AN EXPERIMENTAL STUDY OF STAGGER ANGLE EFFECT ON THE PERFORMANCE OF MARINE SAVONIUS VERTICAL AXIS WATER TURBINE

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Abstract

This paper investigated the performance of Savonius's vertical axis water turbine by varying its stagger angles. In this study, the shape of the turbine blade was modified based on the Myring $n = 1$ equation as well as adding a disturbance in the form of a circular cylinder placed in front of the advancing blade as a barrier. The method used in this research was an experimental study in a water tunnel at a velocity of 0.22 m/s. The turbine had a size of 0.4 m in height and 0.4 m in diameter. The experiment results showed that the use of a circular cylinder in front of the advancing blade had a significant effect on increasing turbine performance. This could be proven by placing a circular cylinder with $ds/D = 0.4$, $S/D = 0.95$, and $\theta = 60°$, where the angular speed achieved was about 53.27% at $\omega = 1.4182\ rad/s$ and the result of maximum power coefficient (Cp) is in about 0.4356.

Keywords: *Stagger angle effect, Savonius's vertical axis water turbine, Shape modification, Circular cylinder.*

1. Introduction

The turbine modification had been performed by the Savonius and Darrieus designs. The Darrieus has been developed to increase the performance by varying the height of the fin. The best result occurs at a height of 2.5 mm with a 45.23% improvement in performance (Setiawan et al., 2023). The development of Savonius water turbine has developed rapidly as shown in Table 1. The research was carried out in a 5 x 3 m^2 water tunnel with a water speed of 0.98 m/s at a Reynolds number of 1.82 x10^5. The performance of the Savonius turbine with the vertical type showed a maximum Cp of 0.038, 0.049, and 0.04 (khan et al., 2009). Next, a study of the Savonius turbine was also carried out at a water speed of 1.1 m/s in a 0.6 x 0.5 m^2 tunnel at a Reynolds number of 1.48 x10^5. Another study related to the Savonius turbine with a horizontal exhibited a maximum Cp value of 0.25 (Nakajima et al., 2008). The same experiment was carried out at different Reynolds numbers of 1.2 x10^5 and 2.4 x10^5, obtaining maximum Cp values of 0.275 and 0.25 for two-stage and one-stage, respectively (Nakajima et al, 2008). This experiment was conducted with a vertical-typed Savonius turbine in a 0.73 x 0.33 m^2 tunnel at a fluid velocity of 1.3 m/s (Re=0.7 x 10^5) The results showed that the power coefficient increased by 50%. (Kailash, at al., 2012).

Table 1. Research roadmap of Savonius Water Turbine

Researcher	Khan et al, 2009	Nakajima et al, 2008	Nakajima et al, 2008	Kailash et al, 2012
Reynolds number ×10^5	1.82	1.48	1.2, 2.4	0.7
Velocity (m/s)	0.98	1.1	1.1	1.32
Tunel Dimension (mxm)	5 × 3	0.6 × 0.5	0.6 × 0.5	0.73 × 0.33
Axis Orientation	Vertical	Horizontal	Horizontal	Vertical
Turbine Testing	one-stage, two-stage, three-stage Savonius water turbine with overlap ratio 0.207	One-stage, Savonius water turbine	one-stage and two-stage, Savonius water turbine with an overlap ratio of 0.36	one-stage, two-stage, three-stage Savonius water turbine with modifying deflector

Researcher	Khan et al, 2009	Nakajima et al, 2008	Nakajima et al, 2008	Kailash et al, 2012
Parameter	CP, CT	Cp, Flow visualization	Cp, Flow visualization	CP, CT
The Results	Cpmax in about 0.038, 0.049, dan 0.04	Cpmax in about 0.25	CPmax in about 0.275 for two-stage and 0.25 for one-stage	Cpmax increased 50% for one stage modified by the plat deflector at optimal position.

