Experimental study of runners for vertical axis wind turbine

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Abstract: *The work presents the results of experimental study of a wind turbine with a vertical axis. Research to make on test rig № 7 in the laboratory of hydropower and hydraulic turbomachinery of the Technical University of Sofia. Examined the characteristics of a wind turbine, whose runners are working with cylindrical blades. It is made planned physical experiment varied the values of the number of blades, the runner diameter and angle of insertion of blades on the grid of the runner. As a result of these studies is the inadequacy of the resulting models (objective function are the values of TSR). Therefore, based on analysis of the results is introduced a new criterion for dynamic similarity. This allows to optimize the geometry of the blade system.*

Keywords: *wind turbine, blade, runner, test stand, TSR.*

Introduction

The rapid development of the wind energy worldwide has shown the need of systematic studies, as well as of training of experts in this area in Bulgaria, too. The share of the wind energy in the energy balance of the planet has been continuously increasing and the reason for this is the countries' pursuit of reducing their dependence on organic fuels and minimizing the environmental impact. With regard to the installed energy capacity, the wind power technology is one of the most dynamic one (compared to other renewable technologies). Creating a new wind power capacity is important especially for the developing countries where the energy consumption has raised as a result of the growth in the population and the industrialization.

For the countries which do not have great wind power resources it is important to develop efficient low-capacity systems. Practice shows that these systems are welcomed on the market and the interest in them is continuously growing.

In 2011 in the Laboratory of Hydropower and Hydraulic turbomachinery (HEHT laboratory) at the Technical University – Sofia a test stand for vertical-axis turbines was brought into operation (stand Nr. 7C). Vertical-axis wind turbines have some important benefits: low cost, relatively simple design, reliable packaging of the wind turbine, long maintenance-free period, low noise level, not dependent on the wind direction and etc.

Test stand

The features and characteristics of the test stand are described in [1]. Stand's parameters are determined based on the technical data and the possibilities of using existing laboratory and equipment, the requirements of the relevant standards, as well as the experience accumulated by laboratories with traditions in this area – for example [2]. Given below are the basic parameters of the stand:

- Maximum wind speed: $c_w = 10\ m/s$;
- Maximum diameter of the runner: $D_1 = 1\ m$;
- Maximum height of the runner : $H = 1m$;
- Maximum effective power: $P = 100\ W$.

One of the main goals in designing the stand was to provide real possibilities of carrying out static and dynamic experiments with different vertical-axis wind turbine structures.

Fig. 1 shows a diagram of a stand (stand Nr. 7C in HEHT laboratory), and in Fig.2 – a picture of the model unit featuring one of the analysed runners. Air stream is generated by an axial fan 1 whose rotational speed may be varied widely by means of a frequency inverter 2.

A straightening grid 3 is installed in an aerodynamic tube. Provided is an option to measure the mean current rate at the outlet of the tube by using an anemometer 5. In this particular case the analysed wind turbine features a vertical shaft 6 and cylinder-shaped blades 10. The rotational rate of the turbine is measured by using an induction converter 7. The construction of the runner (disks 9 with radial porters 8 for the blades) allows for runners with number of blades of $z=2\div9$ with different diameters (in the interval between $D_1=480 \div 880mm$), as well as design of adjustable runner blade angle – Fig.1.

Research scheme

Tests were conducted by using vertical-axis wind turbine runners (Darrieus type). The tests are performed at constant wind speed: $c_w = 9\ m/s$.

The initial idea was to determine the optimal values of the blades (X3), the angle at which the blades are installed in the grid of the runner (X2) and the runner's diameter (X3), and to this end a planned experiment was prepared [3] (3 factors whose values range to up to 3 levels – table 1).

Table1

Values range

Factor	Basic level	Variation rate
X1, m	0.680	0.200
X2, deg	40	20
X3	6	2

As an objective function was used the so called tip speed ratio (TSR) which is the ratio of the speed u in the peripheral section of the runner to the mean speed of the free wind stream c_w (also known as mode parameter in active water turbines, essentially Struhal criterion):

