Experimental Investigation of Cylinder Rotation Effect on the Advancing Side to Savonius Wind Turbine Performance

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***Abstract*—Rotating the cylinder increases velocity in the upper and lower sides, increasing velocity between the advancing and cylinder by rotating in the opposite direction. The increase of velocity in the attached flow will decrease the pressure. The total drag will increase, which can improve the performance of Savonius. The study will be done experimentally to obtain the effect of cylinder obstacles at the advancing area of the Savonius wind turbine. The experiment used conventional savonius without overlap ratio having a size of 0.4m in diameter and height. The cylinder diameter ratio used was ds/D of 0.1, 0.2, 0.3, and 0.4, with stationary and rotation of 25 rotations per minute. The experiment would calculate the tip speed ratio, torque coefficient, and power coefficient. The best result obtained is a cylinder with a 0.4 diameter ratio (ds/D), 25 rotations per minute, improving the coefficient of power of 66.193% compared with no cylinder.**

***Keywords*—Savonius, cylinder, experiment, coefficient of torque, coefficient of power**

I. INTRODUCTION

The design of turbine development has been conducted in the study to determine performance. Design could be performed numerically and experimentally, which numerical study could be applied in manufacturing [1], energy and others. In this work, Savonius has been enhanced by setting obstacles in returning and advancing areas. The experiment is done with the variation of overlap ratio and conventional with a set of two deflector plates on the advancing and returning area at Reynolds number (Re) 1.32×10^5. The experiment indicated that the maximum Cp was obtained at 0.35 at a TSR value 1.08 [2].

The combination of two blades turbine saw the performance of shape circle and elliptical, showing that the Cp maximum increases by 11% to conventional shape at TSR of 0.79 [3]. The performance of Savonius has been investigated experimentally with variation buckets and overlaps. The best performance has occurred at the overlap range from 0.1 to 0.15. Patel *et al.* [4] have continued this work by numerically showing that the best torque was reached at the overlap of 0.2. The equation of myring for a turbine has been studied to investigate the best performance numerically and experimentally. The best performance occurred at n = 1 [5–9]. An experimental and numerical study did an increase in performance by adding the deflector [10–12]. The effect of a rotating cylinder on the turbine performance has been performed experimentally and numerically [13].

The information on performance characteristics has been carried out using experimental methods in water and air-fluid. The conclusion of the experimental study shows the same characteristic [14]. The cylinder in front of the returning area has been done by investigating flow over the turbine with the variation of stagger. The result shows that stagger 60° can enhance turbine performance. The cylinder in front of the turbine center would influence the performance drop [15]. The cylinder was placed in front of the turbine showing an enhancement of performance even though the cylinder was placed in returning area. The rotating cylinder in front of the turbine would enhance performance [13]. Wind and water turbines had the same trend graphic by looking at the pressure coefficient [14].

The obstacle type can be used to enhance the performance of the turbine. Combination types like cylinders and deflectors can enhance the performance utilizing CFD 2D [12]. Flow visualization was performed by putting the cylinder in front of returning, obtaining the highest performance at a stagger angle of 60° with the increase of pressure on the front side and the reduction of the back of the advancing area using the CFD approach.

Manuscript received November 12, 2022; revised March 30, 2023; accepted May 16, 2023.

doi: 10.18178/ijmerr.12.5.284-289

The stagger angle of 0˚ in front of the turbine did not allow because it can be a blockage [16]. The cylinder in the front returning blade can increase the performance of the Savonius turbine by about 12.2%, with a tip speed ratio of 0.65 at S/D = 1.4 [17].

A review study about optimization toward the Savonius turbine was done to see the application in the benefits of hydrokinetic energy. A study of each parameter would influence turbine performance discussed overall, and there is no review study exclusively to fill the gap [18]. The deflector effect, velocity, and shape blade simulation have been done to reveal the deflector increasing the efficiency by about 31% [19]. Innovation of deflectors has been carried out to improve the performance by about 50% compared to stationary [13]. Numerical had been carried out to determine improving the Savonius. The k-ε realizable turbulence model had shown the more accurate [20]. Improving Savonius using the multiple-quarter blade has been done by using CFD. The best performance increased by about 8.89% and 13.69% [21].

