Experimental study of Darrieus wind turbine runners

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Experimental study of Darrieus wind turbine runners

Valentin Obretenov, Rossen Iliev

The results of experimental studies of a Darius vertical wind turbine are presented in the paper. The influence of the type of working blades on the characteristics of the turbine has been investigated. The results of the studies carried out, which were compared to numerical survey results, were analysed. On this basis, guidelines are formulated for the practical application of the results obtained.

Keywords: Darrieus wind turbine, blades, experimental investigation, characteristics.

Опитно изследване на работни колела на вятърна турбина тип Дариус

Валентин Обретенов, Росен Илиев

В работата са представени резултати от опитни изследвания на вертикална вятърна турбина тип Дариус. Изследвано е влиянието на вида на работните лопатки върху характеристиките на турбината. Анализирани са резултатите от направените изследвания, които са сравнени с резултати от числено изследване. На тази основа са формулирани насоки за практическото приложение на получените резултати.

Ключови думи: вятърна турбина Дариус, работни лопатки, опитни изследвания, характеристики.

Introduction

A main purpose in designing each vane machine is to achieve maximum workflow efficiency. Vertical axis wind turbines are characterized by relatively low efficiency and researchers are striving to achieve higher power coefficients with a variety of aerodynamic schemes [2,6,7] and more often - using different catalog aerodynamic profiles for runner blade synthesis [1,5,7]. Very rarely, publications reflecting research on development of blades, for example blade profile synthesis methods of this type of turbine [4].

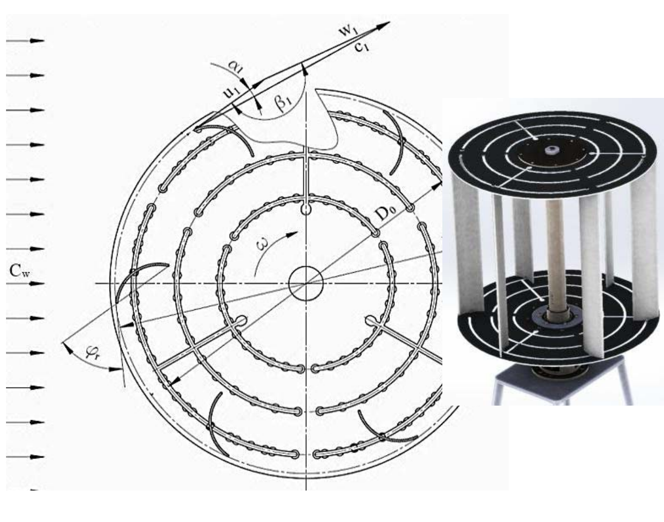


Fig 1. Runner

In this work are presented results of comparatively experimental study of model VAWT with 4 runners, differing in the geometry of the working blades.

Setting of the experimental research

The researches has been done on the test stand of VAWT in HEHT lab of Technical University Sofia (stand #7) [3]. The wind turbine runner consists of two carrier discs, between which the blades are mounted – fig.1. For the purpose of this study four sets of runner blades were made, with which 4 runners were composed, each with 6 blades. The runner blades are mounted on a circle with diameter D_0=800mm and can be rotated around their axes, i.e. the insertion angle of the blade - φ_r can be changed (fig.1).

1. Runner #1

The blades are flat, with length L=180mm, thickness Δ=6 mm and height H=800mm (fig.2a). They are of constant thickness Δ=5 mm, the inlet and outlet are rounded with radius r=3mm.

2. Runner #2

The blades are part of cylindrical surface with radius R=100mm, chord L=150mm, thickness Δ=5 mm and height H=800mm (fig.2b). They are of constant thickness, the inlet and outlet are rounded with radius r=2.5mm.

