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An Experiment on the Electric Energy Performance of the Wind Turbine Rotors

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Abstract: First of all 270 sets of miniature wind turbine rotors with different properties were produced by using some NACA profiles. The produced 270 sets of rotors of different forms were tested in a wind tunnel. During the test, the electric voltages and the electric currents that each rotor form generated under different wind speeds were measured. Then the performance of each rotor form was laid down in view of such measurements. The rotor form made of NACA 4412 profile, with two blades, which are coupled to the rotor with a twisting angle of 0° and a blade angle of 5° was defined as the rotor form yielding the highest performance. The energy which was generated by this rotor form was 161,73 mW.

Key words: Wind turbine, rotor blade, electric energy performance

INTRODUCTION

Energy is the most important power on the earth. But the electric energy that is produced on the earth causes environmental problems of which reason lies at its source. Nowadays has come to use such energy sources, which are clean and sustainable.

While investigating solutions for the energy problem, some sectors should also consider the alternative to demand less energy from the national energy network by producing their own energy, rather than producing more. In view of this, small and medium size operations could produce their own energy in order to meet their energy requirement.

Clean and sustainable energy sources by which small and medium size operations could produce their own energy are miscellaneous. One of those energy sources is the Wind Energy.

The installation cost of giant wind turbines that are intended and designed to generate electric energy is very high therefore small and medium size operations could hardly afford it. For this reason, high-performance wind turbines that could be afforded by small and medium size operations must be developed[1].

Attaining a high performance from a wind turbine depends on a variety of factors. Among such factors are the height of the wind turbine and the rotor area. Still another one is the blade structure. The factors as the turbine height and the rotor area shall require a larger turbine size. This in turn will directly influence the cost. But optimisation of the blade structure shall not require any increase in size and thus its cost will be low.

Nomenclature

λ : tip speed ratio
B : number of blades
C : tip chord width (m)
D : rotor diameter (m)
A : rotor cross section area (m^2)
d : rotor diameter (m)
N : electric energy generated by electro motor (mW)
U : electric voltage produced by electro motor (V)
I : electric current produced by electro motor (mA)

MATERIALS AND METHODS

Blades: The blades that were used during the tests are made of "Balsam" (Fig. 1) tree with a considerably low strength and with a density of 0.075 g cm^{-3} [1]. The blades are designed with a rotor diameter of 310 mm and a hub diameter of 48 mm (the component at the centre of the rotor that conveys to the blades the wind incoming to the rotor centre) and a blade length of 130 mm (Fig. 2).

The guidelines that are recommended by NACA were considered in selecting blade profiles[2].

The number of blades of the blade profiles used during tests as well as their tip speed ratios could be computed by the following equation (3):

$$\lambda = \sqrt{\frac{80}{B}} \qquad (1)$$

When the number of blades used during test is taken two, three and four in the above equation, the tip speed ratios shall be as follows:

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B = 2 ..... λ = 6,325
B = 3 ..... λ = 5,164
B = 4 ..... λ = 4,472

The other dimensions of the blades could be found by the computed λ values[3].

$$C = \frac{4.D}{\lambda^2.B} \qquad (2)$$

For each λ and B value, blade width is found 15 mm at the tip. The blade width value at root is not of much significance. Only, the value at the end must be higher than the one at the tip[3]. Therefore the root value is taken 30 mm for the purpose of this study.

The other characteristics of the blades that were used in the test are defined by assigning to them the “Form Code Numbers”. These characteristics are six different NACA profiles (Fig. 3) the blade angle, the twisting angle of blades and the number of blades on the rotor. The profiles used are NACA 0012, NACA 4412, NACA 4415, NACA 5317, NACA 23012 and NACA 23015. On the other hand, the values that were taken as the blade angles are 5, 8, 10 and 15° whereas 18 and 0°, 10 and 20° are the values that were taken as the twisting angles of blades. Rotors with two, three and four blades were used. Number of rotor forms, which were created by means of the combination of these values is 270.

