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Performance Analysis of a Water Savonius Rotor: Effect of the Internal Overlap

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Abstract The water Savonius rotor is classified as a vertical axis water rotor like the Darrieus, Gyromill or H-rotor. The advancing blade with concave side facing the water flow would experience more drag force than the returning blade, thus forcing the rotor to rotate. In this work, we are interested on the study of the of the internal overlap effect of a water Savonius rotor. The experimental results is developed using a hydraulic test bench. The test bench consists on an intake, a control gate, a penstock, a canalization, a test section, an outflow and a pump. A detailed description of the global characteristics is presented such as power, dynamic torque, power and its coefficients.

Keywords: *Savonius rotor, internal overlap, hydraulic test bench, power coefficient, torque coefficient*

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1. Introduction

Savonius rotor is a unique fluid-mechanical device that has been studied by numerous investigators since 1920s. Applications for the Savonius rotor have included pumping water, driving an electrical generator, providing ventilation, and agitating water to keep stock ponds ice-free during the winter [1,2,3,4]. Savonius rotor has a high starting torque and a reasonable peak power output per given rotor size, weight and cost, thereby making it less efficient. From the point of aerodynamic efficiency, it cannot compete with high-speed propeller and the hydro-kinetic turbine electricity generation is mainly aimed for rural use at sites remote from existing electricity grids. It is a useful tool for improving the quality of life of people in these locations and for stimulating local economies. These rotors also can be considered for the wide variety of application like tides, marine currents, channel flows and water flows from industrial processes. Different designs of water current rotor are available for the extraction of energy from the river water or canals. Based on the alignment of the rotor axis with respect to water flow, two generic classes exist. They are horizontal axis turbine (axial turbines) and vertical axis turbine (cross flow turbines). Horizontal axis turbines are mainly used for extraction of the ocean energy. These turbines are expensive for small power applications. Vertical turbines generally used for small scale power generation and these are less expensive and required less maintenance compared to horizontal axis water turbines. Savonius rotor, helical turbine, Darrieus turbine and H-shaped Darrieus are commonly used vertical axis turbines. Various types of water current turbines are being installed and tested worldwide for various ranges of powers. GCK technology limited (USA), installed a Gorlov helical water turbine (diameter of 1 m and height of 2.5 m) in the Uldolomok Strait off the coast of Korea. Similarly Verdant Power Ltd. (USA) installed a three bladed horizontal axis water turbine as free flow turbine in east river New York [5]. Alternative Hydro Solutions Ltd. in Ontario has developed vertical axis turbines specifically meant to harness the water energy from river [6]. Literature suggests that there is a gaining of popularity for water turbines [7,8,9]. Horizontal axis turbines are common in tidal energy converters and majority of marine current turbines are horizontal axis turbine [10]. They are very similar to modern day wind turbines from design and structural point of view. In the vertical axis turbines domain, the Darrieus turbines, Savonius turbine and Gorlov helical water turbines are generally used. The Gorlov turbine has the blades of helical structure. Gorlov [11] proposed a new helical turbine to convert kinetic energy of flowing water into electrical or mechanical energy. Many researchers have adopted various techniques to maximize the performance and improve the starting torque characteristics of Savonius turbine with wind as working medium. These include use of guide vanes, V-plate deflector [12], deflector plate [13,14] and blade with flat and circular shielding [15]. Some of these techniques require change in design of blade and other involves supplementary devices addition to the system. For example, Mohamed et al. [16] carried out a numerical analysis for identifying the optimum shielding of the returning blade of a Savonius wind rotor. Two

dimensional numerical investigations were carried out using OPAL (Optimizing Algorithms) along with commercial CFD package FLUENT at a fluid velocity of 10 m/s and a tip speed ratio of 0.7. Investigation on the modified Savonius rotor (with shaft) reported by Modi and Fernando [17] was an effort in the direction of improvement of performance of Savonius wind turbine by changing the shape of the blade. Modified Savonius rotor with shaft was reported to have a maximum coefficient of power around 0.32. However, these tests were based on closed wind tunnel testing and coefficient of power was obtained by extrapolation. Kamoji et al. [18] investigated the performance of modified forms of conventional rotors with and without central shaft between the end plates.

According to these anterior studies, it has been noted a paucity on the study of the water Savonius rotor performance [19,20,21,22]. For thus, We are interested in this paper on the experimental characterization of a vertical axis water Savonius rotor type using a hydraulic test bench equipped with a specific instrumentation. In particular, a detailed description of the internal overlap effect on the water Savonius rotor was developed.