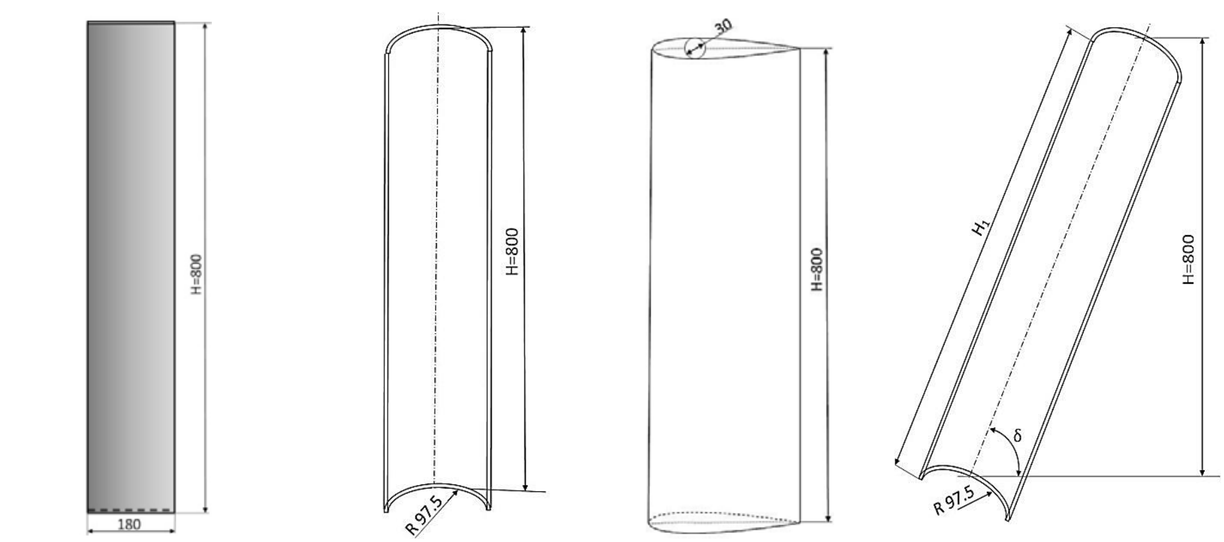
3. Runner #3

The blades are profiled. NACA 0015 catalog profile has been used – symmetrical, with chord L=200mm and maximum thickness Δ=30mm (fig.2c). The blades have height H=800mm.

4. Runner #4

Blades are cylindrical (as runner blade №2), but are mounted in a tilted position relative to the carrier discs (fig.2d), i.e. at angle δ relative to the horizon. This angle may change in range ($0^0 \div 90^0$). The purpose of the study is to determine the influence of the tilt angle on the workflow efficiency.

Photos of the tested runners are shown on fig.3.

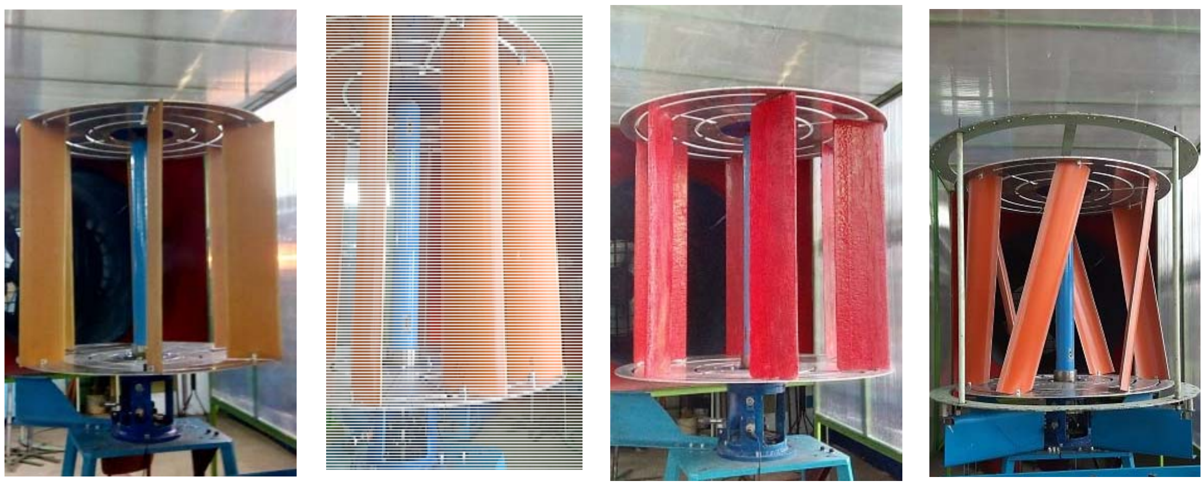


2a. 2b. 2c. 2d.

Fig.2. Blades

The measurement of the shaft torque M_b, the rotational speed n (respectively shaft power $P = M_b\,\omega = \frac{M_b \pi n}{30}$ and the wind velocity C_w is described in detail in [3]. The shaft load (for modeling different modes of operation) is carried out using mechanical brake [3].