Electro motor: The RPM-Energy correlation of the electro motor that was used in the tests is depicted in Fig. 4 [4]. The main characteristics of the motor are as follows[5]:

- Miniature, continuous, magnetic type motor,
- Length 35 mm, diameter 32.7 mm and height 38.6 mm
- Shaft diameter 1.8 mm, shaft length 8 mm
- 2520 rpm at 6 V, 3900 rpm at 9 V and 4900 rpm at 12 V
- Contacts are external and perforated

Test equipment: In this experiment, a wind tunnel in a pipe shape, with an internal length of 2 m, a diameter of 51.35 cm, total height 1.475 m, total width 0.88 m and overall length 2.35 m was used (Fig. 5). On the tunnel fitted a fan with a diameter of 35 cm, at a rated power of 250 W and a speed of 1400 rpm. The system operates under a voltage of 220 V and 50 Hz. Depending on the temperature and the density of the ambient air it is possible to operate the system under a wind speed of 5 ms^{-1}[6].

An anemometer was used in order to measure the wind speed during the tests. The said anemometer also made possible to measure temperature and flow-rate in addition to the wind speed. The resolution of the device was 0.01 ms^{-1} in 0.1°C (Fig. 6).

Two different types of Multi-meter (Fig. 7) were used for the purpose of measuring the electric voltage and the electric current during the tests. These two Multi-meters had the same properties. The standard connecting cables that were used in the Multi-meters were designed considering the circuit to be used in the system. Current was serially connected to the circuit whereas voltage was parallel connected. A resistance of 102.3 Ω was used in the circuit[5].

Wind tunnel tests: The anemometer that was used for the purpose of measuring the wind speed was fitted 20 cm inward of the tunnel exit, where the wind left the tunnel, in a manner to permit a measurement could be done at the centre of the tunnel. With the aim to test the rotors at different wind speeds, the wind speed values of 2, 3 and 4 ms^{-1} were selected. The selected values were the averages of the readings monitored on the anemometer while testing the rotors. The wind speed prevailing at the moment when the rotor to be tested was operated was set by gradually increasing the wind speed on the wind speed panel and then by reading the value on the anemometer.

The electric voltage and the electric current that were generated in the electro-motor during the tests by means of the rotation of the rotor were measured by the test multi-meter under a fixed resistance of 102.3 Ω[7,8].

Calculations about the test blades: The diameter of the rotor used in the tests is 0.311 m. This value is also valid for all other rotors[7]. Assigning the value 0.311 to the equation No.3 shall reveal a rotor cross-section area of 0.07596 m^2. This value was used as a constant in all calculations[9].

$$A = \frac{\pi.d^2}{4} \qquad (3)$$

As a result of the rotation of the rotor with the effect of the wind speed, the electro-motor generated an electric voltage and an electric current under a fixed resistance of 102.3 Ω. The electric voltage and the current were measured by the multi-meter. When these two measured values were assigned to the equation No.4, the value of the generated electric energy was attained[10].

$$N = U . I \qquad (4)$$

RESULTS AND DISCUSSION

The effects of the twisting angle and the blade angle which are made in NACA blade profiles as well as the blade number combinations of the rotor on the generated electric energy were defined. The optimum values found are depicted in Table 1.

Table 1: Performance results of rotor forms

(a) Blade Profile: NACA 0012, Twisting Angle: 10°, Number of Blades: 2;

