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The wind tunnel measuring methods for wind turbine rotor blades

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Abstract. In this study, a wind tunnel, that has been developed for experiments of wind turbine rotor blades, has been considered. The deviations of the measurements have been examined after this wind tunnel had been introduced and the measurements on it had been explained. Two different wind turbine rotor blades miniatures have been used for getting better results from the experiments. The accuracy of measurements have been experimented three times repetitively and examined statistically. As a result, wind speed values which this type of wind tunnel and wind turbine rotors need for starting, wind speed in the tunnel, temperature and moisture values, the number of rotor's revolution, and the voltage that is produced in 102 Ω resistance and current values have been determined to be fixed by measurements used. This type of wind tunnel and wind turbine rotor' performance difference and the difference of revolution figures have been determined to be fixed by measurements used.

Keywords: wind turbine; rotor blade; rotor; rotor experimented; wind tunnel.

1. Introduction

Energy has become inevitable necessity for all the people in the world. Using the energy sources productively is much more important for grandchildren in the future, because technology has been improving rapidly and consumed energy per each person is increasing from day to day. We must ask 'can we use productively all energy sources that we have' and we need to take necessary measures. These measures, on the one hand, could be in the way of saving energy per person, on the other hand to use the most convenient technology for producing efficiently could be a benefit for the companies that produce energy.

There are many ways of producing energy in the world. Some of these ways provide us with the energy we need but also damage the environment. And some of them are clean sources. That subject must not be ignored. Because on the one hand while trying to serve the people, on the other hand we must not pay compensation.

One of the sources that we can call clean energy system is wind energy transformation systems. The most important component of these systems is turbine rotor blades. The aerodynamic characteristics of wind turbine rotor blade are the first and most important stage to produce effectively. So wind turbine rotor blades' performance should be determined earlier. Performance

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experiments can be done in different ways. These can be classified into two groups; the experiments which are made indoors and the ones in nature. But, the real blades must be used in both ways. This costs a lot, before making this expensive investment making miniatures of wind turbine blade designs will be better. As a result, choosing the most suitable design for the blades that will be made in real size, can also give an idea on the small size rotor experiments in addition to the theoretical studies. By means of wind tunnel experiments, the blades which are inefficient can be eliminated earlier and no cost can be spent for inefficient blades.

The aim of this study is to analyse the differences between a wind tunnel that is developed as above and blade turbine rotors' performance and whether the revolution differences can be fixed by measurements ways used or not.

2. Aerodynamic of wind turbine

Wind rotor is designed according to Betz (1926) or Glaubert-Schmitz (1935, 1955/56) to transform into electric energy of wind enegy that occur at the result of temperature of sun at different points on atmosphere (Ozdamar and Kavas 1999).

Rotational speed of a blade element that is r far from rotor centre that is turned by wind can be calculate by using below equation (Ozdamar and Kavas 1999, Beer, *et al*. 1991, Yavuzcan 1994).

$$V_r = \omega r = \frac{\pi n r}{30} \tag{1}$$

Rotor tip speed ratio calculates using below equation (Ozdamar and Kavas 1999, Yavuzcan 1994, Fingersh and Carlin 1998).

$$\lambda = \frac{V_r}{V_1} = \frac{\pi \cdot n \cdot r}{30 \cdot V_1} \tag{2}$$

To create blade design we need to specify the chord length and blade setting angle β (Fig. 1) at each of a series of stations along the span of the blade (Piggott 2000, Eker and Vardar 2002).

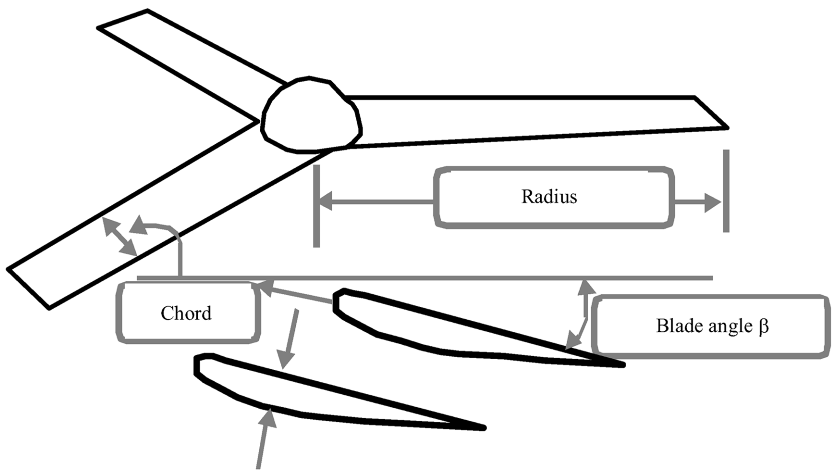

Fig. 1 Blade chord length and blade angle (Piggott 2000, Eker and Vardar 2002)