Experimental studies with runners №1, 2 и 3 are made for several values of insertion angle φ_r, but with runner #4 – for the optimum value of this angle $\varphi_r \approx 55^0$. The purpose is to obtain summarized characteristic $C_{pmax} = f(\delta)$, i.e. the dependence of the maximum valued of the power coefficient on the value of the angle of inclination of the blades δ.



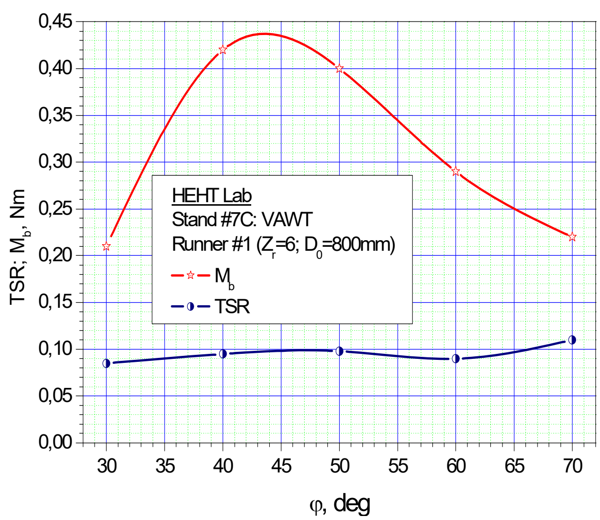
#1 #2 #3 #4

Fig.3. Runners

The runners #1 and #3 have been tested at wind speed C_w=*9m/s*, while runners #2 и #4 – at wind speed C_w=*8.1m/s*.

Results

On fig.4 and 5 are shown the dependencies of torque M_b and the regime parameter TSR (ratio of peripheral speed in the peripheral section of the runner to the wind speed; $TSR = u/C_w$ [4]) of insertion angle of the runners #1 и #3. Experimental studies have shown that the power values are very small (less than 1 W), respectively low power coefficient values.



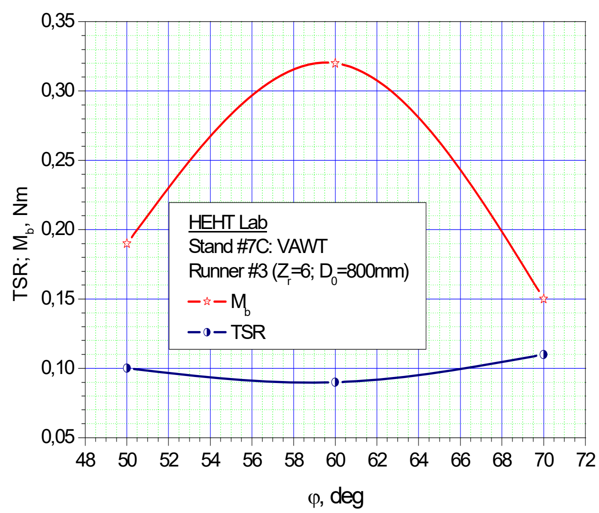


Fig.4. Runner #1

Fig.5. Runner #3

On fig.6 are shown analogous dependencies on the runner #2, while on fig.7 – for runner #4 (here as the independent variable the angle of inclination of the blades *δ* is used – fig.2d).

On fig.8 is shown dependencies of maximum values of power coefficient C_{pmax} to the angle of inclination of the blades *δ* (for runner #2 *δ=90⁰*). The power factor is defined as the ratio of the turbine shaft power to the air flow rate power.

