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Training Kit Learning on the Operation of a Horizontal Axis Wind Power Generator

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Abstract: Wind power is currently used mainly to produce electricity by wind turbines. The environmental impact generated by such energy is less problematic compared to other energy sources, and it is also an abundant and renewable resource that helps reduce dependence on fossil fuels and reduce greenhouse gas emissions. For this reason, it is of great interest to design and build teaching materials so that students of different academic levels can understand the importance of using energy through this resource. With the above, the need to raise awareness and promote the learning of the behavior of the wind resource and the operation of wind turbines becomes evident. For this reason, a didactic kit was developed that will provide an easy and interactive method to identify the parts of a horizontal axis wind turbine, as well as its operation. The kit is made up of a scale wind turbine, its blades were made using the NACA-4412 aerodynamic profile using the Solidworks CAD tool and made by 3D printing, a fan with variable speeds that simulate a wind tunnel and two LEDs that They will be turned on by spinning the rotor with the air stream generated by a fan. In addition, a manual is included with a series of practices that cover topics ranging from the operation and recognition of the equipment to calculations of wind potential, calculation of generated power and the power coefficient, among others. The wind training kit is expected to reach public and private schools in order to help develop students' abilities and guide them to follow an environmental culture with knowledge about clean and renewable energy sources.

Key words: wind energy, wind turbines, didactic kit, wind potential, renewable energy

1. Introduction

With the growing awareness of caring for the environment and its resources, as well as concerns about the inevitable depletion of fossil fuels, alternative energy has taken a leading role globally. Teaching how these alternative energy sources work is very important to student development. The problem with teaching is that on some occasions there is a lack of didactic material that reinforces the knowledge learned. Taking this idea, a functional wind generator was designed to scale, with which students of secondary education and higher education can learn about wind energy in a more palpable way, using laboratory practices that reinforce their learning on the subject.

2. Methodology

The methodology that was followed to design and scale the wind turbine blades is presented below.

2.1 Electric Generator Selection

A JOHNSON PC357XLG DC electric motor has been chosen to serve as a generator. The voltage ranges from 3-15 V and its amperage is 30 mA. The LEDs to light require approximately 20 mA and 1.5 V, these will be connected in a series circuit.

2.2 Rotor Design

The device that will spin the JOHNSON PC357XLG electric motor is the rotor. For its design, it is based on the average power of the electric motor and the average wind speed of the fan, whose value is approximately 3

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m/s. For the calculations, a standard air density of 1.225 kg/m^3 (air density at 1 atm pressure and at T = 15°C) is considered.

2.3 Airfoil and Design Features

There is a wide variety of aerodynamic profiles. The best known are NACA profiles. These have undergone a lot of changes and now the new profiles are indicated with more than 5 digits. In addition to NACA profiles, there are other types of standard profiles such as the American series SERI or LS, designed specifically for aero turbines, as well as those of the Swedish Aeronautical Institute (FFA).

The conventional profiles used in wind generation are those of the NACA230XX and NACA44XX series, which have L/D aerodynamic performance values between 100 and 120, with operating support coefficients of 1.0 to 1.1 [1]. The airfoil selected for the rotor blades is NACA-4412 (Fig. 1), although the other types of profiles can be used.

To establish the design characteristics of the aerodynamic profile, it is important to define the forces acting on it. The bearing force and the drag force are a function of the Reynolds number, defined in Eq. (1) as

$$Re = \frac{\rho v c_{\mathrm{av}}}{\mu} = \frac{v c_{\mathrm{av}}}{\nu} \quad (1)$$

where

c_{av} = Average chord length, in m.

v = Average wind speed, in m/s.

ρ = Standard wind density, in kg/m^3.

μ = Dynamic viscosity, in N s/m^2.

ν = Kinematic viscosity, in m^2/s.

Considering that the kinematic viscosity of the air at 15°C is 1.47×10^{-5} m^2/s and assuming an average chord of 0.012 m, we will have that the Reynolds number will be 2448.98, approximately. The following values were extracted from the "Airfoil Tools" website. The Reynolds number to be taken into account for the design characteristics will be 50 000 due to the intervals provided by the website. Based on the above, it was found that Re = 50 000, the

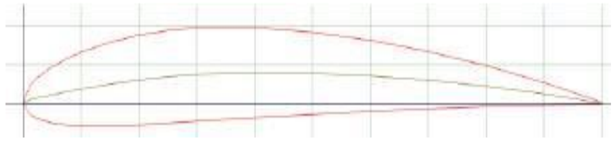

Fig. 1 Airfoil NACA-4412.

mínimum and maximum C_L/C_D ratio are 0.03 and 33.45, respectivelly, are obtained when the angle of attack α is equal to 9.75°. For this angle, C_L is equal to 1.32.

2.4 Number of Blades and Design Power Coefficient

To define the number of blades, B, that the rotor will have, it must be taken into account that the relationship between the speed at the tip of the blade and the wind speed, λ_0, is between 5 and 8, since the best results are obtained from this area values for the power coefficient, C_P [2], based on this, the parameters λ_0 and B were defined. $\lambda_0 = 6$ and the corresponding number of blades were considered as $B = 3$.

Subsequently, the power coefficient C_P as a function of λ_0 was determined based on graphs showing the effect of the C_D/C_L ratio on 3-blade rotors. For $\lambda_0 = 6$, the maximum power coefficient C_{Pmax} is approximately 0.41 and, considering an efficiency of 80%, the design C_P turned out to be 0.328.

2.5 Rotor Diameter and Angular Speed

The formula to calculate the radius, R, of the rotor is given by Eq. (2) as

$$R = \sqrt{\frac{2P}{\pi \rho v^3 C_p}} \quad (2)$$

where:

P= Alternator rated power in W.