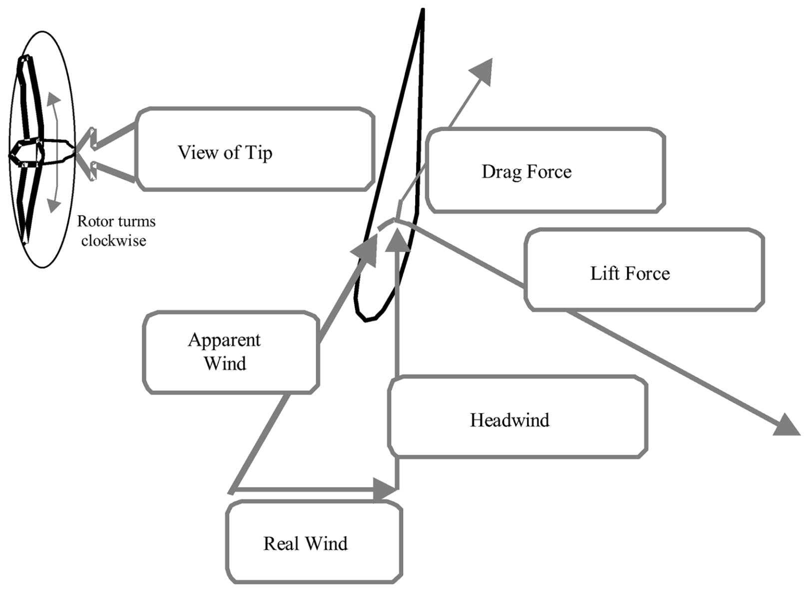

Fig. 2 The forces on the rotor blade (Piggott 2000, Eker and Vardar 2002)

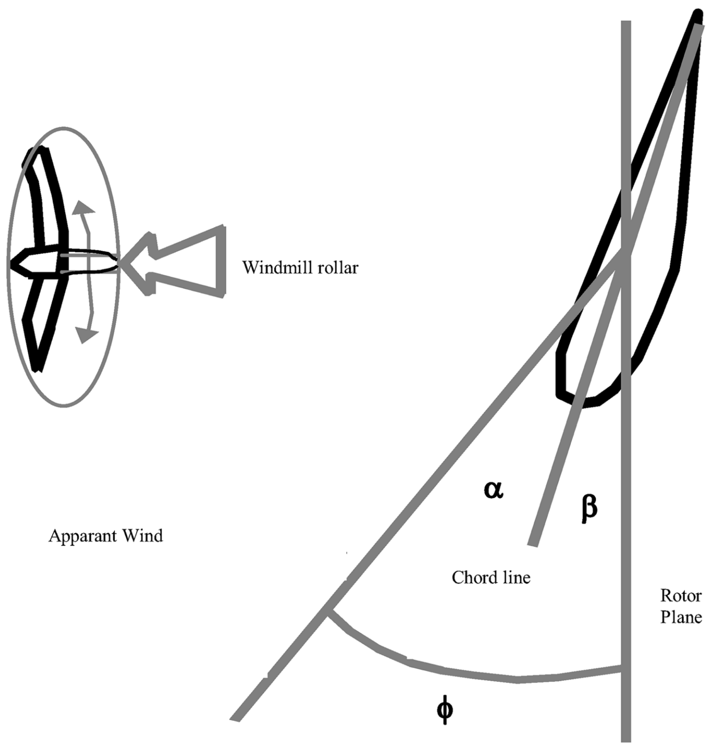

Fig. 3 Important angles of rotor blade (Piggott 2000)

This headwind (Fig. 2) adds to the real wind to give the apparent wind, which creates the lift and drag forces (Piggott 2000).

