of Savonius turbines is not based on the load-bearing force that manifests itself on an aerodynamic profile, but on the resistant force generated when moving a body in a stream of air. The difference in traction between the two semi-cylinders oriented differently from the direction of movement of the air gives rise to an engine torque, which, however, varies significantly with the angle of attack, there being a position where the system is in equilibrium, i.e. zero engine torque.

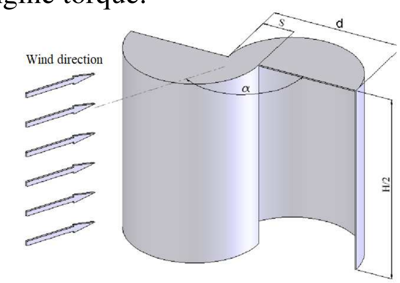

Fig. 7. The constructive principle of Savonius turbines

The horizontal axis turbines that have in the nacelle component, with the transmission and the generator and the rotor located at the top of the support tower, which raises the complexity of the construction and of the maintenance process in relation to the vertical axis turbines. It develops a low starting torque and the nominal wind speed is usually between 10 and 15 m/s. The horizontal axis turbine solution is also preferred for residential applications of several kilowatts. Regardless of the nominal capacity, from the point of view of location in relation to the wind direction, the turbines with the rotor arranged upstream predominate. For higher wind speeds we must limit the mechanical power, respectively the overloads on the rotor blades, multiplier, generator, tower, etc. Thus, there is a need to control the turbine power, and the most widespread methods that control are the following:

- passive aerodynamic braking
- adjusting the angle of attack
- passive aerodynamic braking
- removing the turbine rotor from the direction of wind action [1-2, 4-5].

3. RESULTS AND DISCUSSIONS

In the paper, the authors have proposed the realization of an experimental stand that would allow the numerically controlled movement of a general air flow by a fan in the XYZ plane, in order to simulate as correctly as possible the air flow from nature, on some demonstration models of wind turbines more often used in practice. The main purpose of the research is to validate the 3D printing technology for prototyping in the field of simulation of wind systems and to compare the performance of different types of geometries for turbines based on the developed in the paper experimental stand and the realized turbine models. In the specialized literature, there are studies on the use of 3D printing for the realization of wind turbines, which are based more on the development, simulation and testing of a certain wind turbine model [12-15]. Basically generating a constant air flow, and measuring with the help of a digital tachometer, model AX 2234C (figure 8) the number of rotations made by wind turbines can be concluded the choice of the most suitable model of wind turbine for a certain geographical area.

The tachometer used has a measuring range between 2.5-99999 rpm and an accuracy of ± (0.05%), LCD display, with a photoelectric and anti-interference technology to be able to accurately measure the rotation speed.

Demonstration models of wind turbines were made using Rapid Prototyping technologies, the FDM process, (Fused Deposition Modeling), a thermoplastic extrusion process, an object can be built by selectively deposition of the molten material in a predetermined layer-by-layer form, using Delta type type printers and 3D printers with Cartesian mechanism (figure 10) depending on the dimensions and gauge of wind turbines. The materials used are thermoplastic polymers in the form of filaments with a diameter of 1.75 mm, in all cases it was used as printing material PLA (polylactic acid), a biopolymer, a biodegradable plastic material. It is made from renewable raw materials such as cornstarch or sugar cane, more fragile than ABS, but has a higher surface hardness, having a low melting point, 180-190°C and tensile strength 2.7-16 GPa [3].

Fig. 8. Digital tachometer, model AX 2234C used to determine the number of rotations of printed wind turbines