ρ = Standard wind density in kg/m^3.

v = Average wind speed in m/s.

C_p= Design power coefficient.

Substituting the data into Eq. (2), we obtain that the radius will be 0.051 m, so the rotor diameter will be 0.102 m and the área, A, will be 0.033 m^2. Now we proceed to calculate the angular speed of the rotor starting from Eq. (3)

$$\lambda_0 = \frac{\Omega R}{v} \quad (3)$$

where:

λ_0 = Ratio between tangential speed at blade tip and wind speed.

Ω = Rotor angular speed in rad/s.

R = Rotor radius in m.

v = Average wind speed in m/s.

Solving Ω from Eq. (3) and substituting the known data, we have that the angular velocity is 352,941 rad/s. For convenience, rad/s to rpm conversion was performed, resulting in 3,370.34 rpm.

2.6 Blade Geometry

For the geometry of the rotor blades, Eqs. (4)-(6) [2] and the relations $\phi - \lambda r$ are used for the design of rotors.

$$\lambda_r = \lambda_0 \frac{r}{R} \quad (4)$$

$$c = \frac{8\pi r}{BC_L}(1 - \cos\phi) \quad (5)$$

$$\beta = \phi - \alpha \quad (6)$$

where:

λ_r = Local ratio between tangential speed at r and wind speed.

r = Distance from the center of the rotor to a radius "r", in m.

R = Rotor radius, in m.

c = Blade Section chord.

ϕ = Wind apparent angle.

β = Angle formed by the blade with the plane of rotation.

Table 1 was created from the previous data, which contains the values that will be used in the design of the blades.

Table 1 Design parameters.

r(m)	λ_r	ϕ	1-cos(ϕ)	α	C_L	β	c(m)	1/4c (m)
0.0051	0.60	39.5420	0.2302	9.7500	1.3200	29.7920	0.0075	0.0019
0.0102	1.20	26.6184	0.1064	9.7500	1.3200	16.8684	0.0069	0.0017
0.0153	1.80	19.4060	0.0569	9.7500	1.3200	9.6560	0.0055	0.0014
0.0204	2.40	15.1104	0.0346	9.7500	1.3200	5.3604	0.0045	0.0011
0.0255	3.00	12.2900	0.0229	9.7500	1.3200	2.5400	0.0037	0.0009
0.0306	3.60	10.3596	0.0163	9.7500	1.3200	0.6096	0.0032	0.0008
0.0357	4.20	8.9330	0.0121	9.7500	1.3200	-0.8170	0.0028	0.0007
0.0408	4.80	7.8488	0.0094	9.7500	1.3200	-1.9012	0.0024	0.0006
0.0459	5.40	6.9980	0.0075	9.7500	1.3200	-2.7520	0.0022	0.0005
0.0510	6.00	6.3080	0.0061	9.7500	1.3200	-3.4420	0.0020	0.0005

2.7 Geometric Design of the Blades

Based on the information in the previous section, the geometric values were established at different points along the radius of the blade that defined its physical shape. For this, it was established that the rotor radius R will be 0.051 m, for an average power of 270 mW.

The Soliworks CAD tool was used to define the geometry of each of the ten previous sections and thus be able to develop the 3D model (Fig. 2). The angle of attack α is measured with respect to an axis located a quarter of the cord measured from the leading edge.

2.8 Rotor and Hub

The rotor of a wind turbine is formed by locating the blades around a common axis that is called a hub. The hub design should have less resistance to the air flow generated by the fan. According to Wang (2003) [3], he experimentally verifies that the elliptical curve is the one with the highest efficiency in the design of small

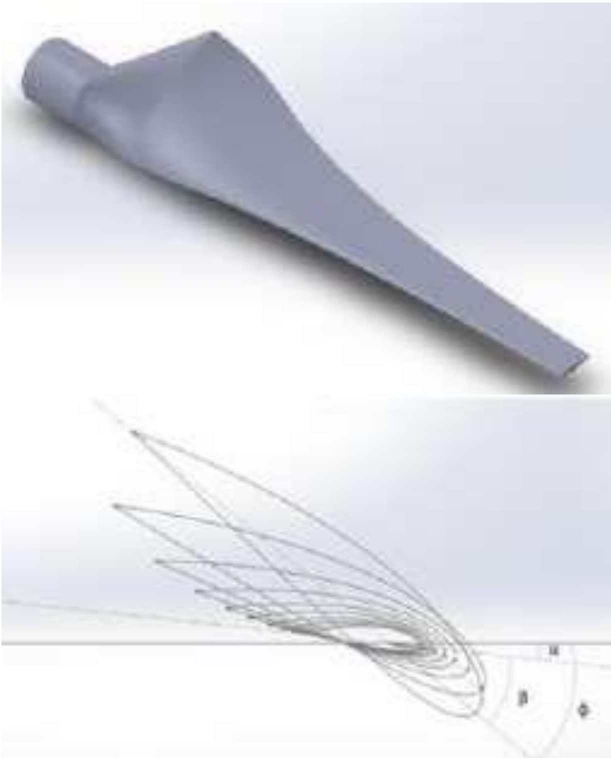

Fig. 2 3D design: isometric view and aerodynamic profile angles for each blade section.

turbines, for which reason this curve has been selected for the hub design.

2.9 Blade Manufacturing

The blades were manufactured with the help of a 3D printer that operates by casting ABS filaments to form overlapping layers whose final result is the desired figure.

3. Conclusions

Having didactic material to support the teaching of the principles of wind energy is of great help to capture the attention of the students. The prototype of the kit was presented at the end of the Fluid Mechanics course in front of the group, the reactions of the students were of interest in the topic once the kit was shown. The students began to ask questions about its operation and the principles of wind energy, thus achieving the stated objective that the kit would help learning the subject of Wind Energy.

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