When designing a wind turbine rotor, the angle α will depend on the angle of the apparent wind Φ, and the blade angle β (Fig. 3). So we have control over α, and thus control over the lift and drag produced by the blade (Piggott 2000).

In practice, most sections will produce their best lift/drag at an angle of attack around 5 degrees, so as a general rule, where detailed data is not available, we can say that the blade angle β should be set to give this angle of attack, thus (Piggott 2000, Matthew, *et al*. 2002):

$$\beta = \Phi - 5 \tag{3}$$

Having worked out β we still need work out the Chord length. Here is the logic: Each blade element has a certain band of wind to process. As radius r grows smaller near the centre, the amount of wind in the band gets smaller too. The outer parts of the blade therefore do the most work (Fig. 4). The inner part is less important but needs a different shape (Piggott 2000).

To satisfy Betz, the wind in each part of the swept area of the rotor must be slowed down to 1/3 of its upstream speed, and this slowing is done by the Thrust force, which is very closely related to the Lift force. This leads to a rough expression for the Chord length (C) which will produce the right amount of thrust to meet the Betz condition (Piggott 2000, Maalawi and Badr 2003).

$$C = \frac{16 \cdot \pi \cdot R \cdot \left(\frac{R}{r}\right)}{9 \cdot \lambda^2 \cdot B} \tag{4}$$

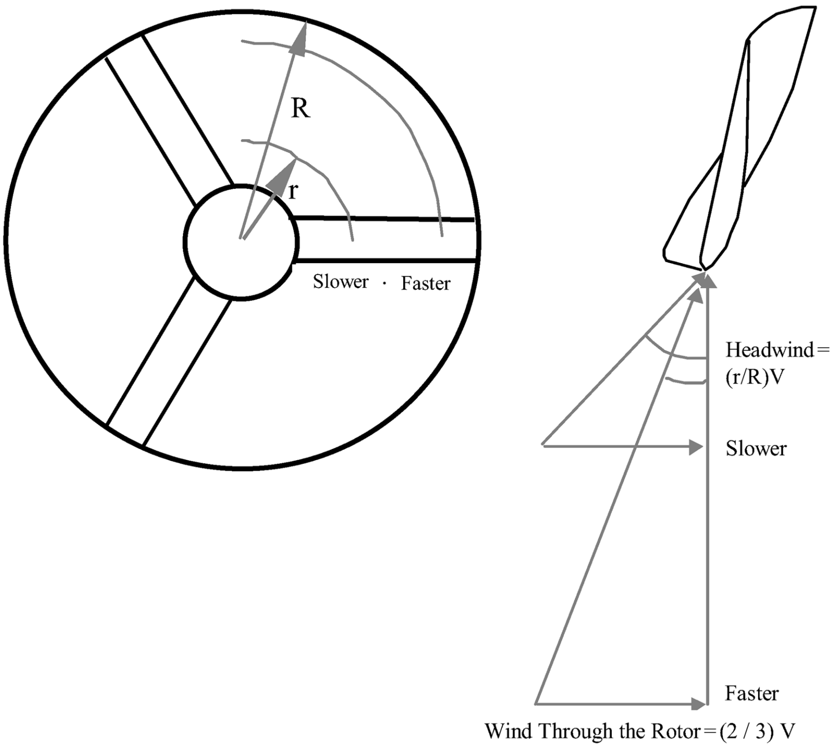

Fig. 4 Effect of wind to rotor (Piggott 2000)

Eq. (5) can be used to decide blade number:

$$B = 80 / \lambda^2 \tag{5}$$

The width of the blade C in the outer portion, will be:

$$C = \frac{4D}{\lambda^2 B} \tag{6}$$

The outer part is the most important, but the inner part should be made wider, to help with starting torque (Piggott 2000).

Blade profiles that were used in rotors are profiles especially belong to airplane blades. Their working principles are same so airplane blade profiles can be used succesfully. Several computes programs were developed related with this subject and these programs are getting easier calculations, blade selection etc. Some of these programa are Snack2.0 (Dreese 2000) and Air2000 (http://academic.engr.arizona.edu/instructor/software/Airscrew.htm).