This work can be implemented by looking for the potential wind in Indonesia. The cylinder would be added to the small turbine to rotate it. The application can be represented in Fig. 1. The airflow goes to the cylinder installed in front of the advancing area. The turbine rotates like in Fig. 1, and the cylinder rotates at 25 rpm in the opposite direction. The cylinder would increase the velocity at the upperside, influencing the attached flow at the edge of advancing. The pressure would decrease at the side of the attached flow. The turbine performance follows the total pressure drag increase.

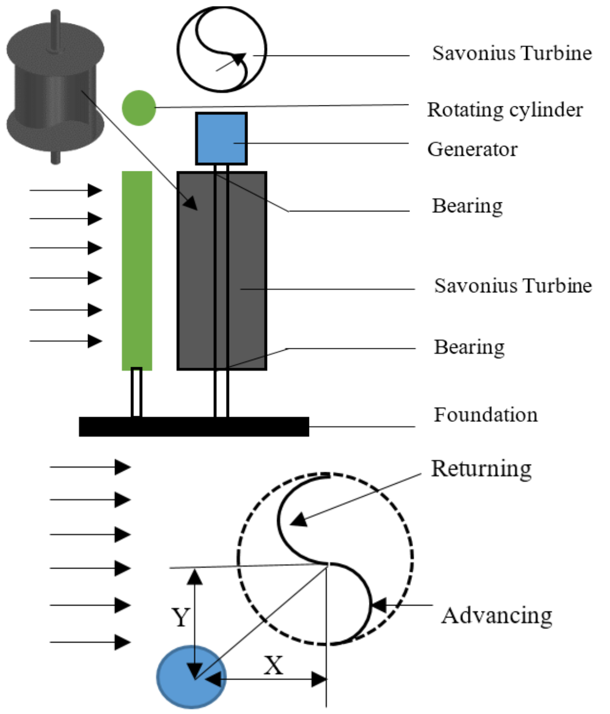


Figure 1. Application of research

From the research background, the rotation of a cylinder will increase the velocity on the upper side of the cylinder. The velocity will influence the area of the attached flow. The flow in the attached flow area will reduce the pressure in the convex blade (advancing), and the total net pressure will increase; however, the performance will indicate an increase. Therefore, the outcome of this study would be calculated, and the best cylinder diameter would be obtained to produce the maximum performance. The study calculated the Ct and Cp experimentally with variation in the diameter ratio ds/D = 0.1, 0.2, 0.3, 0.4 also with 25 rpm and 0 rpm rotation.

II. Methodology

A. Parameters

This study obtained the parameters to calculate the performance of wind turbines as the power coefficient. The first equation was Tip Speed Ratio (TSR) by taking data measurement of Savonius rotation in Eq. (1). The rotation of the turbine can determine torque to calculate the torque coefficient (C_T) in Eqs. (2) and (3). The power coefficient (Cp) is a cross between TSR and torque coefficient in Eq. (4);

$$\mathrm{TSR} = \frac{\omega \times D}{2 \times U} \tag{1}$$

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

$$C_T = \frac{T}{T_f} \tag{3}$$

$$C_p = \mathrm{TSR}\ C_T \tag{4}$$

Angular speed is ω, the free stream velocity is U, the Savonius turbine diameter is D, the power coefficient is Cp, and the moment coefficient from experimental data is C_T.

B. Experimental Setup

The turbine used in the work was the Savonius type having a diameter of 0.4 m and a height of 0.4 m with an aspect ratio of 1. The center of the turbine installed a shaft to connect the bearing in the system. A turbine can be represented in Fig. 1. The Savonius will be installed in front of a wind tunnel. The experiment was carried out using a conventional Savonius turbine. The cylinder placed at horizontal distance ratio (X/D) = 0.5 (20 cm) and vertical distance ratio (Y/D) = 0.9 (36 cm) from the center of the turbine on the advancing side blade in Fig. 3.

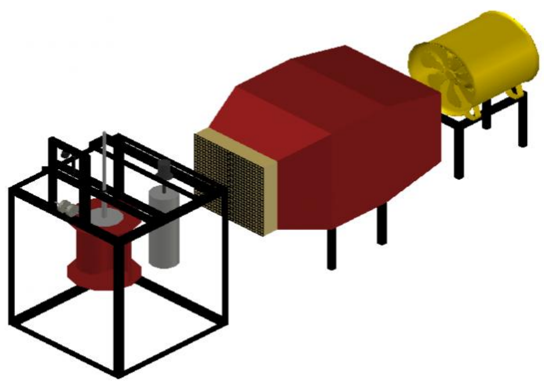


Figure 2. Experimental arrangement

An experimental arrangement in this work can be represented in Fig. 2. The blower will blow the air from the surroundings to enter the wind tunnel. The honeycomb is placed before a wind tunnel to reduce the flow turbulence. And then the airflow blows against the turbine. The experiment was done in the Fluid Mechanics Laboratory Shipbuilding Institute of Polytechnic Surabaya.