2. Materials and Method

Figure 1. Hydrodynamic test bench

The used hydrodynamic test bench consists on an intake, a control gate, a penstock, a canalization, a test section, an outflow and a pump. The collector is a parallelepiped where the water flow inside a square tank located above the test section shape on a closed circuit (Figure 1). In this section, we are interested on the study of the internal overlap effect of a water Savonius rotor. This rotor consists of two buckets of diameter d=100 mm and height H=200 mm. It is assembled on a common axis and secured with a screw nut at an angle of 180° (Figure 2). Particularly, we have considered the internal overlap equals to (e-e')/d=0, (e-e')/d=0.2 and (e-e')/d=0.3 (Figure 3). In this work, the experimental study involved the rotation of the Savonius water rotor. Experimental tests for the determination of global characteristics such as the power, the dynamic torque, and its coefficients required the use of the hydrodynamic test bench. Otherwise, the test bench should be equipped with a specific instrumentation for the development of various experimental tests necessary in the laboratory scale. To achieve this goal, we use a permanent magnet dynamo creating a constant magnetic flux through the coil of the rotor, driven by the turbine rotation. The flux variation undergoes by rotating the coil creates a voltage proportional to the rotational speed. Why the higher water flow increases, the turbine rotates faster, and the generated current increases. By connecting the resistor with the multi-meter in the output of the generator, the generator is rotated by the dynamometer. For a same rotational speed imposed by the dynamometer, we change the electrical resistance and we measure the current supplied by the generator and the rotational speed of the Savonius rotor. Indeed, the dynamic torque and the power can be deduced.

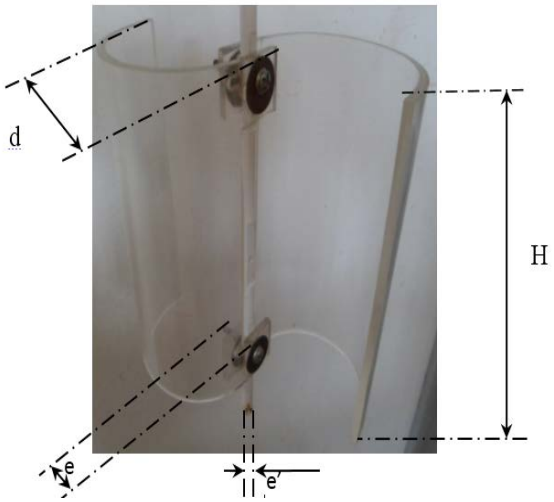

Figure 2. Geometrical arrangement

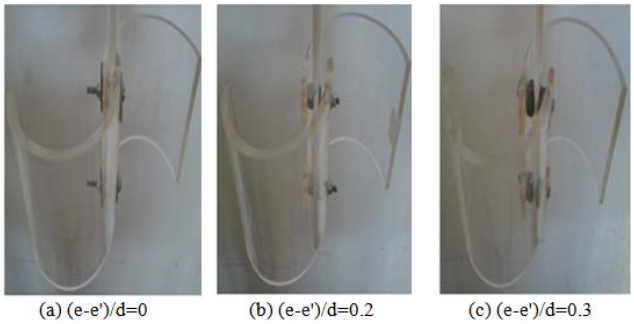

Figure 3. Internal overlap cases

3. Experimental Results

3.1. Power

Figure 4 shows the variation of the power in function of the rotation speed for different internal overlaps equals to (e-e')/d=0, (e-e')/d=0.2 and (e-e')/d=0.3. These curves are superimposed on the same scale. These results are obtained at a speed water equal to V=2.45 $m.s^{-1}$ corresponding to a Reynolds number equal to Re=588300. According to these results, these curves have a parabolic shape. Moreover, these results show that the internal overlap has a direct effect on the presentation of these curves. In fact, we find that the power reaches the most important values for the internal overlap (e-e')/d=0.3. With the decrease of the internal overlap, a gradual decrease of

the power is then reported. In fact, it has been noted that the maximum value of the power is equal to P=19.28 W. It is obtained in the case of an internal overlap equal to (e-e')/d=0.3 for a rotation speed equal to Ω=737 rpm. With the decrease of the internal overlap, we find that the extremum characteristic decreases on value. For example, for the internal overlap (e-e')/d=0 the maximum value of the power is equal to P=15.05 W for a rotation speed Ω=685 rpm. The increase of the power value is due to the decrease of the Savonius rotor diameter. This implies that when the diameter decreases the Savonius rotor power decreases also.