The development of wind turbines was studied in more detail to increase the performance. This paper aimed to improve the performance of the Savonius-type water turbine. In this research, a disturbance in the form of a cylinder with a diameter of 45 mm and a length of 280 mm was used. The disturbance was placed in front of the returning blade with a distance variation $(S/D) = 1.5 < S/D < 2.4$. This study was conducted in a wind tunnel with dimensions of 457 x 304 x 304 mm in length, height, and width. The wind tunnel used in this research was a subsonic and open circuit typed with an 8-sided cross-section shape. The model employed in this study had dimensions 60 mm in diameter, 80 mm in height, and 14 mm in overlap. The output power measurement process was carried out by connecting the Savonius turbine shaft to the electric generator shaft using a flexible coupling. The output of the electric generator was used to power the load in the form of lights. The results revealed that the use of a circular disruptive cylinder placed in front of the returning blade of a Savonius-type wind turbine was effective in improving its performance. The circular cylinder placed in the vicinity of $S/D = 1.7$ proven to be the most effective position. The investigation in this research was insufficient since the size of the Savonius wind turbine generates a significant blockage when compared with the wind tunnel cavity (Retno Dewi et al., 2016). Hence, further study needs to be conducted comprehensively.

Based on the numerous research conducted above, it can be stated that there are still many methods to improve the performance of Savonius-type water turbines. It is possible to improve the performance of a Savonius-type water turbine by referring to the study conducted by Retno Dewi (2016) who modified by adding an obstacle in front of the returning blade on a Savonius-type wind turbine. Then, research carried out by Wenlong Tian et al, (2015) was modified by using the Myring equation $n = 1$ to design the blades of the Savonius-type wind turbine. Therefore, the present study proposed to complete the investigation of the Savonious water turbine by installing obstacles or disturbances in the form of circular cylinders positioned in various locations in front of the advancing blade with a certain diameter. The present study also used the same turbine for Myring $n = 1$ and placed the cylinder at a stagger angle and side of the advancing blade to improve the performance of the turbine.

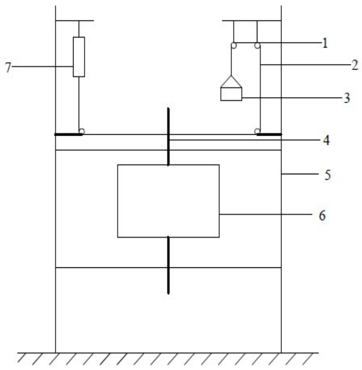
2. Material and methods

2.1. Material

This research used a water tunnel with a cross-sectional size of 1 x 1 m^2 using a pump to drain the fluid as shown in Figure 1. The turbine used in this research was a Savonius with a diameter of 40 cm, and a height of 40 cm, with a Myring turbine type $n = 1$ as depicted in Figure 2. The turbine was installed in the water tunnel and loaded following a scheme as illustrated in Figure 3. The turbine rotation was measured using a tachometer by applying a load until the turbine stopped.

Figure 1. Experimental set up

Figure 2. Savonius turbine with type of Myring n=1



Component Name:
1. Pulleys
2. Nylon thread, D = 1 mm
3. Scales
4. Shaft
5. Supporting structure
6. Rotors
7. Spring balance

Figure 3. Schema of loading

2.2. Methods

The method used in this research was an experimental study using a water tunnel test section as shown in Figure 1. Data collection was carried out in the water tunnel at a speed of 0.3 m/s. First, the experiment was carried out on a turbine that was moving without any load by measuring the turbine rotation in RPM (revolutions per minute) using a tachometer. Then, a load was introduced until the turbine stopped. The turbine rotation was converted into rad/s to calculate the tip speed ratio (TSR) of the turbine.

To calculate the torque the load value and pulley diameter were used, whereas the angular velocity parameter in rad/s was used to calculate the power produced by the Savonius turbine. The water properties were taken from its density value in kg/m^3 and viscosity value in $kg/m.s$. The power coefficient was obtained from the product of the torque coefficient and TRS. The basic equations used in calculating TSR, torque, torque coefficient and power coefficients are as shown in Equations 1, 2, 3, and 4, respectively.

$$TSR = \frac{.D}{2.U} \qquad (1)$$

$$T = (M - S).(d_{sh} + r_n) \qquad (2)$$

$$C_T = \frac{T}{T_f} \qquad (3)$$

$$C_p = TSR \;\; C_T \qquad (4)$$

3. Results and discussion

3.1. Torque Coefficient toward Tip Speed Ratio (TSR)

The correlation between the torque coefficient and the TSR values is presented in Figure 4. To distinguish the curve in the figure, an example was made as follows. The curve belongs to Myring 8_60 and represents a Savonius turbine with a cylinder diameter of 8 cm at a stagger angle of 60 degrees. As shown in Figure 4, the lowest torque coefficient value occurred at a stager angle of 0 degrees and the torque coefficient value increased at a stager angle of 30 degrees. The highest torque coefficient value was achieved at a stagger angle of 60 degrees.