3. Methodology

In the study, a pipe shaped wind tunnel of height 1.475 m, width 0.88 m, length 2.35 m, the lenght inside tunnel 2 m and diameter 51.35 cm is used. Height of the tunnel's centre is 1.11 m from ground level. The tunnel has a fan of diameter 35 cm, power 250 W and it runing by 1400 rpm. Inside the tunnel there are a venturi pipe and a conditioner that regulates the air flowing which exists by moving of the fan (Fig. 5) (Vardar 2002, Birnie 2001, Eker and Vardar 2002).

On the other end of the tunnel there is a mechanism which is established for experimenting the blades in the centre of the tunnel. It works by 220 V and 50 Hz. The system works between 0 and 5 m/s wind speed depending on the temperature and density of the weather. In the system it is possible to measure the wind speed in the tunnel, the temperature, density, flow rate and in how

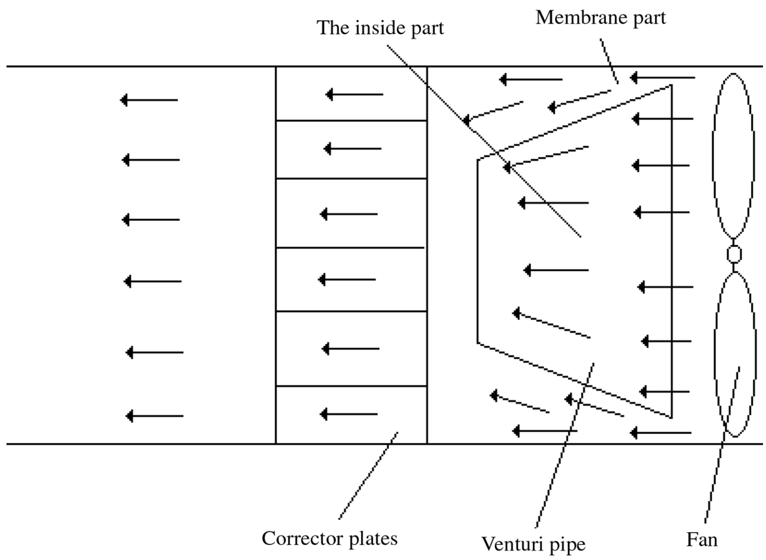

Fig. 5 Wind tunnel wind flowing regulator and venturi pipe (Eker and Vardar 2002)

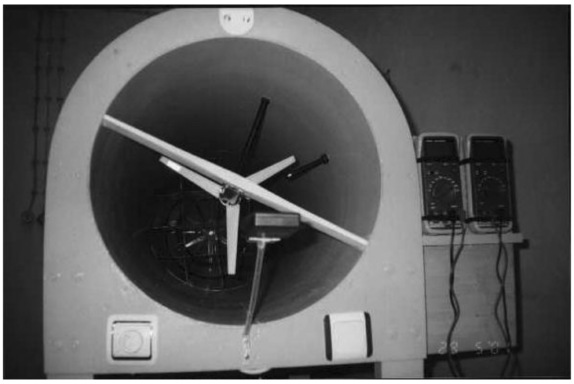

Fig. 6 Wind tunnel (Vardar 2002)

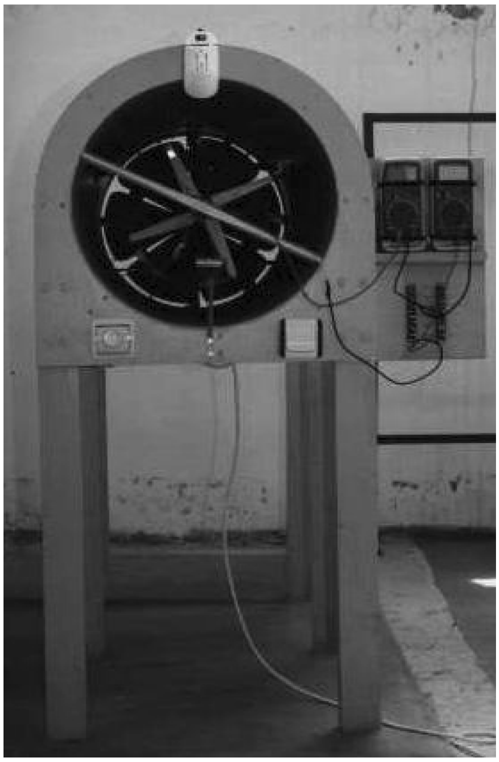

Fig. 7 Wind tunnel (Vardar 2002)

much degree it is going to be converted into liquid (Figs. 6, 7). Besides those, it is also possible to read electrical voltage and current values of the blades that are experimented by an electrical motor in the system; resistance values are 23.5 Ω, 57.1 Ω, 102.3 Ω, 151 Ω, 219.1 Ω and 327.3 Ω. There is also a panel sized 42×30 cm on which the measurements devices are placed and a lamp for 25 W (Vardar 2002).