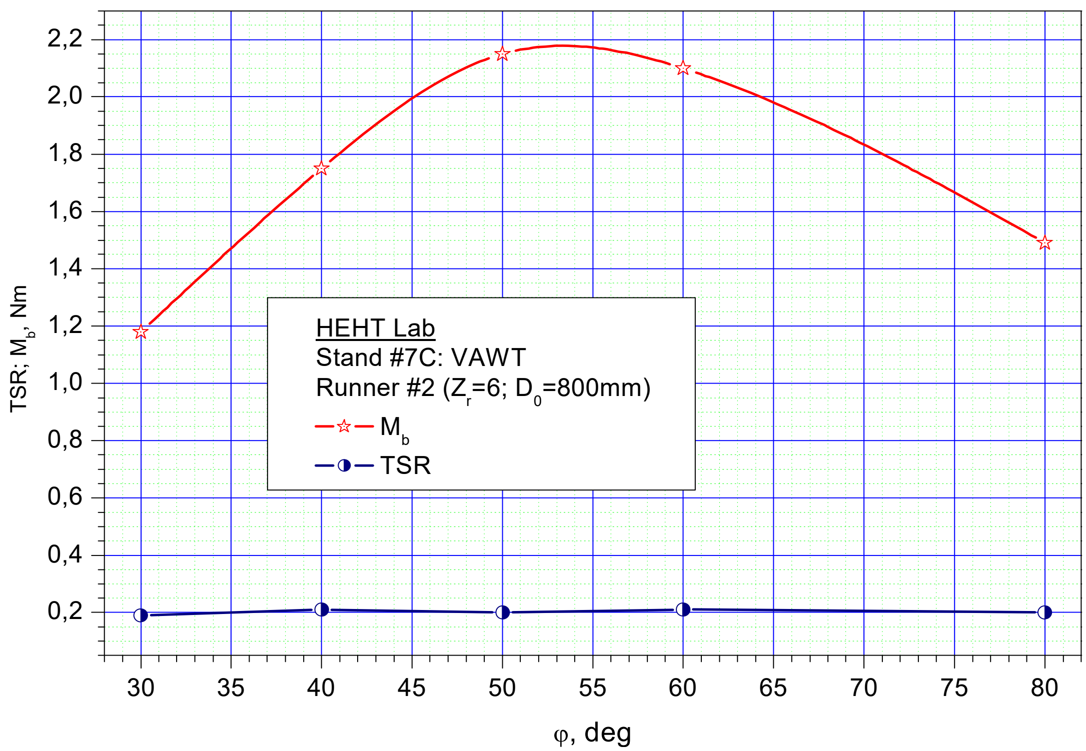


Fig.6. Runner #2

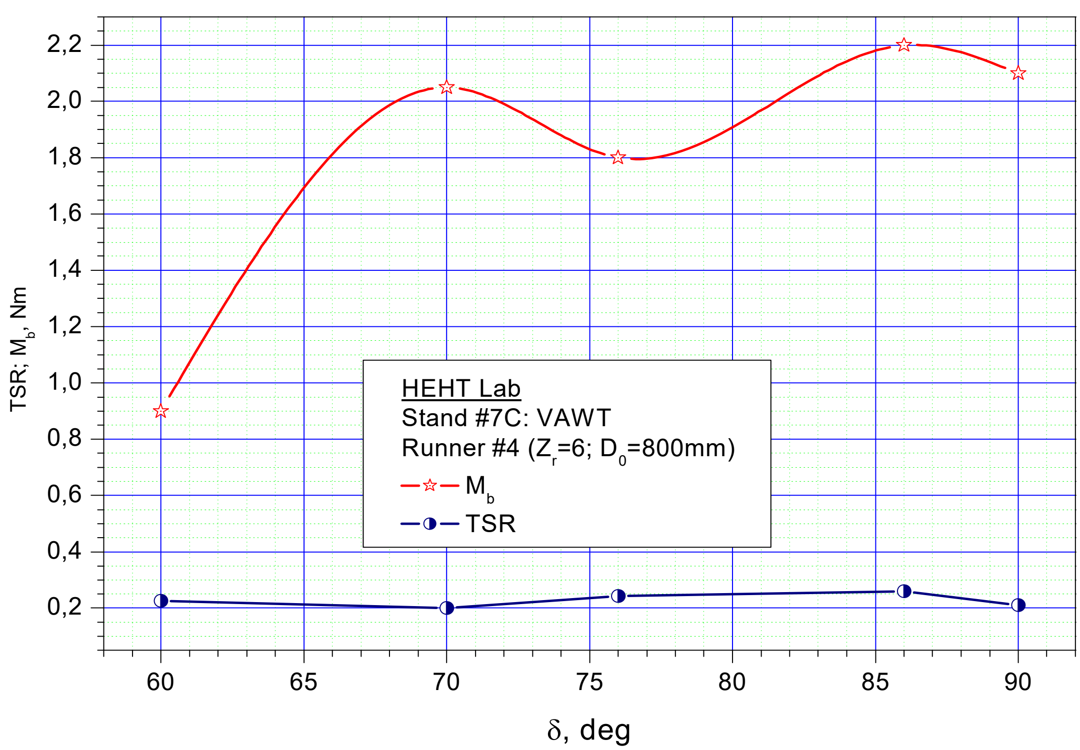


Fig.7. Runner #4

The power factor is defined as the ratio of the turbine shaft power to the airflow power: $C_p = P/P_w$, where $P_w = \rho S C_w^3/2$ and $S = DH$ is conditional area of the runner (his cross section area).