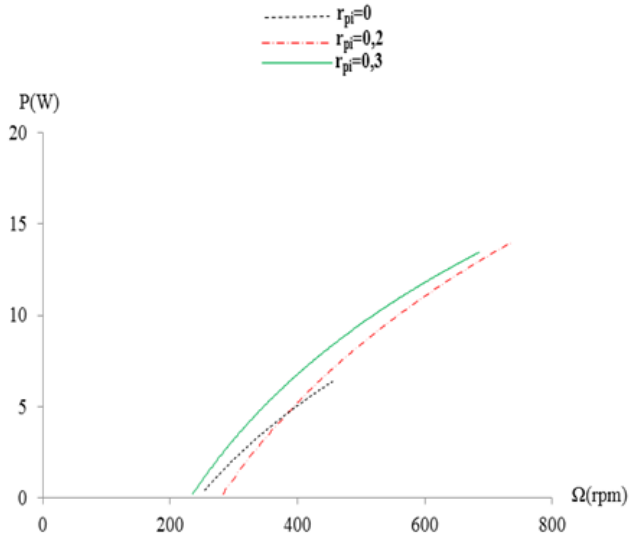

Figure 4. Variation of the power P for different internal overlap

3.2. Dynamic Torque

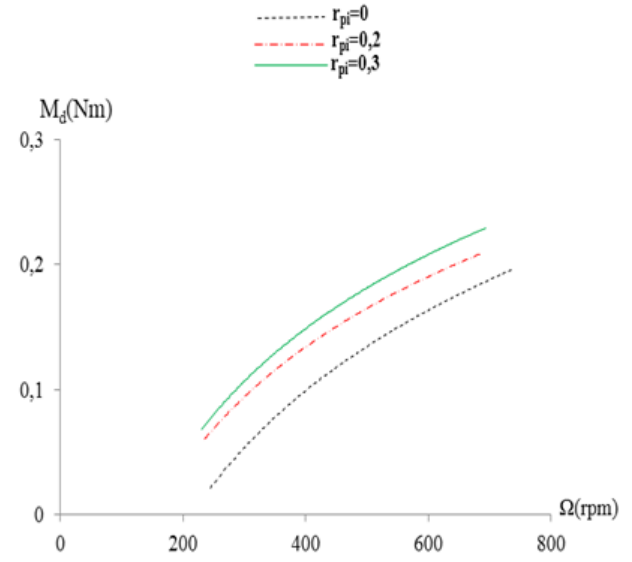

Figure 5. Variation of the dynamic torque M_d for different internal overlaps

Figure 5 shows the variation of the dynamic torque M_d in function of the speed of rotation for different internal overlaps equals to (e-e')/d=0, (e-e')/d=0.2 and (e-e')/d=0.3. These curves are superimposed on the same scale. These results are obtained at a speed water equal to V=2.45 $m.s^{-1}$ corresponding to a Reynolds number equal to Re=588300. According to these results, these curves have a parabolic shape. Moreover, these results show that the internal overlap has a direct effect on the presentation of these curves. In fact, we find that the dynamic torque reaches the most important values for an overlap (e-e')/d=0.3. With the internal overlap decrease, a gradual decrease of the dynamic torque M_d is then reported. In fact, it has been noted that the maximum value of the dynamic torque is equal to M_d=0.25 N.m. It is obtained in the case of an internal overlap (e-e')/d=0.3 for a rotation speed equal to Ω=737 rpm. With the decrease of the internal overlap, we find that the extremum characteristic decreases of value. For the internal overlap (e-e ')/d=0, the maximum value of the dynamic torque is equal to M_d=0.21 N.m for a rotation speed Ω=685 rpm. The increase of the dynamic torque value M_d is due to the decrease of the Savonius rotor diameter. This implies that when the diameter decreases, the dynamic torque of the Savonius rotor decreases also.

3.3. Power Coefficient

Figure 6 shows the variation of the power coefficient C_p in function of the specific speed for different internal overlaps equals to (e-e')/d=0, (e-e')/d=0.2 and (e-e')/d=0.3. These curves are superimposed on the same scale. These results are obtained at a water speed equal to V=2.45 $m.s^{-1}$. In these conditions, the Reynolds number is equal to Re=588300.

According to these results, these curves have a parabolic shape. Moreover, these results show that the internal overlap has a direct effect on the presentation of these curves. In fact, we find that the power coefficient reaches the most important value for the overlap equal to (e-e')/d=0.3. With the decrease of the internal overlap, a gradual decrease of the power coefficients values C_p is then reported. In fact, it has been noted that the maximum value of the power coefficient is equal to C_p=0.327. It is obtained in the case of an internal overlap equal to (e-e')/d=0.3 for a specific speed equal to λ=2.51. With the decrease of the internal overlap, we find that the extremum characteristic decreases of value. For the internal overlap (e-e')/d=0, the maximum value of the power coefficient is equal to C_p=0.215 for a specific speed λ=3.027. The increase of the power coefficient value C_p is due to the decrease of the Savonius rotor diameter. This implies that when the diameter increases, the Savonius rotor efficiency increases also.