By using an anonometre we can measure wind speed as m/s, temperature as ^{0}C and flow rate as m^3/h if cross-section area is put as m^2 (Eker and Vardar 2002, Hunter 1999). Total lenght is 365 mm and it is possible to fold. The measurement head showing the result has a digital indicater and it can turn up 180^o. It can be carried in a pocket and it can be attached to the tunnel in which the the measurement will be done. Wind speed measurement range of measuring device are 0...5 m/s 0...+50^{o}C. The flow rate measurement range is 0...99.990 m^3/h in the temperatures 20...+50^{o}C. The device determination is 0.01 m/s /0.1^{o}C. Temperature measurement sensitivity is ±0.5^{o}C. Running temperature of the measuring device is 0......+50^{o}C, storing temperature is –20.....+70^{o}C. Measuring device works with three micro (AAA) batteries. The device in about five minutes' measurement time closes automatically. Prob diameter of the measurement device is 12/16 mm and prob length is 300 mm.

It is possible to measure using temperature and with moisture measuring device the % moisture value, as ^{o}C weather temperature and how much ^{o}C we can change the moisture in the air into liquid. Total lenght is 174 mm. The measurement head showing the result of measuring has a digital indicator and can be turned around 180^o. And the device can also be carried in pockets and put in the tunnel in which the measurement is going to be done. The measuring distance of the measurement device is % 5.....95 RH for moisture measurement and $-20...+70^{o}C$ for the temperature. Determination of the device is % 0.1/0.1°C. In 25°C the system sensitivity is ±% 3 for moisture measurement and ±0.5°C for the temperature measurement. Running het of the measuring device is $0...+50^{o}C$ and storing temperature is $-20...-70^{o}C$. The measuring device works with three *V*-button cell (CR2032) batteries. Prob diameter of the measuring device is 12 mm and prob length is 125 mm.

Revolution measuring device used as rpm can measure the revolution. It executes the revolution measurement with its reflectors' help and by means of perception system by light. The distance between the reflector and the light source of device must be maximum 350 mm. At the end of measurement the minimum value, maximum value and the last value is in the head of the device stored. The device has a digital indicator and measurement sensitivity is % 0.02, working temperature $0...50^{o}C$ and storing temperature $20...+70^{o}C$. The revolution measuring device work with 2 1.5 V R6-AA (alkali manganese) batteries. The sizes are $145\times 60/55\times 25$ mm.

In the study, two multimeters have been used. One of them is for electrical voltage measurement and the other one is for electrical current measurement. In these multimetres as volt beside the electrical voltage as *A* and mA current, as Ω resistance, as °C temperature, as hFE transistor, as nF capacitance and diode measurement can be done. It is also convenient for DC and AC measurements. Beside the standart connecting cables of the device there is one more connecting cable to be connected to a computer. In a disc which is in the box of the device by means of the programme the time distance wanted of the device and the measured values also appear on the computer screen beside the device's screen and are reflected to the graphs. This measuring device works with 6F22 9 V battery. The only difference of the second multimetre used in this study can not measure temperature but can the measure frequency as kHz.

The standart connecting cables used in the multimetres have been arranged by considering the circuit in the system. The current as serial and voltage as parallel is connected to the circuit. In the circuit has been used a resistance for 102.3 Ω (Vardar 2002, Birnie 2001).

The electrical motor (Fig. 8) used and particulars:

- Miniature, constant, magnetic type electrical motor.
- The length 35 mm, diameter 32.7 mm and height 38.6 mm.
- Shaft diameter 1.8 mm, length 8 mm.
- Speed in 6 V 2520 rpm, in 9 V 3900 rpm and in 12 V 4900 rpm.
- Contact tips exterior and punched type.