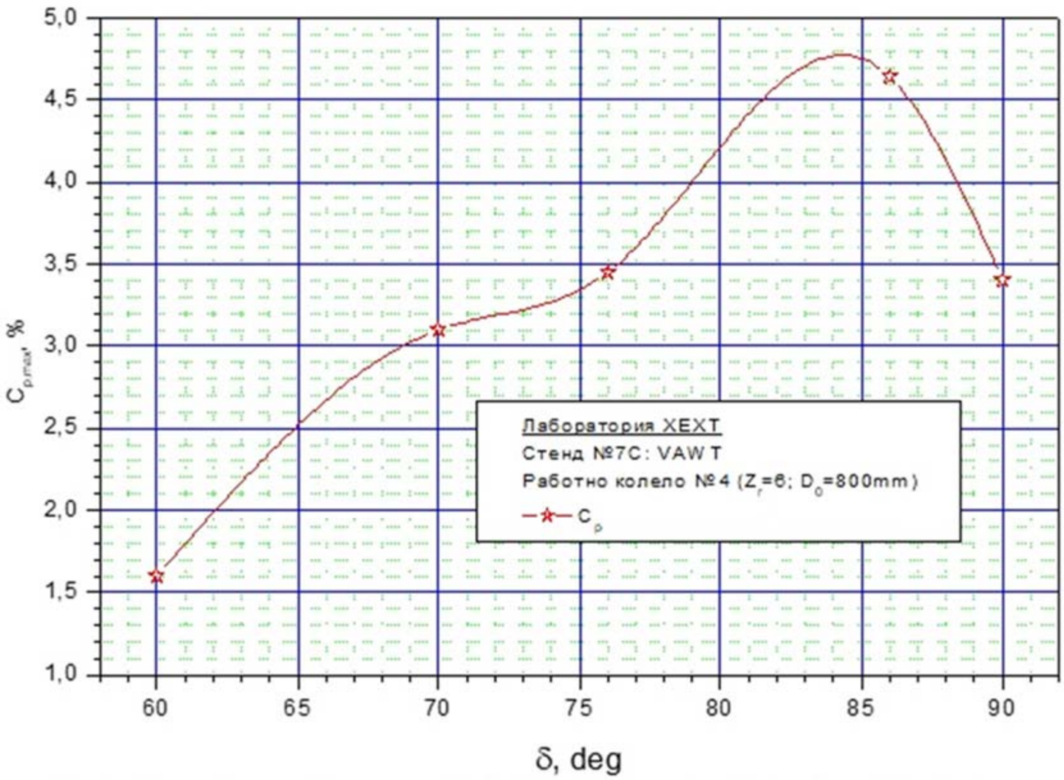


Fig.8. Dependence of the power factor from the angle of inclination of the blades (runner #4)

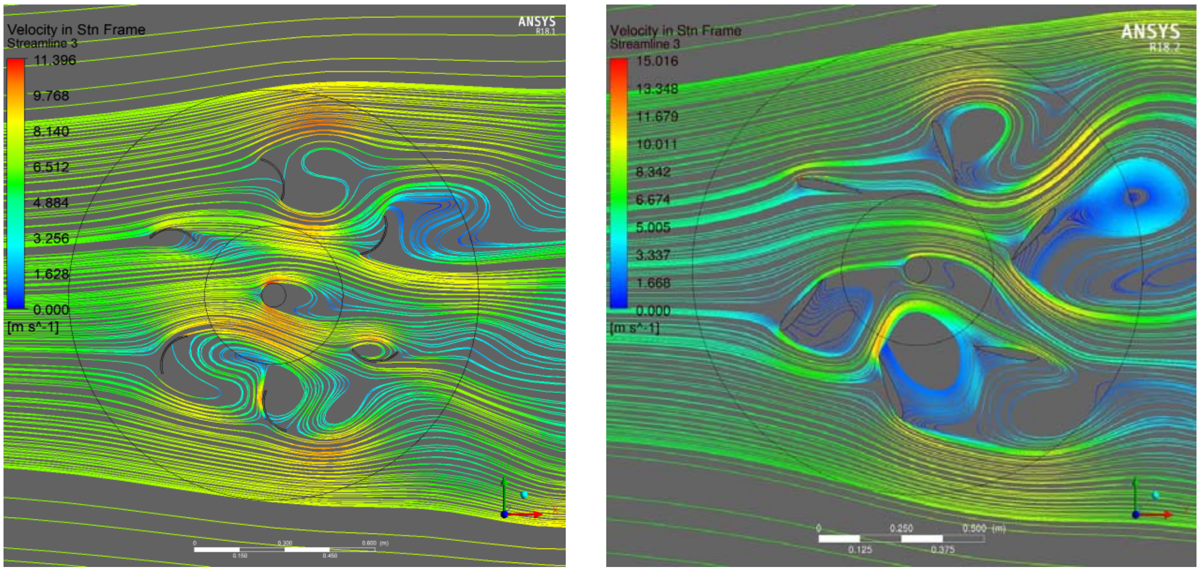
Results analysis

The main conclusions that can be drawn from the results of the experimental studies are the following:

