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by Fahruddin Arasy

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Experimental study of two-stage vertical axis hydrofoil water turbine NACA 64-212 with variation of blades number

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Experimental study of two-stage vertical axis hydrofoil water turbine NACA 64-212 with variation of blades number

M F Fadlil, A Fahruddin* and A Akbar

Mechanical Engineering Department, Universitas Muhammadiyah Sidoarjo, Jl. Raya Gelam No.250, 61271, Sidoarjo, Indonesia

*arasy.fahruddin@umsida.ac.id

Abstract. Efforts to utilize the potential energy sources of water flow for electricity generation generally using water turbines. One of them is the hydrofoil turbine which can work without any water head, by utilizing the speed of the river flow. This study aims to determine the power and efficiency generated by a prototype hydrofoil water turbine with a multi-stage installation. This experiment used a hydrofoil turbine with NACA 64-212 standard with variations in the number of blades: 4, 5, and 6 blades on the second stage. The experimental results show that the highest total power is 2.5 Watt at the number of blades 6 at a water discharge of 0.057 m3/s. While the greatest efficiency produced was 7.47% with the number of blades 6 at a water discharge of 0.036 m3/s.

1. Introduction

River flow is a renewable energy source that can be utilized for electricity generation. In Indonesia, many power plants have been developed using water turbines, but most of these turbines use high pressure head as a driving force, such as waterfalls and dammed water. However, not all regions in Indonesia have potential energy in the form of pressure head, but they have water kinetic energy. It is necessary to make efforts to utilize the kinetic energy source of water for electricity generation. One of them is a Darrieus turbine that can work without falling water, by utilizing river flow velocity [1–6].

Jaini, et.al has examined the Darrieus six-blade water turbine with variations in the configuration of the blade arrangement [7]. The results show that parallel configuration produces the best efficiency. Irsyad has researched about Darrieus water turbines with variations in turbine diameter and water flow rate. The results of his research showed that the greater the diameter of the turbine the greater the torque produced [8]. Bachant and Wosnik have investigated helical cross-flow hydro turbines, and the results show that 3 blades produce better power and efficiency than 4 blades. However, this still needs to be investigated for parallel configurations [9].

The use of hydrofoil turbines in the water flow will leave a lot of energy that has not been captured. Therefore, the use of two-stage rotors is expected to increase the power and efficiency of hydrofoil water turbines [10,11]. The optimal number of blades needs to be investigated to get the best results.

2. Methods

This research using direct experiments by making a water channel made from wooden board, making two turbine runners, and two frame turbine holders. Research to be conducted using independent variables and dependent variables. The independent variable in this study consisted of the number of blades of second-stage hydrofoil turbine, with variations: 4 blades, 5 blades and 6 blades. As well as water discharge: 0.036, 0.048, and 0.057 m3 / s. Dependent variables in this research are turbine power (P) and efficiency (η).

The turbine runner includes three main parts, there are: the shaft of the runner from iron material, circular plate for blade holder from acrylic with 20 cm diameter, and the hydrofoil blade with 10 cm cord width. The turbine blades which are used in the form of an airfoil with NACA 64-212 standard are shown in Figure 1. The turbine runner under study was of the Darrieus type with a hydrofoil blade shape, with the design and size as shown in Figure 2.

Power output is calculated by multiplying torque by turbine rotational speed. Turbine rotational speed measured with a digital tachometer. While torque measured with the braking force of the rope against the pulley. The rope around the pulley is pulled and the end of the rope is bounded to digital scales. To calculate the turbine power generated, the equation is used:

$$P_t = 2\pi . N . T \quad (1)$$

where: P_t = turbine power (Watt)
N = rotational speed (rpm)
T = torque (N.m)

The power of water calculate with the following equation [6]:

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

where: P_w= water power (Watt)
ρ = water density (kg/m^3)
A = ducting cross section area (m²)
V = water velocity (m/s)

The turbine efficiency is determined by the comparison between the turbine power produced and the water power, as shown in the equation:

$$\eta = \frac{P_t}{P_w} \, x \, 100\% \quad (3)$$

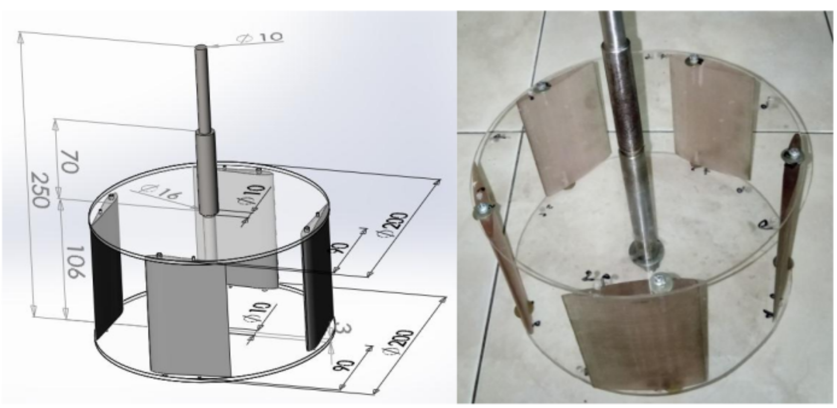

Figure 1. Rotor design.

Figure 2. Testing channel.

3. Results and discussion

From the experimental results, data taken in the form of rotation and torque for each change in discharge and number of turbine blades. The data obtained is used to calculate turbine power and efficiency. Then the data is displayed in several graphs to facilitate analysis of the results.

3.1. Effect of water discharges on the speed rotation of turbine

In Figure 3 shows that the greater the discharge given at each variation of the number of blades, the rotation speed generated will increase. The highest rotation speed is produced on the variation of 6 blades with a discharge of 0.057 m^3/s, resulting 316.64 rpm. Turbine rotation speed increases with increasing flow rate. While the number of blades in the second stage turbine has no significant effect on the rotation speed of the first stage turbine.