Blade Angle (°)														
5			8			10			15			18		
Wind Speed (m/s)														
2.0	3.0	4.5	2.0	3.0	4.1	2.1	3.0	4.4	2.0	3.0	4.5	2.1	3.1	4.6
Performance (mW)														
-	-	-	-	-	91.6	10.7	38.0	84.1	4.7	16.3	51.0	2.9	9.1	27.0
(b) Blade Profile: NACA 4412, Twisting Angle: 0°, Number of Blades: 2;														
Wind Speed (m/s)														
1.9	3.0	3.8	2.0	3.0	4.1	2.0	2.9	4.1	2.1	3.1	4.3	2.0	3.0	4.2
Performance (mW)														
13.4	91.7	161.7	12.7	59.2	156.1	4.5	23.8	70.3	1.0	20.9	55.5	0.9	19.6	49.3
© Blade Profile: NACA 4415, Twisting Angle: 0°, Number of Blades: 2;														
Wind Speed (m/s)														
2.1	3.2	3.7	2.1	3.0	3.9	2.0	3.2	4.4	2.1	2.9	4.5	2.3	3.1	4.4
Performance (mW)														
16.2	86.2	145.4	8.5	55.2	139.0	4.0	37.0	97.0	1.0	6.0	33.2	1.2	4.9	23.4
(d) Blade Profile: NACA 5317, Twisting Angle: 10°, Number of Blades: 2;														
Wind Speed (m/s)														
2.0	3.0	4.0	2.0	3.0	4.3	2.3	3.0	4.1	2.1	3.1	4.1	2.2	3.1	4.3
Performance (mW)														
	-	-	-	-	21.1	4.3	11.3	64.5	4.8	28.4	116.6	4.2	18.8	84.4
(e) Blade Profile: NACA 23012, Twisting Angle: 0°, Number of Blades: 2														
Wind Speed (m/s)														
2.0	3.0	4.1	2.1	3.2	4.6	2.0	3.0	4.8	2.0	2.9	4.2	2.2	3.3	4.1
Performance (mW)														
-	-	134.8	5.3	29.7	83.0	3.0	13.5	57.1	2.0	10.7	46.6	1.0	6.4	38.4
(f) Blade Profile: NACA 23015 Twisting Angle: 0°, Number of Blades: 2;														
Wind Speed (m/s)														
2.0	3.3	3.9	2.1	3.0	4.3	2.0	3.0	4.4	2.0	3.2	4.2	2.2	3.2	4.2
Performance (mW)														
-	2.1	132.5	0.3	30.3	101.2	1.7	18.9	72.5	1.1	10.0	50.2	0.9	6.3	33.0

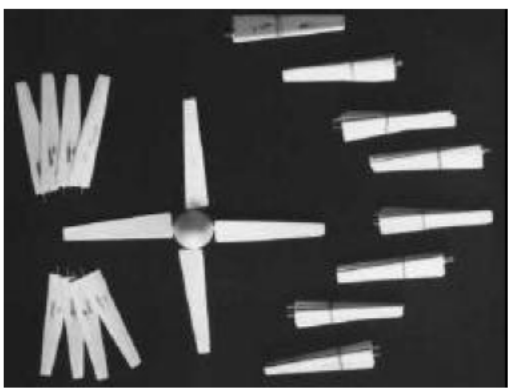

Fig. 1: Blades designed according to the profiles used

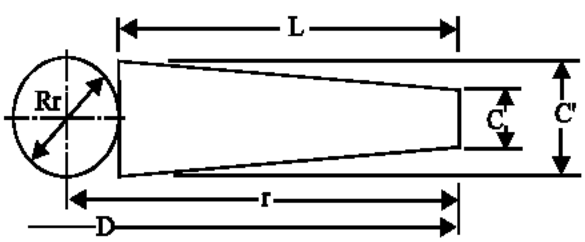

Fig. 2: Rotor blade size

Depending on the results regarding the electric energies, which were generated by different rotor forms, the one that was generated by the rotor made of NACA 4412 profile, having two blades, a twisting angle of 0° and a blade angle of 5° was 161,73 mW. The evaluation that was conducted as for the electric energies generated by different rotor forms revealed that the best rotor was the one defined in the preceding paragraph.