The torque coefficient at a stagger angle of 0 degrees was the lowest compared to other stagger angles. It indicated that the position of the cylinder at a stagger angle of 0 degrees blocked the upstream flow towards the turbine. As a result, the torque produced by the Savonius turbine was lower than without the cylinder. A cylinder with a stagger angle of 30 degrees showed that the turbine torque coefficient had increased because some of the upstream flow could flow more towards the Savonius turbine, thus increasing the torque coefficient. In addition, increasing the stagger angle to 60 degrees could improve the torque coefficient which exceeded the value without the cylinder. The results also revealed that the stagger angle of 60 degrees increased the torque coefficient significantly compared to others.

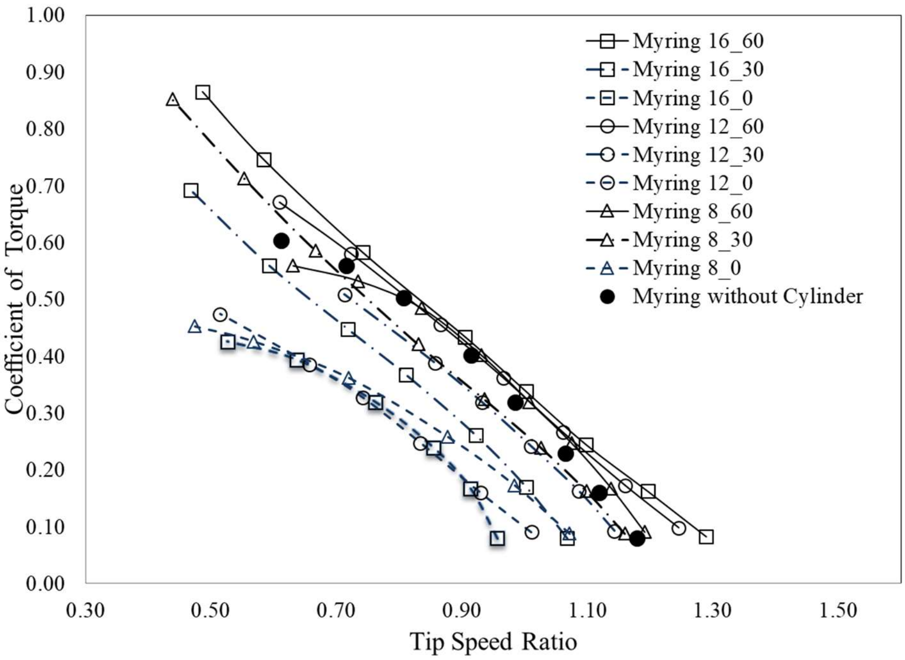


Figure 4. Torque coefficient toward TSR

3.2. Power Coefficient toward Tip Speed Ratio (TSR)

Figure 5 presents the trend of the power coefficient towards TSR values. The data from the experiment of the Savonius water turbine (Myring $n = 1$) with a variation of cylinder being placed in front of the advancing blade was compared with the one without a circular cylinder and the conventional blade Savonius water turbine. The comparison is shown in Figure 5. As depicted in Figure 5, smaller tip speed ratio (TSR) values resulted in greater coefficient of power Cp. However, at certain tip speed ratio (TSR) values, the coefficient of power Cp values decreased due to it had reached its peak. This occurrence was consistent with the turbine rotation reduction and approaching stop due to the load on the turbine shaft.