In the wind speed measurement 2 m/s, 3 m/s and 4 m/s wind speeds have been able to experiment

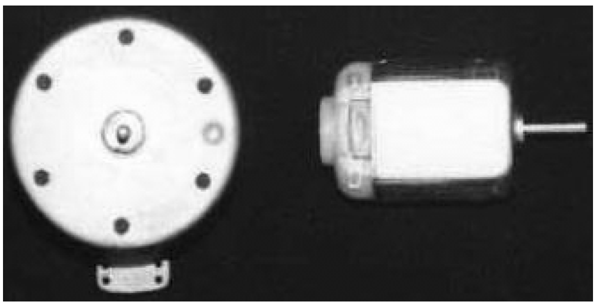

Fig. 8 Electrical motor (Vardar 2002)

the rotors that are existed by wind turbine blade miniatures which are going to be experimented with anemometer. In these chosen steps the rotors have been experimented for 5 minutes and the values on anemometer have been saved.

By the temperature measurement as ^{o}C the temperature value in the wind tunnel during the rotor working has been determined. This value is effective as a directly of on the power value from the rotor and the revolution of rotor. During the measurements the average of the values saved in different times has been taken base.

By revolution measurement, the revolutions that the experiment rotors provided in the wind speeds 2, 3 and 4 m/s have been determined. Minimum and maximum revolutions of the measuring device during the measurement have been determined. Rotor revolution speed is an effective factor on the tip speed rate of the blade. Rotor revolution is influenced indirectly because of the weather temperature and the moisture in the air being effective on the wind speed.

Electrical voltage that has appeared in the electricity motor as a result of the rotor turning and the electrical current value are measured under static resistance for 102.3 Ω by using two multimeters. The measurement has lasted for 5 minutes and electrical voltage on the multimeters and the electrical current values have been saved for 5 minutes.

In the experiements, two different rotors, which have been made of two different wind turbine rotor blade miniatures, have been used. The particulars of these two different rotors (Fig. 9) are:

The first rotor:		The second rotor:	
Blade profile	: NACA 4412	Blade profile	: NACA 4415
Twist angle	: 10 derece	Twist angle	: 10 derece
Number of blade	: 3 adet	Number of blade	: 3 adet
Blade angle	: 10 derece	Blade angle	: 10 derece

All the experiments have been carried out six times, for the same values of wind speed, temperature, number of revolution, electrical voltage and the electrical current were analyzed as statistically. 10 measures were done for every replication.

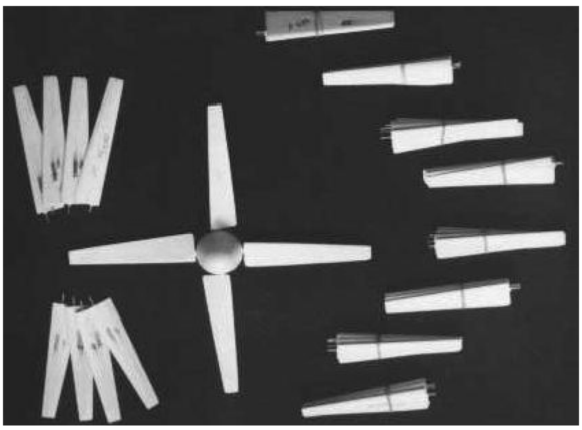

Fig. 9 Rotor blades miniature

Arithmetical averages related with wind speed, temperature, moisture, revoluation, electrical voltage and electrical current were calculated by using equation (Duzgunes 1983).

$$\bar{X} = \frac{\sum x}{z} \tag{7}$$

z is here number of measurement.

Minimum and maximum deviations were calculated by using arithmetical average values (Duzgunes 1983).

$$DA = \left| \bar{X} - x_{\min} \right| \tag{8}$$

$$\%DA = \frac{x_{\min} \cdot 100}{\bar{X}} \tag{9}$$

4. Results

The results are showed by Figs. 10, 11, 12, 13, 14 and 15. In these figures rotors were given as first rotor (■) and second rotor (□).

In figures, results that were obtained separately for 2, 3 and 4 m/s wind speeds were shown in the same figure.

The wind tunnel results of wind speed shows in 2 m/s approximate wind speed that the first rotor against the second rotor still higher worth has. In 3 m/s and 4 m/s approximate wind speed have the two rotors variable worth.

