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Experimental Study of Blade Angle Effect on Two-Stage Vertical Shaft Hydrofoil Water Turbines on Power and Efficiency

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Abstract. The limitations of fossil energy sources are one of the most fundamental energy problems. Therefore, it is necessary to make power plants with alternative sources that are environmentally friendly and affordable. One effort that can be done is using water energy to drive turbines. This study aims to determine the effect of blade angle on the total power and efficiency produced by the hydrofoil water turbine. In this study using a two-stage hydrofoil turbine with NACA 64-212 standard blade. The turbine blade angle is varied by 4, 6, and 8 degrees. Water discharge is varied by 40, 50, and 60 L/s. The results show that the largest total power is 3.046 Watt, achieved at a 4-degree blade angle with a water discharge of 60 L/s. And the highest efficiency is 11.22%, achieved at a 4-degree blade angle with a water discharge of 40 L/s.

Keywords: Hydrofoil; Water turbine; Two-stage; Blade angle.

1. Introduction

The issue of renewable energy innovation as an alternative to fossil energy has grown rapidly. This appears as an anticipatory step to the reduction in fossil energy sources due to massive use, the reduction in fossil energy can affect the scarcity and increase in the price of electricity [1]. On the other hand, the limitations of electrical energy are one of the most fundamental energy problems. This can be seen from the many remote areas that have not been electrified. Therefore, it is necessary to continue to develop power plants with renewable energy that are easily applied in remote areas. One effort that has been made is to utilize water energy as a turbine mover [2,3].

However, hydroelectric power plants that are often used are hydroelectric power plants with high fall and large discharge models. While hydroelectric power plants with the model of flat currents and small water discharges have not been widely used, whereas in some areas of Indonesia have considerable potential to be developed. So an effort and research need to be done to utilize the potential of a horizontal water flow energy source for electricity generation, one of which uses a vertical shaft crossflow turbine type [4,5]. This research is very important considering the potential of hydropower is spread almost throughout Indonesia and is estimated to reach 75,000 MW [6,7].

Choi, et al (2008) conducted a numerical study (CFD) to determine the effect of turbine structural configuration on the performance and internal flow characteristics of cross flow type turbines by varying the shape of the nozzle, runner inlet angle (nozzle angle), runner blade angle and number of blades. The results showed that the shape of the nozzle, runner blade angle, and number of blades greatly influenced the performance and shape of fluid flow in the turbine [8]. Mafruddin, (2016) has conducted research on blade angle variations in cross-flow turbines, and concluded that the nozzle



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angle and blade angle greatly affect the performance of the water turbine. The highest turbine efficiency of 77% was obtained using a 16° blade angle [9]. According to Adrian, et al (2014), the performance of kinetic turbines is very dependent on the number of blades, flow direction, turbine blade angle, flow velocity, and blade dimensions. However, in the kinetic turbine the main factor is the speed of water flow [7]. Asroful, et al (2016) conducted research on the effect of variations in the angle of the input blade of the blade on the performance of the kinetic turbine and concluded that the angle of the input of the blade of the blade affected the performance of the kinetic turbine. The smaller the angle of the input blade of the bowl, the greater the curvature of the blade. The greater the curvature of the blade of the bowl, the greater the tangential force, torque, power, and efficiency [6].

Crossflow turbines generally use horizontal shafts and curved blades so that they require directional flow and casing [10–12]. In this research, the crossflow turbine made adopts the Darrieus turbine design which is generally used for Vertical Axis Wind Turbine (VAWT) type wind turbines which have high efficiency and are capable of producing large enough torque. Darrieus turbine blade shape in the form of aero-foil or hydrofoil has the advantage of not taking into account the direction of fluid flow because of its symmetrical shape, and is able to operate at head and low speed [13]. To maximize the amount of water energy that can be captured, the crossflow turbines can be mounted in stages [14]. To obtain optimal performance, it is necessary to examine the effect of the blade angle on the Two-Stage Vertical Shaft Hydrofoil Water Turbines on Power and Efficiency.

2. Method

This research was conducted by direct experimental by making a prototype. Turbines are made in two pieces and arranged parallel to the artificial channel as shown in Figure 1. The turbine runner is bound to the channel, then the channel is dipped into the river flow. The shape of the turbine blade refers to the NACA (National Advisory Committee for Aeronautics) standard which provides standards in the design of an airfoil or hydrofoil. Hydrofoil geometry has a major influence on aerodynamic characteristics with important parameters in the form of lift (lift force generated) [15]. The type of blade used is NACA 64-212 as shown in Figure 2.

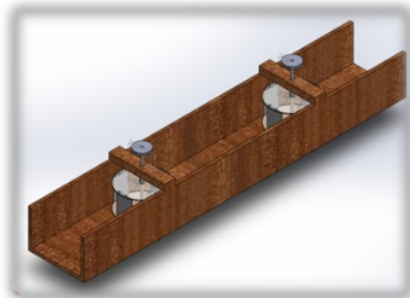


Figure 1. Testing installation.