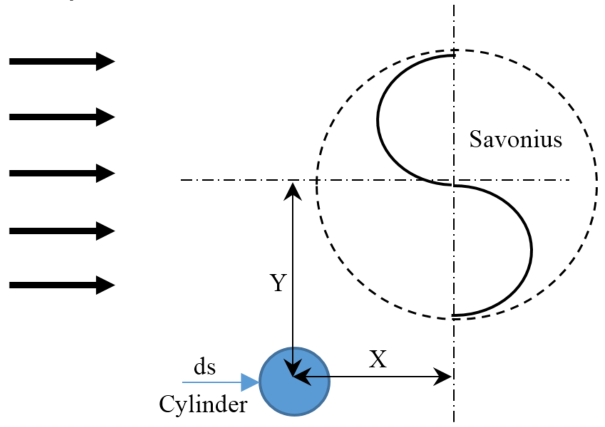
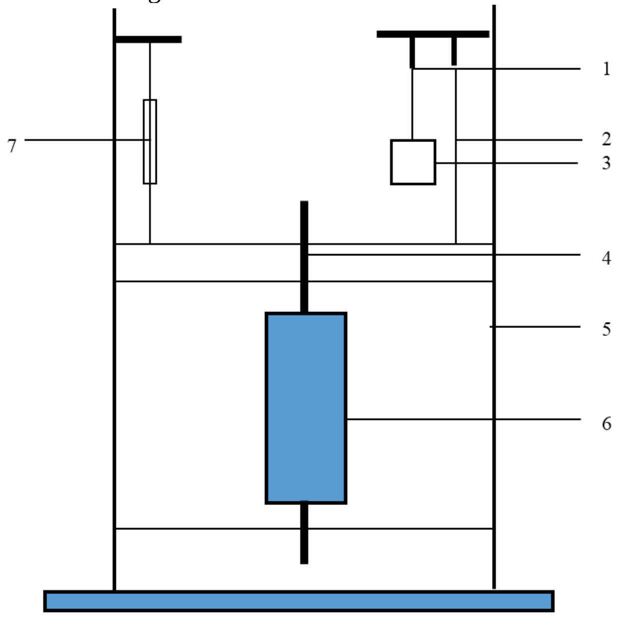


Figure 3. Cylinder Arrangement

The brake dynamometer is used to measure the dynamic torque generated by the rotation of the turbine [2], as represented in Fig. 4. Brake dynamometer measurement is done by a pulley system, mass, and spring connected by nylon. The dynamic torque is measured on the rotating turbine. Testing is done by placing the mass of scales from light loads until the turbine almost stops and measuring the turbine's rotation with the tachometer.



(1) Pulley, (2) Nylon string 1 mm diameter, (3) Weighing pan, (4) shaft,
(5) Supporting structure, (6) Savonius rotor, (7) Spring Balance

Figure 4. Measurement of torque

C. *Tachometer*

The tachometer is a digital measurement measuring rotation at the rotating object with a range of reading levels from 0.05 to 7.6 m with a reading accuracy of 0.01% or ±1 digit. The tachometer is used to measure air velocity in front of a honeycomb. The tachometer is represented in Fig. 5. The result of turbine rotation can be obtained tip speed ratio.

Figure 5. Tachometer

D. *Anemometer*

The velocity in the experiment used 7 m/s kept constant and tested by using an anemometer in front of a wind tunnel. Anemometer can measure the air velocity at a range of 0.4 m/s to 35 m/s with an accuracy of 1% or ± 0.01, as displayed in Fig. 6.

Figure 6. Anemometer

The details of this work can be seen in the following flow chart, which can be displayed in Fig. 7.