The results of temperature is in the first rotor between 12.1-12.2^{o}C, in the second rotor between 20.7-20.8^{o}C. In the repetitions see we nearly no deviation.

Also in the results of moisture values we see nearly no deviation. The results of moisture is in the first rotor between 84.8-85.8%, in the second rotor between 40.5-42.1%.

And the results of revolution number values, electrical voltage values and electrical currrent values to 2 m/s, 3 m/s and 4 m/s approximate wind speed the fact that first and second rotor is different.

According to statical evalutions it was determined that there are +1.71-1.68% deviation in wind speed measurements, ±0.41% deviation in temperature measurements, ±0.3% deviation in moisture measurements, ±1.65% deviation in revolution measurements, +2.41-4.36% deviation in electrical current measurements and +0.6-0.48% deviation in electrical voltage measurements in wind tunnel.

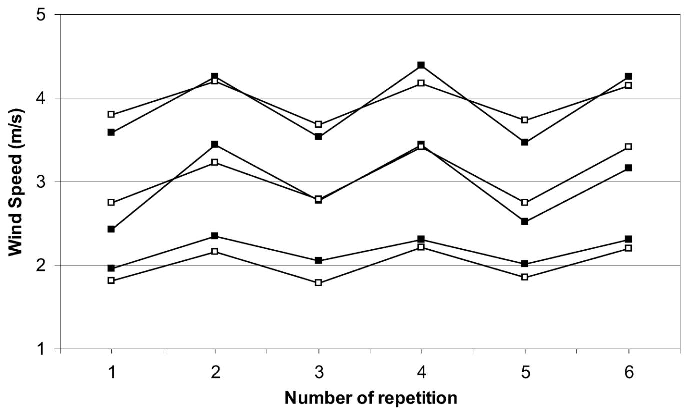

Fig. 10 The results based on the wind speed deviations

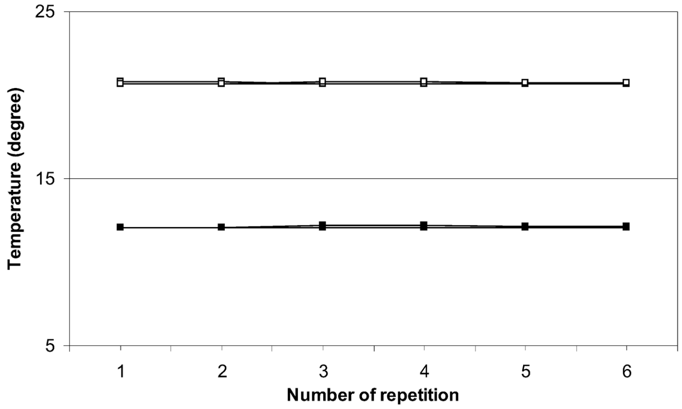

Fig. 11 The results based on the temperature value deviations

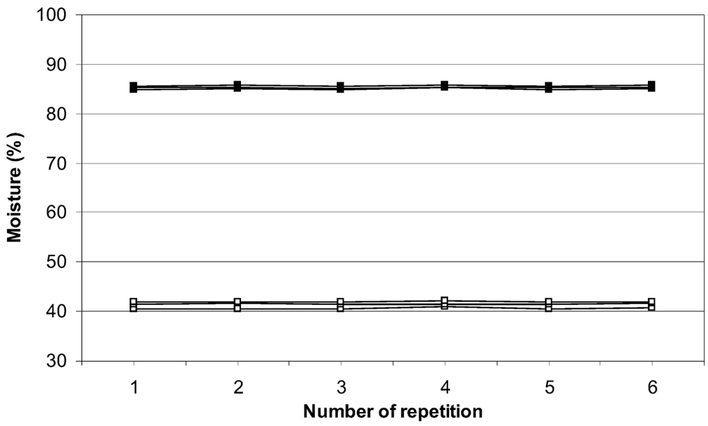

Fig. 12 The results based on the moisture value deviations

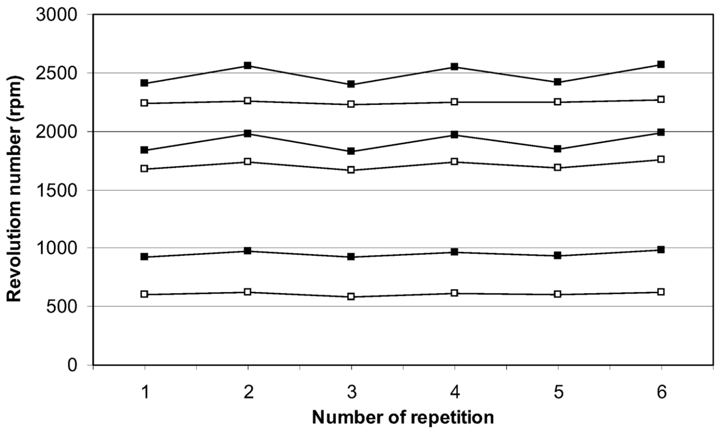

Fig. 13 The results based on the revolution number deviations

In addition, it was determined that there is a difference among wind turbine rotors in terms of revoluation numbers, electrical current and voltage in 0.05 importance level.