Fig. 9. Example of fastening bearings to the axis of printed wind turbines

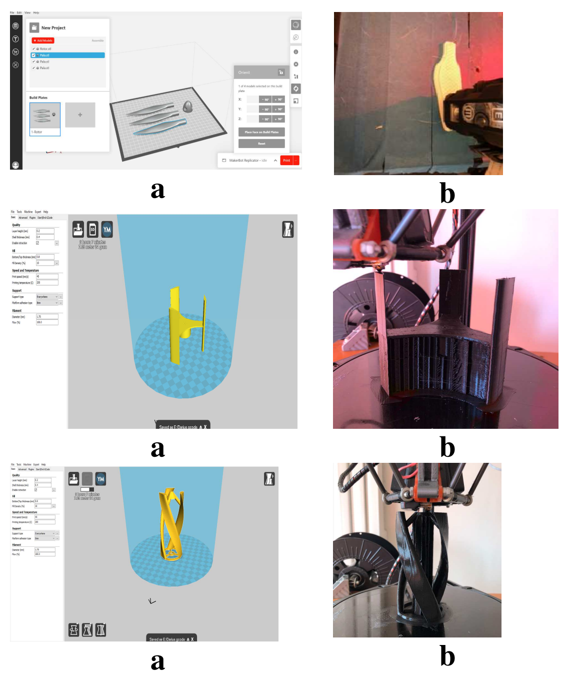

Fig. 10. Realization on 3D printers of demonstration models of wind turbines
a-program interface 3D printer; b- printed wind turbine models

For fixing all the demonstration models obtained with the help of additive technologies [3], the same type of radial bearing was used for all types of wind turbines studied, the rotor of wind turbines being fixed in the bearing, there being no additional transmissions and friction forces at the multiplier and generator, figure 9.

The experimental stand is designed to be able to direct in the XYZ plane the position of the fan and implicitly of the air cone 1 by means of numerically controlled stepper motors. For the positioning on the OX and OZ axes of the air cone, where there are no high drive forces, 8 mm guide axes and corresponding linear bearings were used, the displacement being achieved by means of a transmission with a toothed belt.

In the case of the OY axis, due to the weight of the experimental stand, a transmission with

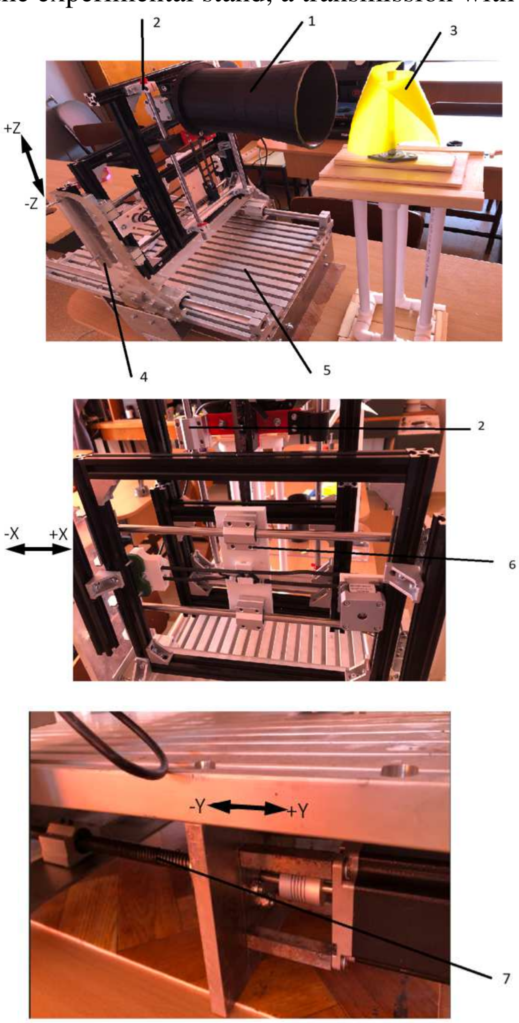

Fig. 11. 1- the fan mounted in the air cone; 2- Z axis; 3- printed model of the wind turbine; 4- traverse the Y axis; 5-platform; 6-axis Y-axis with guides and linear bearings; 7 – X-axis;

trapezoidal screw and guide bars with a diameter of 22 mm and linear bearings of 22 mm was used. The experimental tests aimed at determining the best constructive solution for a wind turbine demonstration model with horizontal axis or vertical axis, in the conditions of a simulated wind, constant throughout the experiment (figure 12)

All simulations took place under the same conditions: the same simulated wind power, the same axis distance from the source. The duration of the experimental simulation was for all cases of 5 minutes, in which with the help of the tachometer were determined for each case the average speed, but also the maximum speed obtained in the 5 minutes. Figure 13 presents the results of the experimental researches, in which it is observed that the most efficient turbine can be called the one from the model 2 obtaining an average speed of 872.7 rpm and the maximum one of 1869 rpm (however, a large difference between the average value and the maximum value). Then comes the model 4 with an average speed of 641.7 rpm and the maximum of 962.5 rpm.