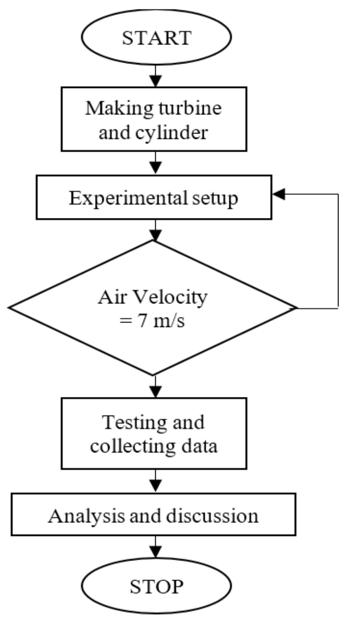


Figure 7. Flow chart

E. Calibration

The calibration would be done to determine the wind velocity in m/s. The equation of voltage as the function of mean velocity and the result of calibration can be displayed in Fig. 8. Calibration wa be done by using the anemometer and observing the blower voltage that can see in the inverter (volt). The calibration would be used to determine voltage in volts at the velocity of 7 m/s.

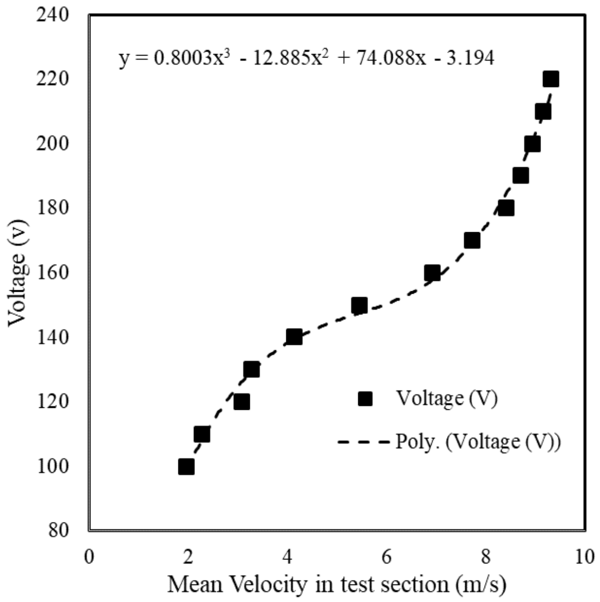


Figure 8. Calibration curve

III. Result and Discussion

A. Torque and Power Coefficient

Fig. 9 illustrates the torque coefficient (CT) from the low tip speed ratio (TSR) to the high tip speed ratio. The lowest coefficient of torque occurred without cylinder and the best coefficient of torque occureed at ds/D = 0.4. The CT increased by the TSR decreased. The turbine would be added the mass step by step until stop experimentally. The mass would influence the torque of turbine increase and the rotation would reduce as be represented in Fig. 9.

Fig. 10 illustrates the coefficient of power (CP) from low tip speed ratio (TSR) to high tip speed ratio. The lowest power coefficient occurred without cylinder variation in about 0.21 at a tip speed ratio 0.72. The best power coefficient achieved on cylinder diameter variation ds/D = 0.4 with 25 rotations per minute which are 0.3501 at a tip speed ratio of 0.8082 and increasing 66.193% than without cylinder condition. That condition can happen because when a cylinder is placed on the advancing blade side, the fluid velocity on the upper side of the cylinder will be faster, affecting the turbine-attached flow area. When the diameter of the circular is increased, the fluid velocity will also increase. It makes the attached flow area of the turbine bigger and creates higher pressure. The bigger pressure difference will occur on the advancing blade side and returning blade side, thus making the turbine performance increase.