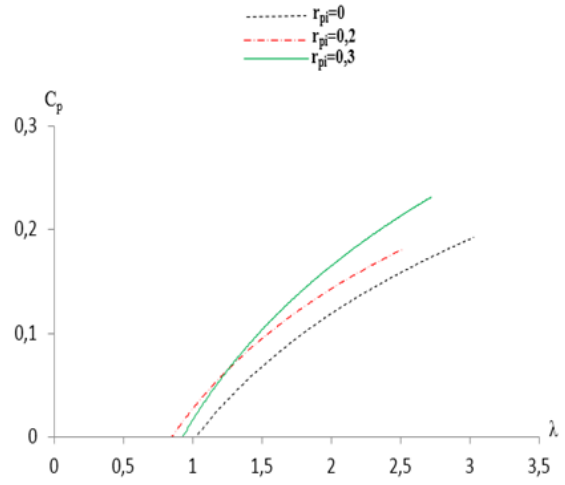

Figure 6. Variation of the power coefficients C_p for different internal overlap.

3.4. Dynamic Torque Coefficient

Figure 7 shows the variation of dynamic torque coefficient in function of the specific speed for different internal overlap equal to (e-e')/d=0, (e-e')/d=0.2 and (e-e')/d=0.3. These curves are superimposed on the same scale. These results are obtained at a speed water equal to v=2.45 m.s^{-1} corresponding to a Reynolds number equal to Re=588300.

According to these results, these curves have a parabolic shape. Moreover, these results show that the internal overlap has a direct effect on the presentation of these curves. In fact, we find that the dynamic torque coefficient reaches the most important values for an overlap (e-e')/d=0.3. With the decrease of the internal overlap, a gradual decrease of the of dynamic torque coefficient C_{Md} is then reported. In fact, it has been noted that the maximum value of the dynamic torque coefficient is equal to C_{Md}=0.26. It is obtained in the case of an internal overlap (e-e')/d=0.3 for a specific speed equal to λ=2.51. With the decrease of the internal overlap, we find that the extremum characteristic decreases of value. For the internal overlap (e-e')/d=0, the maximum value of the dynamic torque coefficient is equal to C_{Md}=0.155 for a specific speed λ= 3.02. The increase of the dynamic torque coefficient value C_{Md} is due to the decrease of the Savonius rotor diameter. This fact implies that when the diameter decreases the dynamic torque coefficient Savonius rotor decreases also.

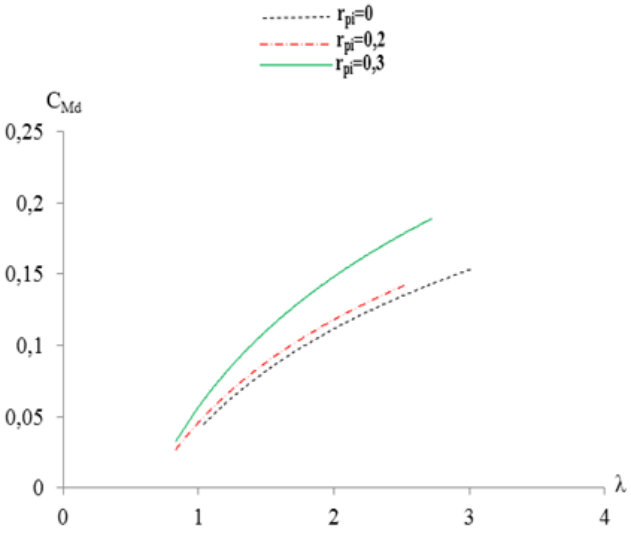

Figure 7. Variation of the dynamic torque coefficient C_{Md} for different internal overlaps

4. Conclusion

In this paper, we focalise our attention on the study of the overlap effect on the global characteristics of the water Savonius rotor. Particularly, we have studied the variation of the power, the dynamic torque, and its coefficients depending on the rotational and the specific speed. In this work, we confirm that the global characteristics of the Savonius rotor increases in the used test section with the increase of the overlap.

In the future, we suggest the deflector addition to improve the rotors performance.

Acknowledgement

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Nomenclature

C_{Md} dynamic torque coefficient
C_p power coefficients
d rotor diameter [mm]
H Rotor height [mm]
M_d Dynamic torque [N.m]
P power [W]
V Water speed [m/s]
ρ Density of the water [kg.m^{-3}]
μ Dynamic viscosity [m.s^{-2}]
λ specific speed
Ω Rotational frequency [rad.s^{-1}]

Acknowledgement

The authors would like to thank the Laboratory of Electro-Mechanic Systems (LASEM) members for the financial assistance.

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