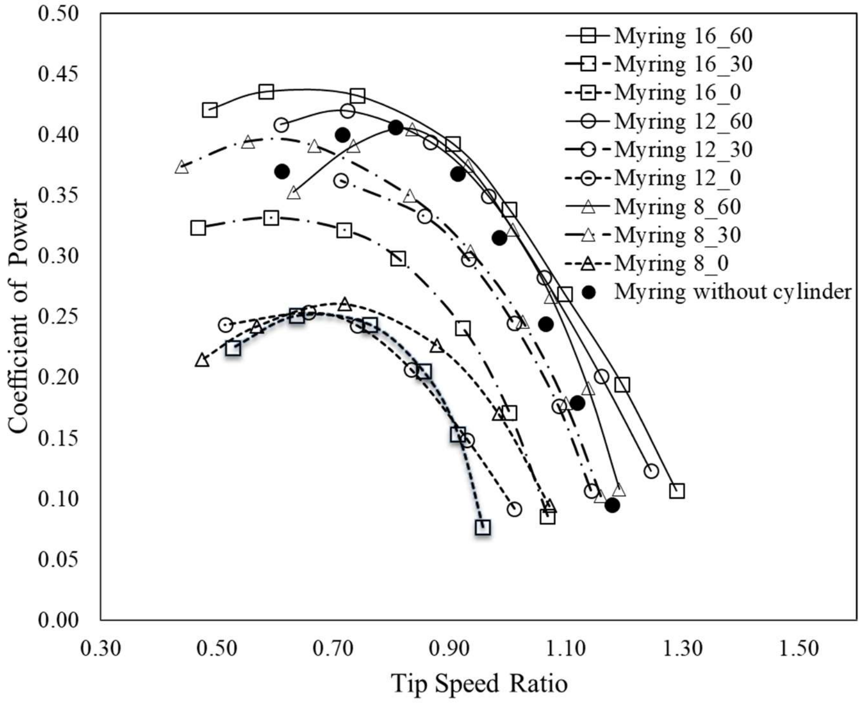


Figure 5. Power coefficient toward TSR

Myring with stagger angles 0° and 30° had the Cp value decrease compared to Myring without cylinder as can be seen in Figure 5. The phenomenon at a stagger angle of 0° showed that the flow from upstream to downstream would be blocked by the cylinder so that the flow quantity would decrease when passing through the Savonius turbine causing the turbine performance to decrease on larger cylinders. Likewise, the same phenomenon occurred at a stagger angle of 30°. However, a stagger angle of 60 degrees showed that the flow from upstream to downstream would increase the velocity on the upper side of the cylinder with increasing cylinder diameter so that performance increased on larger cylinders.

3.3. Improvement of the Turbine Performance

The performance improvement of the Cp values is summarized in Table 2. At stagger 0° the improvement presented negative values indicating the peak of Cp value is below the conventional one. From Table 2, the best Cp value could be achieved using at a cylinder with a diameter of 16 cm and a stagger angle of 60° (Setiawan et al., 2019). Furthermore, a cylinder installed at a stagger angle of 0° would provide a barrier to flow from upstream to downstream. Finally, a 60° stagger angle increases the speed on both the upper side and lower side of the cylinder, resulting in a nozzle with an advancing side. As a result, it increased the torque and turbine power and the detailed discussion regarding performance in Cp has been carried out in Figure 2.

Table 2. Improvement of Cp

Parameter	Cp peak	TSR	Improvement (%)
Conventional	0.2842	0.7679	0
Myring without cylinder	0.4061	0.8069	42.89
Myring 8_0	0.2605	0.719	-8.33
Myring 8_30	0.3975	0.5528	39.86
Myring 8_60	0.3778	0.6756	32.93
Myring 12_0	0.2546	0.6109	-10.42
Myring 12_30	0.3625	0.7136	27.55
Myring 12_60	0.4198	0.7232	47.71
Myring 16_0	0.2509	0.6366	-11.72
Myring 16_30	0.3993	0.6975	40.50
Myring 16_60	0.4356	0.6318	53.27

4. Conclusion

The installation of a circular cylinder in front of a Savonius turbine with various size ds/D of 0.2, 0.3, and 0.4 was carried out on the advancing blade side with variations in distance $S/D = 0.95$ and stagger angle of 0°, 30°, and 60°. The experiment was proposed to figure out those variation effects on the performance of the Savonius turbine. The experiment was conducted in a water tunnel with a water velocity of 0.22 m/s. The findings of this study revealed that the best power coefficient could be obtained at a stagger angle of 60°, resulting in Cp value of 0.4356.

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