Fig. 12. Measurement for different geometries of wind turbines

Models 1 and 3 showed almost similar results, but it can be emphasized in their case that the smallest difference between the average and maximum speed value was obtained, being able to conclude that these models had the most constant behavior without great deviations, an extremely important thing in this field. Model 5 presented the most non-efficient results, and the model 6 could not be set in motion under the conditions studied, it needed a much more powerful energy source.

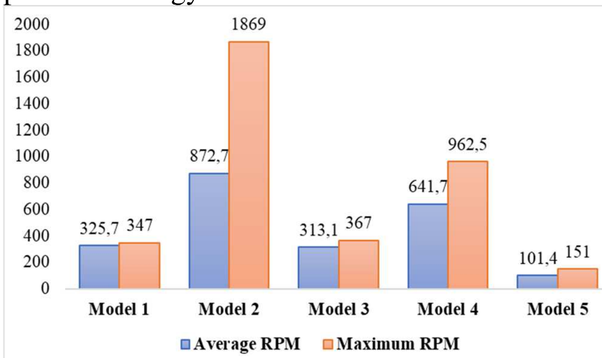

Fig. 13. Results obtained from experiments for different types of wind turbines

4. CONCLUSIONS

The location of wind turbines and their size is a key factor in terms of their acceptance by specialists was one of the reasons why isolated locations were mainly sought and that do not visually affect certain natural landscapes.

In the process of designing turbine blades, the level of noise produced during operation is always taken into account, trying to minimize it. It has been found that the dominant noise, characteristic of turbine operation, is continuous and has frequencies of over 100 Hz, mainly due to the interaction of the blades with the atmospheric turbulence. To all this is added the noise of mechanical origin caused by the operation of the transmission, generator, hydraulic and auxiliary equipment, etc. Among the techniques and methods of reducing noise with frequencies above 100 Hz are the reduction of the peak speed of the blade, lower values of the angle of attack, the placement of the rotor configurations upstream, the implementation of solutions operating at variable rotor speeds, special shapes for the vanboard (the edge behind the blade) and for the tip of the blade. Mechanical noise can be reduced by optimizing mechanical components and their operating parameters, using deflectors and sound insulation of the nacelle, using vibration dampers.

The major wind potential is concentrated on the coasts, on the hills and in the mountains. But there are many other territories with a wind potential required for use. Wind resources depend on the relief of the earth and the presence of obstacles placed at heights of up to 100 meters. That is why the wind depends to a greater extent on the relief than on the sun and the atmospheric conditions [1-2, 4-8, 16].

As a result of the experimental researches, the most efficient wind turbines were determined, building models/ prototypes of them through some available technologies – the additive technologies. These prototypes can be of great use when designing a new model of wind turbine and it is desired to check and test their potential performance, and in addition their manufacture is not expensive.

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DISPOZITIV DE POZIȚIONARE 3D PENTRU SIMULAREA FUNCȚIONĂRII SITEMELOR EOLIENE

În lucrare, autorii prezintă un stand experimental pentru simularea funcționării a două tipuri de turbine eoliene (cu ax vertical - VAWT și ax orizontal - HAWT). Standul experimental permite generarea fluxului de curent controlat numeric pe 3 axe astfel incat modelul experimental să fie cât mai aproapiat de modelul real. Cele două modele experimentale de turbine eoliene propuse pentru studiu au fost realizate folosind tehnologii de prototipare rapidă. Lucrarea își propune să determine cel mai eficient profil al turbinelor eoliene, pentru același flux de curent, având în vedere eforturile specialiștilor de a găsi noi abordări pentru obținerea de energie regenerabilă.

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