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Experimental research on increasing the static torque for a small Savonius rotor of helical type

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Abstract. A small Savonius wind turbine of helical type was tested in an open jet wind facility for identifying the optimum position of the rotor blades aiming the maximization of static torque. The two blades of the wind turbine of U shape were twisted up to 180^0 from bottom to top and three values for blade overlap were considered i.e. 0.35, 0.2 and 0.0. The turbine torque was measured for no load conditions and wind velocities between 2-8 m/s. In the same time the air flow through Savonius rotor was observed by using a visualization setup aiming to identify the correlation between the torque and the flow pattern inside the returning blade at rotating angles where the torque has highest values. Best results for the torque coefficient of 0.72 and power coefficient of 0.265 were obtained at a wind velocity of 5.8 m/s and low overlap ratio of 0.2. By measuring the overall torque of the rotor for each case study, the positive effect of pressure recovery was explained as a result of air flow through the blade overlap from the concave side of the advancing blade to concave side of the returning blade for a certain interval of the rotating angle a = 50-60°.

1. Introduction

The Savonius wind turbines are of vertical axis and their rotors are considered as drag-type. These turbines are preferred for some applications because are independent of wind direction, have simple structure and good starting torque characteristics, low noise level. On the other hand, all Savonius wind turbines have poor values for power coefficient and low tip speed ratio. The number of studies related to power producing mechanism of Savonius turbines is large and irrespective of the turbine structure and design these studies are focused basically on: visualization of the flow and measuring the pressure distributions in and around the rotor [1-3], experimental investigations on measuring mechanical parameters for computing power and torque coefficients [4-6], numerical simulations and experimental validation of various models [7-9]. The main research issues for Savonius wind turbines are as follows: reducing the fluctuations of dynamic and static torque by increasing the number of blades [10,11], optimizing the turbine blades design either by modifying their shape [12] or by using supplementary inner blades [13], modifying the turbine aspect ratios [14,15] or number of stages [16,17] for increasing output power, assessment the role of blade overlap on overall flow inside the rotor [19,20], the influence of Reynolds number on the efficiency of the rotor [21,22], the effect of endplates on turbine coefficients an tip speed ratio [5,23]. A special attention among the studies related to Savonius type wind turbine is related to helical rotors due to their ability to enhance classic rotors performance. Similar research issues like above are considered for such type of rotors aiming to maximize the torque and power coefficient such as: studies on Savonius rotors with various twist angles of the blades from bottom to top of the rotor i.e. 0°, 45°, 90°, 135°, 180° [24] or for specific angles - 90° [25] or 180° [26]. From these researches one can observe that better performance for Savonius wind turbine are obtained for two rotor blades with endplates, aspect ratio values between 1.0-2.0, overlap ratios of 0.1-0.2 and increased Reynolds numbers.

In this paper a small Savonius wind turbine of helical type with blades that are twisted up to 180^0 from bottom to top was tested. The aim of the study is to evaluate the optimum blade overlap as function of air flow rate for maximization the torque. It was observed the correlation between the torque and the flow pattern inside the returning blade at critical rotating angles i.e. where the torque has lowest values.

2. Material and methods

The study on wind turbine performance was performed by using a free jet wind facility consisting of a propeller - D = 2 m - and honeycomb for turbulence reduction. The various air velocities are obtained by changing the rotation frequency of the propeller electric motor. A hot-wire anemometer was used for measuring the air current velocity with an accuracy of ± 0.15%; the maximum air velocity was 8 m/s. The torque of the rotor shaft was measured by using a DC generator that transformes the torqe on its axis to electric current and the rotating velocity was measured by means of a laser digital counter. For visualizing the air flow inside the rotor a laser sheet was used and a video camera placed at the bottom level of the transparent rotor. The final position of the camera was settled down after assessing its optimum level for the best flow visualisation - i.e. testing the top and the bottom positions. The shape and the geometric data of the helical Savonius rotor are presented in figure 2, figure 3 and table 1.