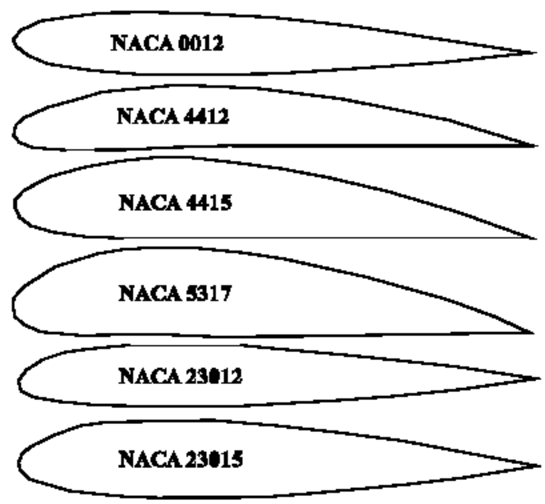

Fig. 3: Blade profiles used

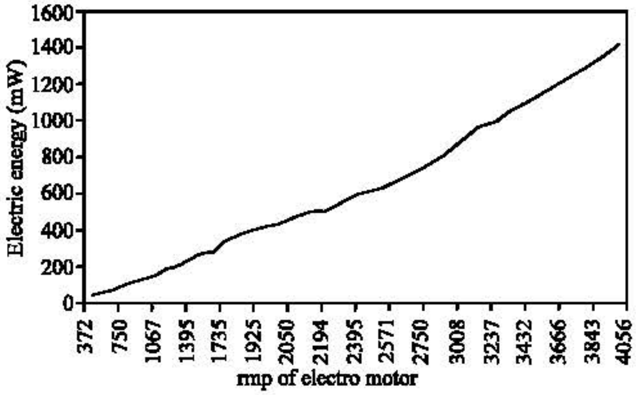

Fig. 4: Correlation between RPM of the electro motor and the electric energy

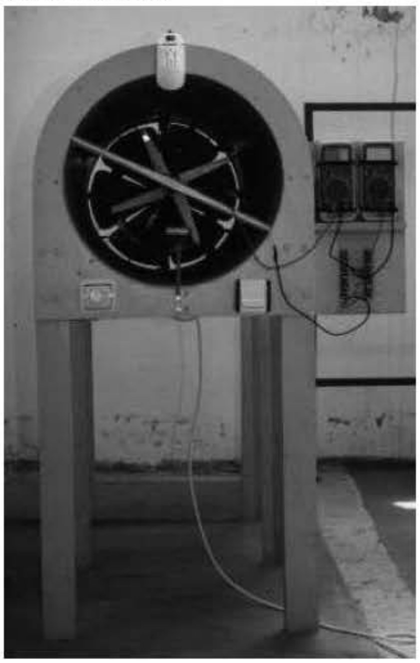

Fig. 5: Wind tunnel

Fig. 6: Anemometer

In this experiment, wind tunnel tests were conducted on 4 groups of turbine blade configurations under different resistances[11]. A performance up to 360 Volts X DC mA under the resistances of 51, 100 and 200 Ω was attained. In this experiment, rotors with 3 blades, with a hub radius of 2.8 cm, a blade radius of 10 cm, a pitch angle of 8° and a twist angle of 0° were used.

Fig. 7: Multi-meter used for measuring the electric voltage and the electric current

Eight different types of rotors were used in this experiment. 6 of these rotors had 3 blades whereas 2 of them had 2 blades[7]. The blade radii of these rotors are between 12.5 and 15 cm. On the other hand pitch angle at hub is between 9 and 21°. The yields attained from these rotors are between 32.0 mW and 576.6 mW.

When the electric energy generated by different rotor forms are considered, we observe that the rotor forms which have generated the maximum energy are those with NACA 4412, NACA 4415, NACA 23012 and NACA 23015 blade profiles, a twisting angle of 0 and 10°, with two and three blades and blade angles of 5 and 8°. The evaluation also reveals that the blades with an electric energy of "0" are more frequently found in the rotor forms with a twisting angle of 20°.