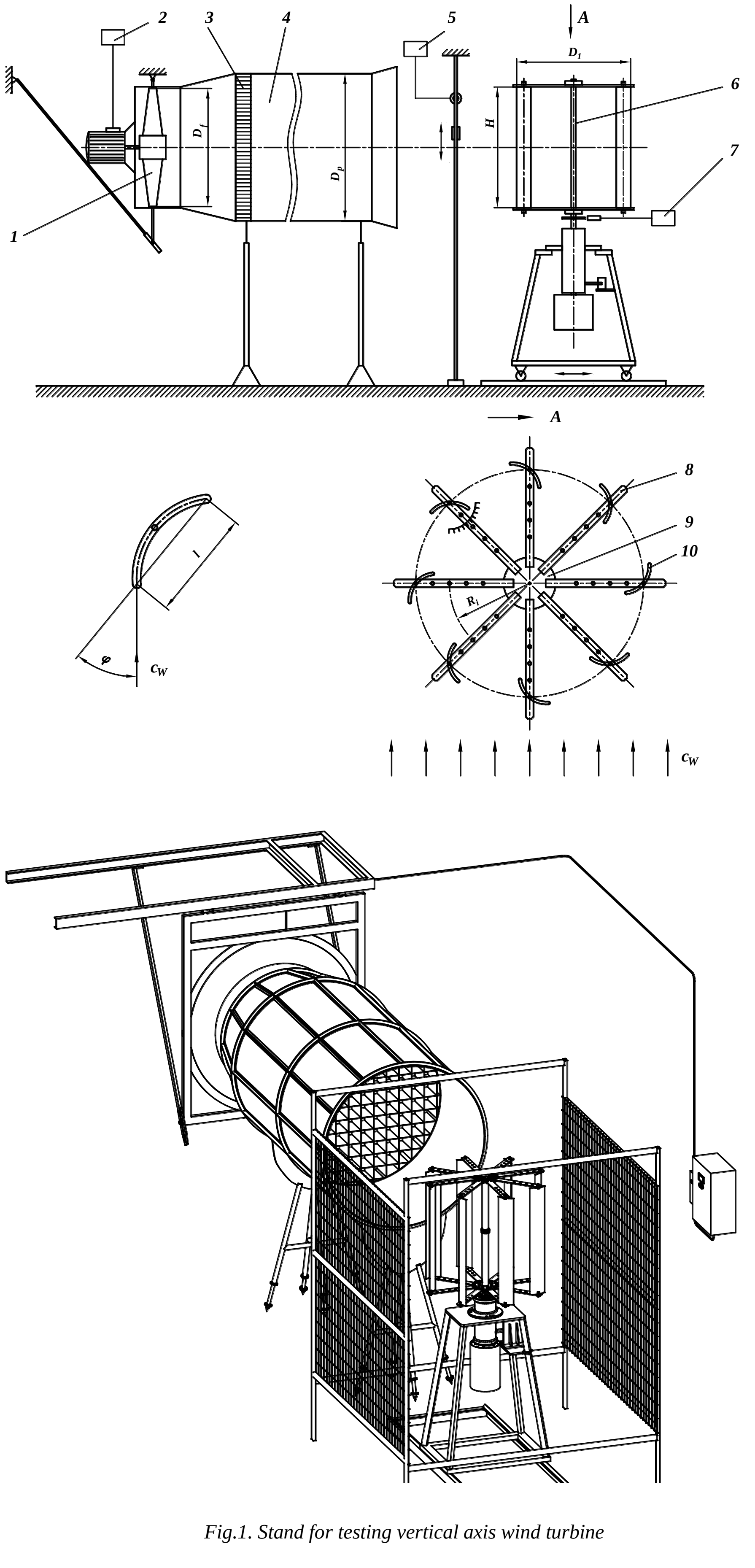


Fig.1. Stand for testing vertical axis wind turbine

Fig. 2. Model turbine

(1) $$TSR = \frac{u}{c_w}.$$

The test results showed inadequacy of the model used – polynomial type [3]:

(2) $$Y = b_0 + \sum_{k=1}^{3} b_k x_k \sum_{l=k+1}^{3} b_{kl} x_k x_l + \sum_{k=1}^{3} b_{kk} x_k^2.$$

This made it necessary to look for new methods for determination of the correlation between the main parameters of the blade system. By analysing the results from the tests performed and the effect that these parameters have on the values of the objective function and by using the Dimension theory it became possible to define a new aggregate parameter which according to the test results proved to have great impact on the TSR values:

(3) $$K_0 = \frac{lHz}{D_1^2},$$

where l is the chord of the blade, H – the height of the runner, and D – outer diameter of the runner.

It is appropriate to consider K_0 as a dynamic similarity criterion as it can be presented as a force ratio (the force F_b from the air stream on the blades of the runner to the total force F_w of the air stream acting on the total area of the runner):

(4) $$F_b = p_d S_b z = \rho \frac{c_w^2}{2} lHz;.$$

(5) $$F_w = p_d S_r = \rho \frac{c_w^2}{2} k_s D_1^2.$$

In equations (4) and (5) p_d denotes the dynamic pressure, S_b– the runner's area, and S_r –the runner's total area which is proportional to the square value of its diameter (k_s acts as a coefficient of a geometric similarity). Provided that $t = \pi D_1/z$ is the step (distance between the adjacent blades) of the blade grid and $\tau = l/t$ is its density, than K_0 is equal to:

(3a) $$K_0 = \frac{\pi \tau H}{D_1}.$$

Results

The tests performed (full factorial experiment) made it possible to determine the extent to which *TSR* is dependent on the two factors (K_0 and φ). Fig. 3 represents the correlation between *TSR* and K_0 with several different φ values, and Fig.4 shows the aggregate correlation $TSR = f(K_0, \varphi)$.