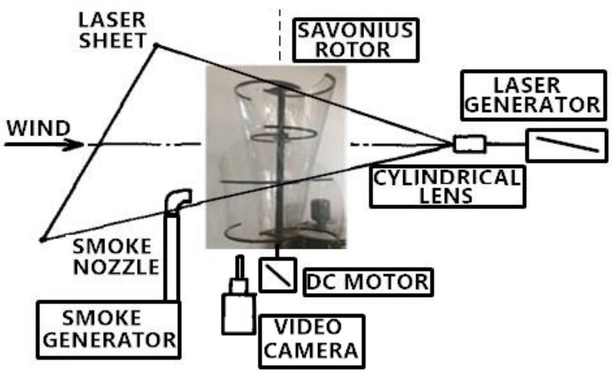


Figure 1. Experimental setup

Figure 2. Savonius rotor

The main relations used for computing the main characteristics for the helical Savonius wind turbine are as follows:

$$P_{max} = \frac{1}{2}\rho A \mathrm{v}^3 \text{ (W)} \quad (1)$$

$$P_r = \frac{1}{2}\rho A(\mathrm{v_1}^2 - \mathrm{v_2}^2)R\omega \text{ (W)} \quad (2)$$

$$C_P = \frac{\frac{1}{2}\rho A({v_1}^2 - {v_2}^2)R\omega}{\frac{1}{2}\rho A v^3} \tag{3}$$

$$\lambda = \frac{u}{V} = \frac{R\omega}{V} = \frac{\pi D n}{60\ v} \tag{4}$$

$$C_T = \frac{C_p}{\lambda}, \tag{5}$$

where P_{max} is the theoretical available power from the air current, P_r - the effective power extracted from the wind, C_P - the power coefficient, λ - the tip speed ratio and C_T - torque coefficient; v = v_1 and v_2 are the average wind velocity values at measuring sections i.e. upstream and downstream the rotor; the distance between the measuring sections and the rotor was of one diameter both upstream and downstream to the rotor; R - rotor radius (m); A is the swept area of the rotor (m^2); ω - angular velocity (s^{-1}); ρ = 1,225 kg/m^3 is the air density.

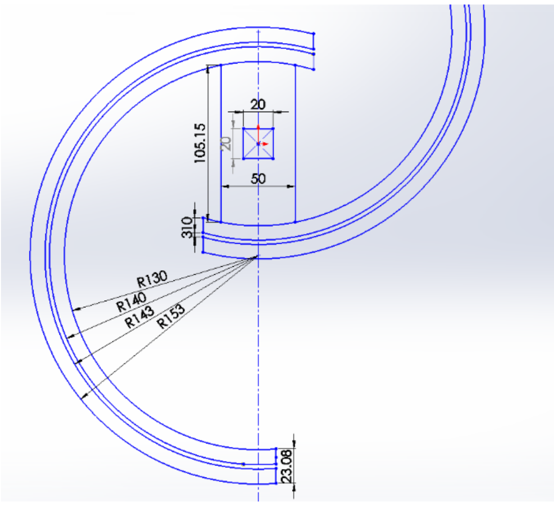


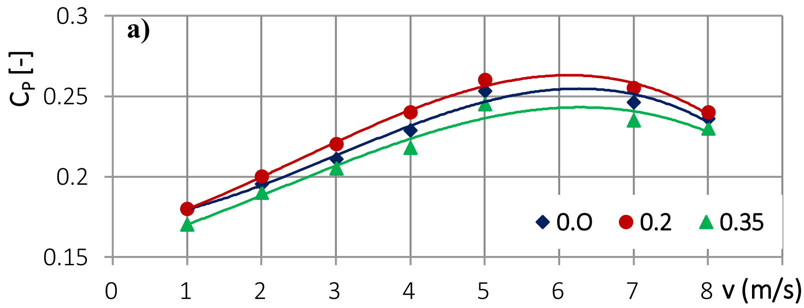
Figure 3. Geometry of the Savonius rotor

Table 1. Data for helical Savonius VAWT – basic case study δ = 0.35

Wind speed	v (m/s)	2 up to 8
Rotor height	H (m)	0.80
Rotor diameter	D (m)	0.456
Swept area	A (m^2)	0.364
Nr. of blades	z (-)	2
Aspect ratio	H/D (-)	1.75
Overlap distance	e (m)	0.1
Twist angle degree	(^{0})	180°
Blade chord lenght	d (m)	0.228
Overlap ratio	δ = e/d (-)	0.35
Solidity	(-)	0.54
Wheight	m (kg)	2.38

3. Experimental results

Experiments were carried out for the three overlap cases considered: 0.35, 0.2, 0.0, mantaining the height of the wind turbine. For each case the wind velocity, torque values and rotation velocity were measured. Also, the instant flow-field in the Savonius rotor was visualized by using the visualzation setup. The characteristics for the 3 rotors are presented in figure 4 a,b,c.