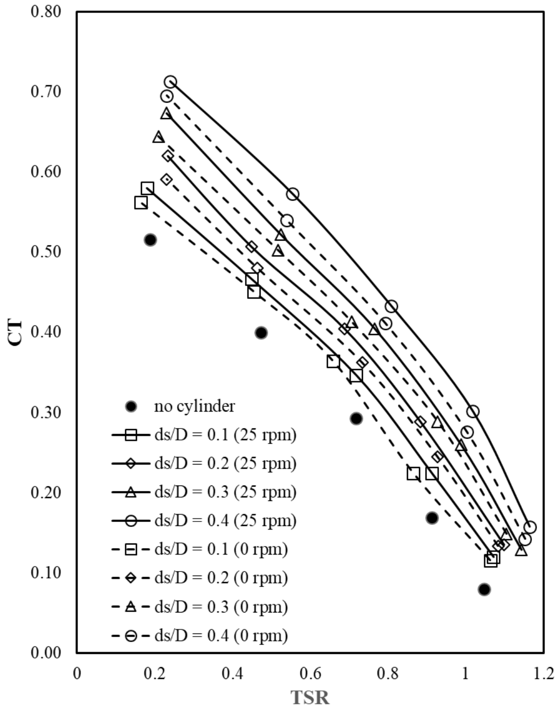


Figure 9. Coefficient of Torque as the function of TSR

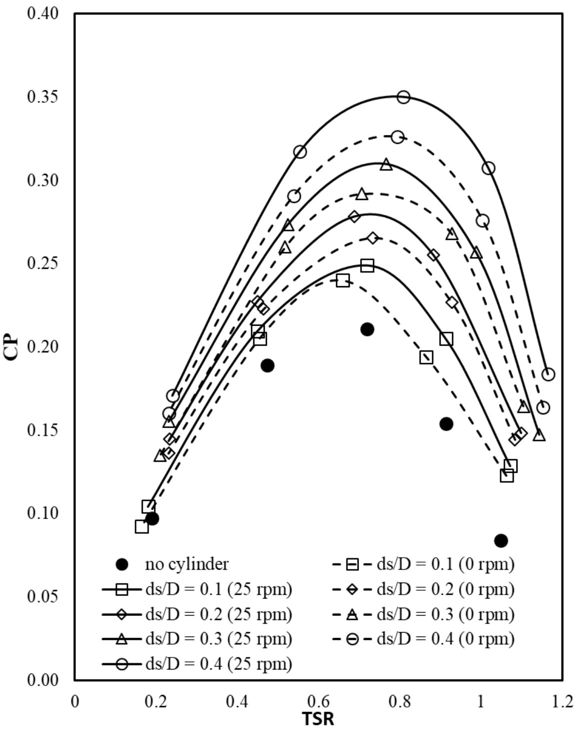


Figure 10. Coefficient of Power as the function of TSR

B. Improvement of Performance

Savonius turbine performance has been disturbed by a cylinder installed in front of turbines at advancing side with the change of the diameter cylinder and turbine ratio (ds/D) of 0.1, 0.2, 0.3, and 0.4. The cylinder has been rotated 25 rpm could influence the performance that can be illustrated in Table I.

TABLE I. DIFFERENCE OF MAXIMUM OF POWER COEFFICIENT (C_P) AFTER ROTATION GIVEN TO CYLINDER.

Variation	TSR	C_p	(%)	Result
No cylinder	0.7184	0.2107	-	-
ds/D = 0.1 (0 rpm)	0.6585	0.2399	13.889	Increasing
ds/D = 0.1 (25 rpm)	0.7184	0.2489	18.182	Increasing
ds/D = 0.2 (0 rpm)	0.7333	0.2656	26.057	Increasing
ds/D = 0.2 (25 rpm)	0.6884	0.2784	32.134	Increasing
ds/D = 0.3 (0 rpm)	0.7064	0.2919	38.561	Increasing
ds/D = 0,3 (25 rpm)	0.7663	0.3098	47.071	Increasing
ds/D = 0.4 (0 rpm)	0.7932	0.3260	54.751	Increasing
ds/D = 0.4 (25 rpm)	0.8082	0.3501	66.193	Increasing

From Table I, we can see that rotation given to the circular cylinder placed at the advancing blade side will increase the turbine performance. The best increase in the coefficient of power is diameter variation ds/D = 0.4 in about 66.193%.

IV. CONCLUSION

The cylinder rotation could influence and increase the performance of turbine at all of variation. The best configuration of a cylinder on the advancing blade side of the savonius wind turbine is with a diameter ratio (ds/D) of 0.4 with a rotation of 25 rpm. The maximum power coefficient is 0.3501 at a tip speed ratio of 0.8082, with increased 66.193% higher than without cylinder.

CONFLICT OF INTEREST

The authors have stated that there is no interest conflict in the article.

AUTHOR CONTRIBUTIONS

Priyo A. Setiawan wrote the article journal, Triyogi Yuwono performed conceptual and reviewed the article; Projek P. S. Lukitadi, Emie Santoso, Nopem Ariwiyono, Muhammad Shah, Bambang Antoko, and Budi Prasojo observed the experiment and collected experimental data; Endang P. Purwanti and Edy P. Hidayat helped to write the article.

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