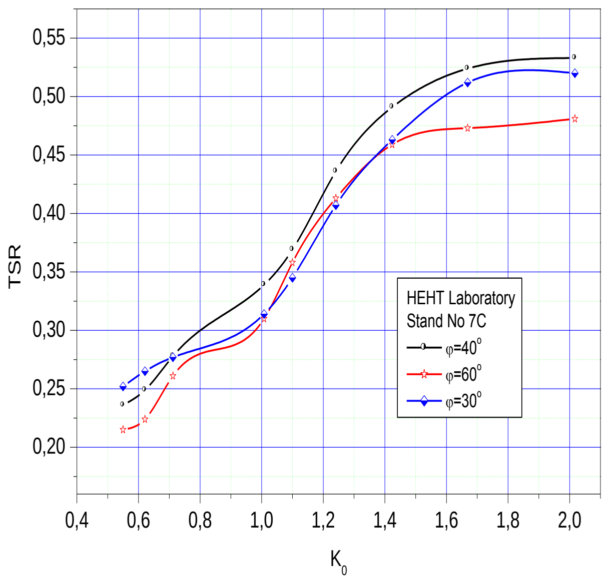
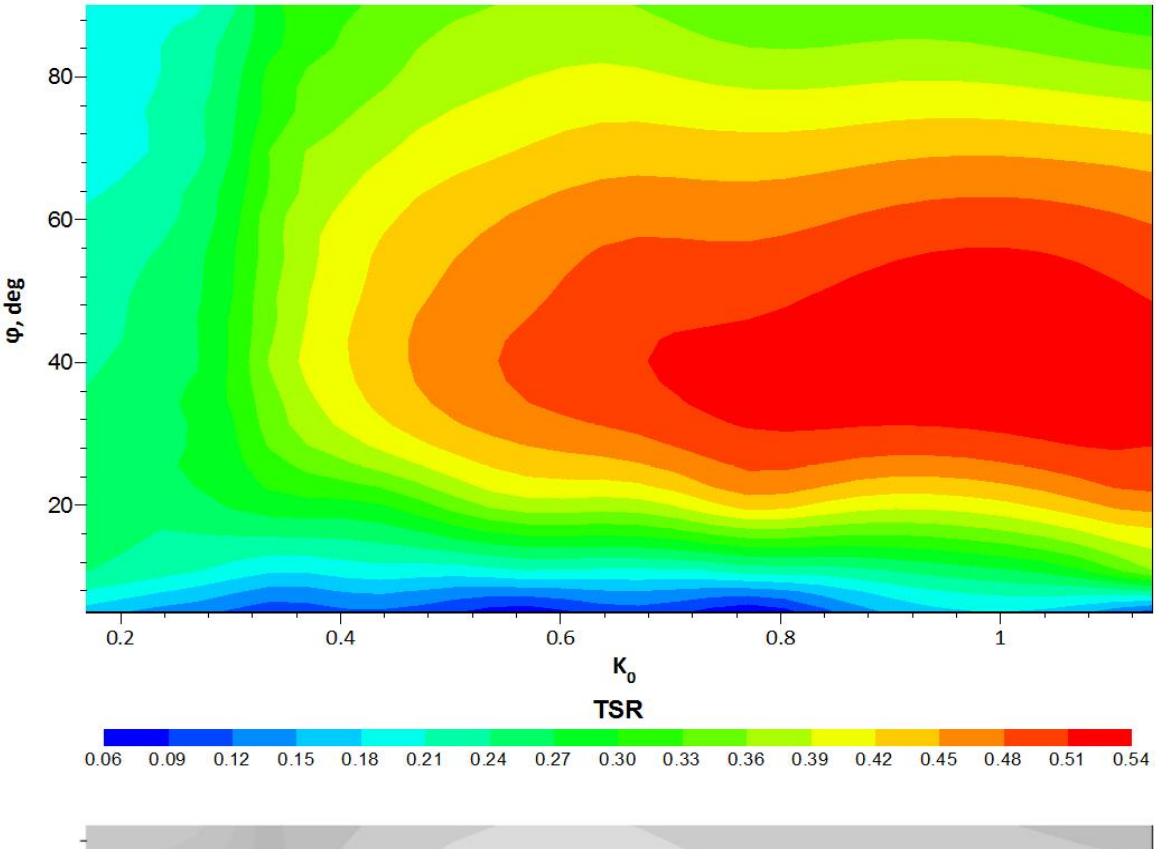


Fig. 3. TSR- K_0 relation

Conclusion

The test results lead to the following major conclusions:

1. The maximum TSR rates are reached at runner blade angle of $\varphi \approx 40^0$.



2. The maximum TSR values are reached with dimensionless criterion of $K_0 \approx 0.9$.

3. The set K_0 similarity criterion allows for the design of turbines of this type in order to ensure the efficient operation of the original machines provided that test model data are available.

References

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Biography

Valentin Obretenov was born in Dryanovo, Bulgaria, on July 2, 1950. He studied at the Technical University of Sofia-Bulgaria and received Dr. degree from the same university in 1982. Since 1976 he worked in the Faculty of Power Engineering and Power Machines of the Technical University of Sofia as a Assistant and Associate Professor in the field of hydropower and hydraulic turbomachinery .

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