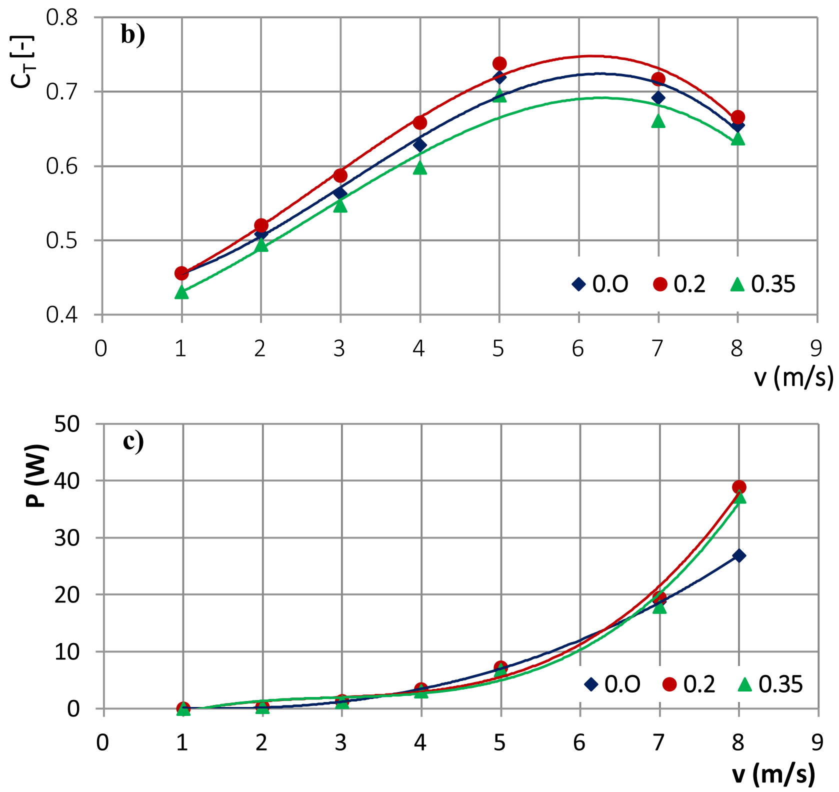


Figure 4. Variation of power coefficient C_P (a), torque coefficient (C_T) (b) and wind power with speed for various blade overlaps – 0.0; 0.2; 0.35 (c)

Figure 4 a illustrates that the best operating point of the turbine is obtained at a wind velocity of 5.7-5.8 m/s. For this wind velocity the maximum value for the power coefficient is $C_P = 0.265$ corresponding to the overlap value of $\delta = 0.2$ – comparing to $C_P = 0.253$ for the overlap value of $\delta = 0.35$ and $C_P = 0.245$ for the overlap value of $\delta = 0.0$. For the case $\delta = 0.2$ the torque was measured at different rotor angles – 0° - 360°. Highest torque value of 0.72 was obtained for the wind velocity of 5.8 m/s corresponding to an angle of rotation $\alpha = 56°$ – figure 5. This result is similar with the one reported in [5].

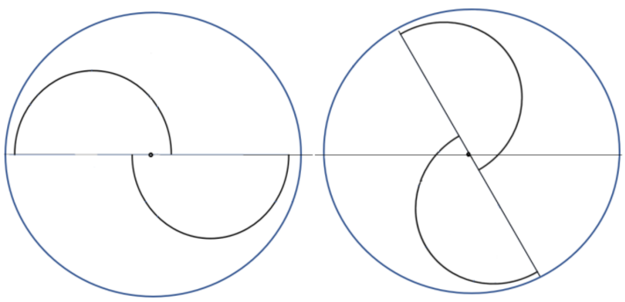


Figure 5. The Savonius rotor for rotating angles: $\alpha = 0°$ and 56°

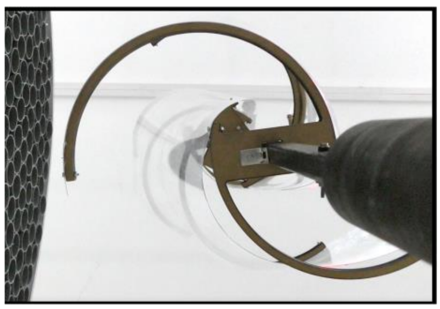


Figure 6. Bottom section of the rotor selected for visualization for $\alpha = 0°$

During the turbine rotation the pressure difference between the concave sides of the rotor blades causes an air flow through the blades overlap section, from the advancing blade to the returning one. The result is increasing the value of the pressure on concave side of the returning blade and therefore decreasing of its negative torque. Hence, higher torque values are related to pressure recovery effect that is the result of air flow through the blade overlap from the concave side of the advancing blade to concave side of the returning blade. If $\delta = 0.0$ the internal flow does not exist and therefore negative torque have high values e.g. at $\alpha = 90°$ e.g. - $C_D = 0.4$ for the convex side of the blade acting in the wind direction and $C_D = 1.7$ for the concave side of the blade acting in the wind direction. For assessing the role of the flow through the overlap, one observes the flow spectrum inside the returning blade for $\alpha = 50° - 60°$ corresponding to the experimental data obtained above. Flow spectrum in the concave returning plate for $\delta = 0.0$ and $\delta = 0.2$ is presented in figure 7.