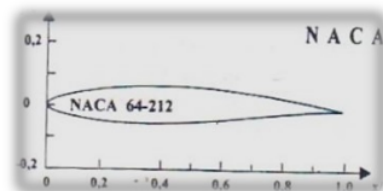


Figure 2. NACA 64-212.

The second stage turbine blade angle is varied by: 4°, 6°, and 8° as shown in Figure 3. The source of water flow is varied by 40 L/s, 50 L/s, and 60 L/s by adjusting the height of the water cap. The rotation speed of the water turbine is measured using a digital tachometer. While the output torque is measured by the braking method on a pulley using a belt that is attached to a spring balance. To calculate the power of water flow in a certain cross section, the following equation is used in the calculation [11]:

$$P_w = \frac{1}{2} \cdot \rho \cdot A \cdot V^3 \quad (1)$$

Where P_w is water power, ρ is water density, V is water velocity. To calculate the turbine torque, the equation is used:

$$T = F \cdot l \quad (2)$$

Where F = force ($F_1 - F_2$), l = pulley radius. Whereas to calculate the turbine power the following equation is used,

$$P_t = T \cdot \omega \quad (3)$$

Where T is turbine torque, ω is turbine angular velocity. The efficiency of a crossflow turbine is determined by the comparison between the turbine power produced and the water power, as shown in the equation [3]:

$$\eta = \frac{P_t}{P_w} \times 100\% \quad (4)$$

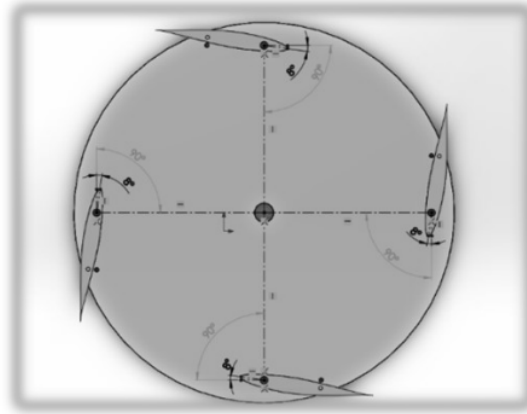


Figure 3. Turbine blade angle.

3. Result and Discussion

3.1. Effect of blade angle variations on the speed rotation of turbine

Based on Figure 4, the highest rotation is obtained at 4° blade angle variations with 60 L/s water discharge and the resulting speed is 338 rpm, while the lowest rotation is obtained at 8° angle variation with 40 L/s water discharge and the resulting speed is 225 rpm. The rotational speed of the turbine is affected by water discharge and blade angle. From Figure 4 it can be seen that the greater the flow of water and the smaller the angle of blade opening applied, the faster the rotation generated by the turbine. And conversely, the smaller the flow of water and the greater the angle opening of the blade, the slower the turbine rotational speed.

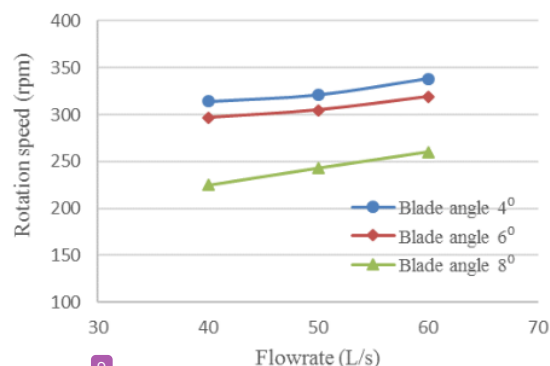


Figure 4. Graph of the effect of blade angle on the first-stage turbine speed rotation.

Based on Figure 5, it can be seen that the second highest level of turbine rotation is obtained at 4° blade angle variation with 60 L/s discharge and the resulting rotational speed is 246 rpm, while the lowest rotation is obtained at 8° angle variation with 40 L/s water discharge and speed the result is 127 rpm. As in the first level turbine, the highest rotation in the second level turbine results in the largest water discharge and the smallest blade angle.

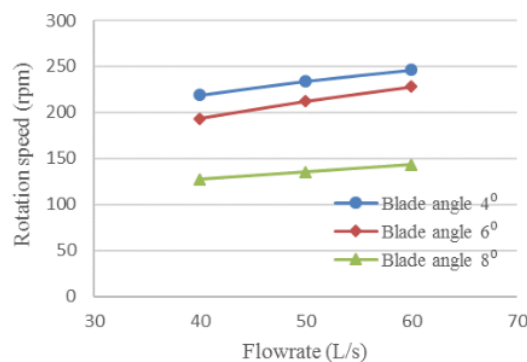


Figure 5. Graph of the effect of blade angle on the second-stage turbine speed rotation.