In this experiment, in the modeling designed with the blade profiles NACA 0012, NACA 4412, NACA 4415, NACA 23012 and NACA 23015, the best result was attained with NACA 4412[12]. Also it was concluded in this experiment that the 4 blade rotors yielded better results.

The independent review of the blade profiles reveals that the rotor form, with a NACA 0012 blade profile, a twisting angle of 10°, a blade angle of 8° and having two blades yields the best result.

For NACA 4412 blade profile, the rotor forms yielding the best result are those with a twisting angle of 0°, blade angles of 5 and 8° with two blades.

For NACA 4415 blade profile the rotor form generating the highest electric energy is the one with a twisting angle of 0°, a blade angle of 8° having two blades.

We found that the rotor forms made of NACA 5317 blade profile has generated lower electric energy when compared with other rotor forms. For this blade profile the rotor form with a twisting angle of 0° and a blade angle of 15° with two blades yielded the best result.

For the blade profiles NACA 23012 and NACA 23015 which were used in the experiment the rotor forms with a twisting angle of 0° and a blade angle of 5° with two blades yielded the best result.

Depending on the findings of the experiment, we can suggest a wind turbine, which is made of NACA 4412 profile. That the turbine of that profile has no twisting angle but has a blade angle of 5° is of utmost importance. Also the rotor should have two blades. In this experiment the rotor with these characteristics was defined as the rotor with the best performance.

It will be possible to get a higher performance from the wind turbine if we use the rotor form that yields the best result. On the other hand, in order to get a better result from a rotor that operates at a low performance it will required to increase either the turbine height or the rotor area. This means an additional cost. But, a rotor that yields the best performance shall both promote the efficiency of the wind turbine and incur a lower cost.

The wind turbines that will be built by using the appropriate rotor forms shall be a good choice in meeting the energy requirements of small and medium size operations. Also keeping the cost at a reasonable level is another important criterion in terms of its attractiveness.

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REFERENCES

1. Vardar, A. and B. Eker, 2003a. Some proposes about wind turbines for Trakya Agricultural Regions II. Renewable Energy Sources Congress, Izmir, Turkey, pp: 203-210.
2. Dreese, J., 2000. Aero basics and design foil, user guide, Capitola, California, USA.
3. Anonymous, 2002. http://homepages.enterprise.net/hugh0piggot/wpNotes/index.htm.
4. Vardar, A. and B. Eker, 2003b. Select of Suitable Wind Turbine Blades, 3e Electrotech, Istanbul, Turkey, 105: 134-138.
5. Vardar, A., 2002. A research on determination of the fittest blade type, blade angle and blade position for establishing a wind turbine with Agricultural Aim in Trakya Region, Graduate School of Natural and Applied Sciences Ph.D. Thesis, Tekirdag, Turkey.
6. Vardar, A. and B. Eker, 2003c. A research on determination effect of axle power on wind turbine blades structure, Agricultural Mechanization 21. National Congress, Konya, Turkey, pp: 47-52.
7. Anonymous, 2000. http://mse.arizona.edu/faculty/birnie/engr102/102index.htm .
8. Arin, S., 1998. Measurement Knowledge, Trakya University Tekirdag Agriculture Faculty Publication No: 97/261, Tekirdag, Turkey.
9. Yavuzcan, 1994. Energy Technologies, Ankara University Agriculture Faculty Publication No: 134, Ankara, Turkey.
10. Erna, H., 1977. Practical Electric and Applications of Modern Electronic, Inkilap Publishing House, Istanbul, Turkey, pp: 28-38.
11. Anonymous, 2001. http://www.ece.arizona.edu/~cellier/engr102-pr3.pdf.
12. Coskun, M.B., 1992. Modeling of optimal wind energy conversion systems for the rural areas of Turkey, Department of Agricultural Machinery, Faculty of Agriculture, University of Ankara, Doctoral Dissertation, Ankara, Turkey.