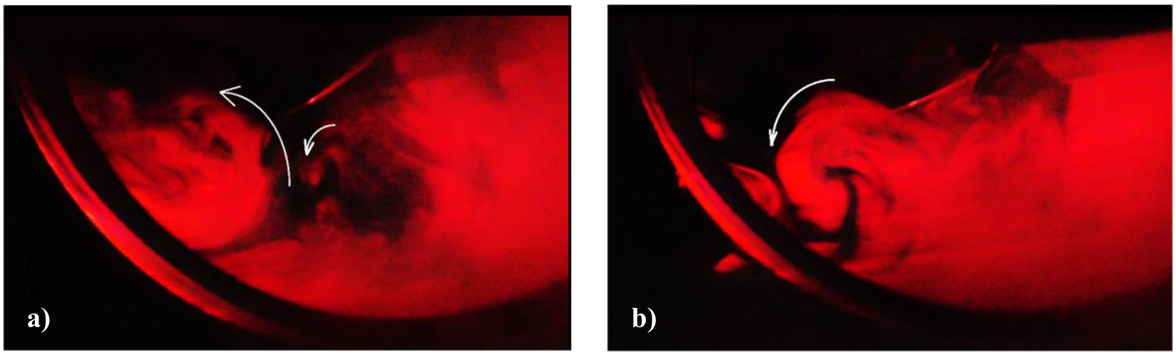


Figure 7. Flow spectrum in the concave returning blade at a rotating angle a = 54° – 56° for: d = 0.0 (a) and d = 0.2 (b)

Figure 7a illustrates that for $\delta = 0.0$ an air vortex is placed on the surface of the blade and therefore a low pressure is acting to increase the drag forces of the returning blade; the overall effect is reducing the torque value of the rotor. For $\delta = 0.2$ the vortex has the opposite rotating direction and it is not attached to the blade i.e. the air flow entering the concave side of the returning blade is acting to separate the vortex from the blade and therefore reducing the drag forces - figure 7b. The overall effect is increasing the torque value comparing with previous case. Therefore, for the proposed Savonius rotor the effect of blade overlap is positive for $\delta = 0.2$. For $\delta = 0.35$ similar flow spectrum is obtained but increased recirculation area inside the rotor increases the aerodynamic losses and decrease the torque values – figure 7b. Also, by increasing the blade overlap the positive influence of the Coandă effect on convex side of the advancing blade is decreasing for torque production [27].

4. Conclusions

A small Savonius wind turbine of helical type was tested in an open jet wind facility for identifying the optimum position of the rotor blades aiming the maximization of static torque. For the U type rotor twisted at 180^0 three blade overlaps were selected for assessing the best performances. The results obtained are as follows:

- the highest value for the power coefficient of $C_P = 0.265$ was obtained for an overlap value $\delta = 0.2$;
- the best value for the torque coefficient was $C_T = 0.72$ for a rotating angle of the rotor $\alpha = 56°$;
- visualization of the absolute flow inside the rotor revealed that increasing the torque value is due to pressure recovery explained as a result of air flow through the blade overlap ($\delta = 0.2$) from the

concave side of the advancing blade to concave side of the returning blade for a certain interval of the rotating angle: $\alpha = 50$ - $60°$.

The results are in line with similar research on performance of Savonius wind turbines where best results are reported for blade overlaps of 0.15-0.2 [24, 26] and aspect ratio of 1-2 [24]; for the present study d = 0.2 and aspect ratio H/D = 1.7. Also, visualization revealed that the flow through the blade overlap are similar with available research that studied the flow and pressure values in and outside the Savonius rotors. Still, some studies have contradictory outputs specially concerning the influence of blade overlap on turbine performance – see [24, 26] – e.g for assessing the performance of the Savonius rotors for d = 0.0.

Future research will be focused on studying the relative motion of the air inside the Savonius rotor for a better design of the blade geometry e.g. providing a gap flow guide to the advancing blade. This type of study (both numerical and experimental) will reveal more of the wind flow behavior in the vicinity of the blades, allowing the authors to improve the torque.

Acknowledgments

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