3.2. Effect of blade angle variations on the torque of turbine

Based on Figure 6, the greatest torque is obtained at 4° blade angle variations with a discharge of 60 L/s and the resulting torque is 0.057 Nm, while the smallest torque is obtained at 8° angle variations with a water discharge of 40 L/s and the resulting torque is 0.019 Nm. The torque produced in the turbine is affected by the discharge and blade angle. As in rotational speed measurements, the greater the water discharge and the smaller the blade angle opening that is applied, the greater the torque produced by the turbine, and vice versa, the smaller the water discharge and the greater the blade angle opening, the smaller the torque velocity of the turbine. This is because crossflow turbines with hydrofoil blades are classified as kinetic turbines, the rotating speed and torque of the turbine is determined by the speed of the water that hits the blade.

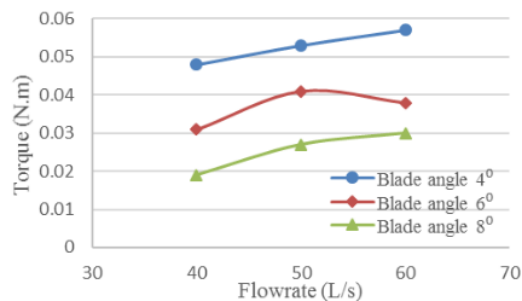


Figure 6. Graph of the effect of blade angle on the first-stage turbine torque.

Based on Figure 7, the largest torque at the second level turbine is obtained at 4° blade angle variations with a discharge of 60 L/s with a value of 0.040 Nm, while the smallest torque is obtained at 8° angle variation with a water flow of 40 L/s with a value of 0.012 Nm. The torque in the second level turbine tends to be smaller than the torque in the first level turbine. This is because the water force from the front has been captured by the first level turbine, resulting in a pressure drop.

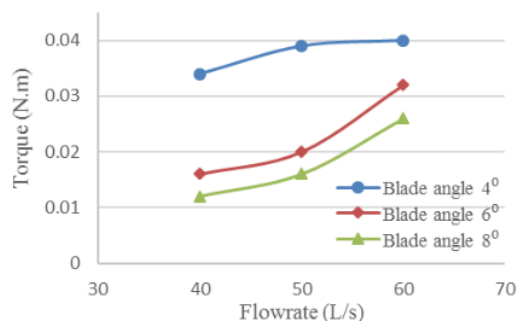


Figure 7. Graph of the effect of blade angle on the second-stage turbine torque.

3.3. Effect of blade angle variations on the total power of turbine

Based on Figure 8, the largest turbine power is 3.03 watts obtained in the use of 4° blade angle variations with a discharge of 60 L/s. While the lowest turbine power is 0.61 watts obtained at the use of 8° blade angle variations with a discharge of 40 L/s. Turbine rotation at blade angle 6° is closer to blade angle 4°, but torsion angle of blade 6° is closer to blade angle 8°. So the 6° turbine power is in the middle between the 4° and 8° turbine power.

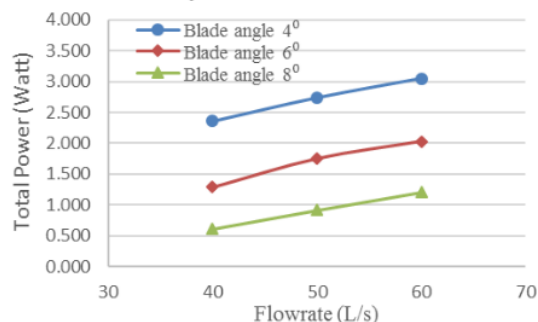


Figure 8. Graph of the effect of blade angle on total power of turbine.

3.4. Effect of blade angle variations on efficiency of turbine

Based on Figure 9, the largest turbine efficiency is 11.15% obtained at the use of a 4° blade angle with a discharge of 40 L/s, while the lowest turbine efficiency is 2.12% obtained at the use of an 8° blade angle with a discharge of 60 L/s. The greater the water discharge the lower the efficiency, this is because the rotation and torque of the kinetic turbine is limited so that the increase in turbine power is not able to compensate for the increase in water power provided [15]. To get greater efficiency, it might be possible to increase the number of turbine levels.

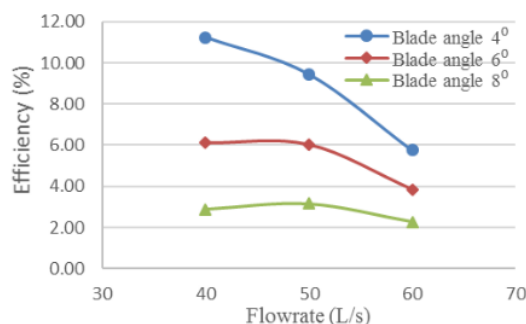


Figure 9. Graph of the effect of blade angle on total turbine efficiency.

Conclusion

The smaller the turbine blade angle, the greater the rotating speed and torque of the turbine produced, so the power and efficiency of the turbine are also greater. The greater the flow of water the greater the rotating speed and torque of the turbine so that the greater the turbine power, but the increase in turbine power is not able to compensate for the increase in water power so that efficiency decreases.

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