1. Runners with flat and profiled blades (runners #1 and #3) work with very low efficiency (values of the power coefficient are under 1%), flat blades even surpass those profiled by this indicator.
2. The optimal value of the insertion angle of the blades for the runners #2 and #3 is in range $\varphi = 50^0 \div 60^0$, while for runner #1 is lower ($40^0 \div 50^0$).
3. The slope of the blades towards the horizon has a noticeable impact on the efficiency of the work process. The slope of the blades towards the horizon has a noticeable impact on the efficiency of the work process. Moreover, the results of the experimental studies show that at *θ=86⁰* the value of the power coefficient is the highest (higher than upright blades: *δ=90⁰*).
4. The runner with cylindrical blades (#2) shows about 10 times higher values of power coefficient, in comparison with the runner #3 (with profiled blades) – table.1. Reasons should be sought in the particularities of the work process In these turbines: the interaction of the blades with the air flow in the active and passive zones, their curvature, etc. Obviously, only the angle of attack can not provide the necessary circularity around the blade. On the other hand, in these turbines significantly more important is the change of direction and velocity in the working blades. In support of this finding, on fig.9 are shown CFD result analysis: streamlines and velocity distribution for the optimum operating mode of runners #2 ($\varphi_r = 55^0;\ C_w = 9\frac{m}{s}; n = 20\ min^{-1}$) and #3 ($\varphi_r \approx 55^0;\ C_w = 9\frac{m}{s}; n = 18\ min^{-1}$).

Maximum value of the power coefficient Table1.

Runner	#1	#2	#3	#4
Maximum value of C_p, %	0.25	3.07	0.20	4.6



Runner #2 Runner #3

Fig.9. Streamlines and velocities

5. The results of the experimental studies show low energy efficiency of the runners. One possible hypothesis about the relatively low power factor for the tested runners is the higher values of the mechanical losses in the model block. Therefore, studies have been conducted for several air flow speed at the optimum value of the insertion angle of the runner blades. The results of these studies for optimum turbine operation are presented in table 2.

Main results for optimal mode of operation Table 2.

No	C_w, *m/s*	4	6	8	9	10
1.	*n, min*$^{-1}$	12	22	32	38	44
2.	*P, W*	0.38	2.30	6.70	9.72	13.36
3.	*TSR*	0.14	0.17	0.19	0.20	0.21
4.	*Cp, %*	1.35	2.45	3.07	3.07	3.08
5.	*Re.*10^{-5}	2.78	4.18	5.57	6.27	6.96

The data in Table 2 shows that with increasing of the air velicity, the rotation frequency of the turbine naturally increases (in it's optimal mode), respectively the number of Reynolds $Re = C_w D_1/\nu$ (D_1 – inner diameter of the runner, ν – coefficient of kinematic viscosity), while the values of the power factor increase to current speed, then practically do not change. On the other hand, it is known that mechanical losses in bearings increase linearly with an increase in the rotational speed of the runner. Low values of the power factor and the nature of the change in its values with an increase in the flow rate show that, the mechanical losses in the bearings do not significantly affect the turbine's energy balance.

Conclusion

The results of the research have given rise to the following more important conclusions:

1. The characteristics of a vertical wind turbine with four rotors have been investigated, differing in the geometry of the blades (flat, cylindrical, profiled, cylindrical with tilted axis).
2. The results of the research are analyzed, with the most important conclusions being drawn:

 the highest values of the power factor are obtained with the rotor with cylindrical blades with inclined axis;

 the optimum insertion angle for the rotors with cylindrical and profiled blades is in the range $\varphi_r = 50^0 \div 60^0$, while for runner with flat blades is ($40^0 \div 50^0$);

 the mechanical losses in the bearings do not affect significantly the turbine's energy balance.

3. The results obtained, in addition to expanding the knowledge of vertical wind turbines, enable the development of more efficient machines of this type.

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