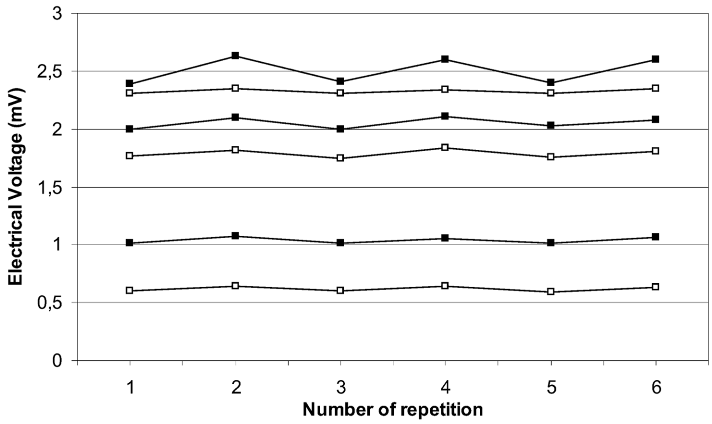

Fig. 14 The results based on electrical voltage deviations

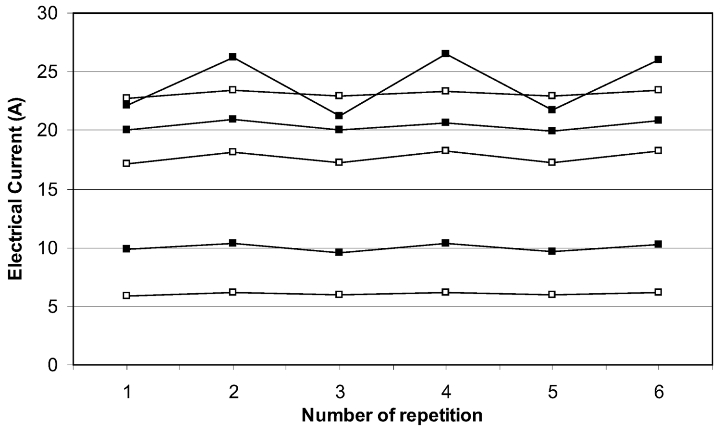

Fig. 15 The results based on electrical current deviations

5. Conclusions

As a result, with this type of wind tunnel the wind speed values which the wind turbine rotors need for getting started, the wind speed in the tunnel, temperature and moisture values, rotor revolution number, the voltage made under 102.3 Ω resistance and current values can be determined by these measurement ways. With this type of wind tunnel, besides the performance differences between the wind turbine rotors, revolution number differences can be determined by these measurements.

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Notation

ω : Angular velocity (degree)
V_r : Rotational speed (m/s)
V_1 : Wind speed front the rotor (m/s)
r : Distance of a point on rotor from rotor axis (m)
R : Radius (m)
D : Diameter (m)
n : Number of Revolution (rpm)
C : Chord (m)
B : Number of blades
λ : Tip speed ratio
β : Blade angle (degree)
α : Angle of attack
Φ : Angle of the apparent wind (degree)
$\overline{X}$: Arithmetic average
x : Measured data
$x_{\min}$: Minimum measured data
z : Number of measuring
DA : Deviation from average
$\%DA$: Deviation as % from average

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