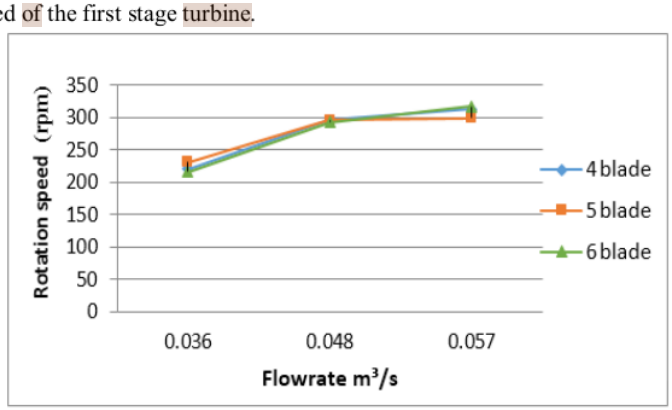

Figure 3. The first-stage turbine speed rotation.

Figure 4 shows that the greater the discharge, the greater the rotation speed produced by the second stage turbine. The highest rotation speed is produced on the variation of 6 blades with a flow rate 0.057 m^3/s, resulting 293.5 rpm. The number of blades 6 has a better water catchment capacity, but the closer blades will interfere the flow towards the blades nearby. The number of blades 4 gives a better response to changes in water discharge.

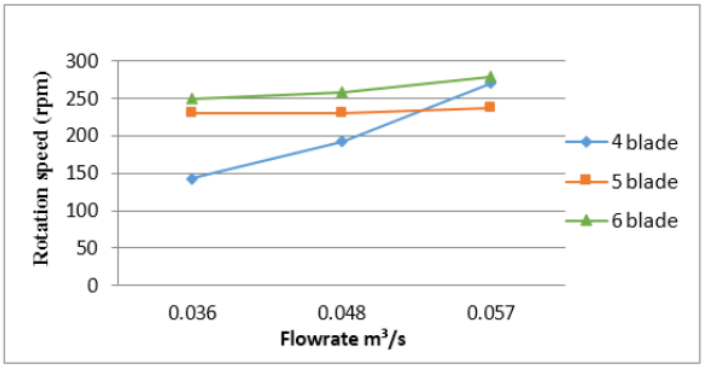

Figure 4. The second-stage turbine speed rotation.

3.2. Effect of water discharges on the torque of turbine

From Figure 5 it can be seen that the higher the discharge, the greater the torque produced. The lowest torque is generated at a flow rate of 0.036 m^3/s at a number of blades 4, that is 0.01 N.m. While the highest torque is generated at a discharge of 0.057 m^3/s at the number of blades 6 with the result of 0.046 N.m on a first stage turbine. The number of blades 6 still shows better water catch, because it has a larger area.

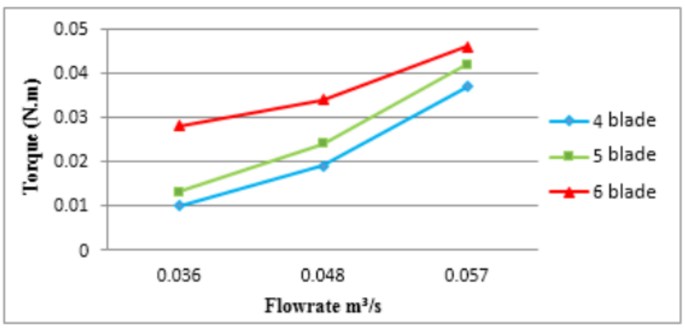

Figure 5. The first-stage turbine torque.

From Figure 6 it can be seen that the higher the discharge, the higher the torque generated in the second stage turbine. The lowest torque is generated at a discharge of 0.036 m^3/s at the number of blades 4, while the highest torque is generated at a discharge of 0.057 m^3/s at the number of blades 6 with the result of 0.032 N.m. It is also seen that the torque in the second stage turbine tends to be lower than the torque in the first stage turbine, because some of the water energy has been absorbed by the first stage turbine.

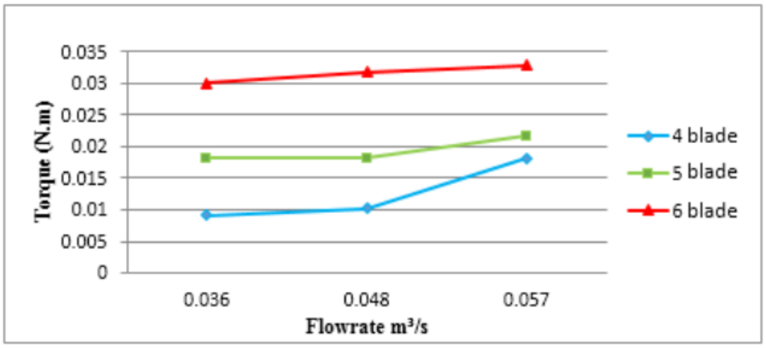

Figure 6. The second-stage turbine torque.

3.3. *Effect of number of turbine blades on the turbine power*

From Figure 7 it can be seen that the highest total power at a discharge of 0.057 m³/s with the number of blades 6 is 2.5 Watt, while the lowest total power is 0.36 Watt at the number of blades 4 at a discharge of 0.036 m³/s. At low to high water discharges the number of blades 6 produces better total power than turbines with fewer blades. The total power is obtained from the sum of the power of the first stage turbine and the power of the second stage turbine, which is influenced by the rotation speed and torque of the first stage and second stage turbines.

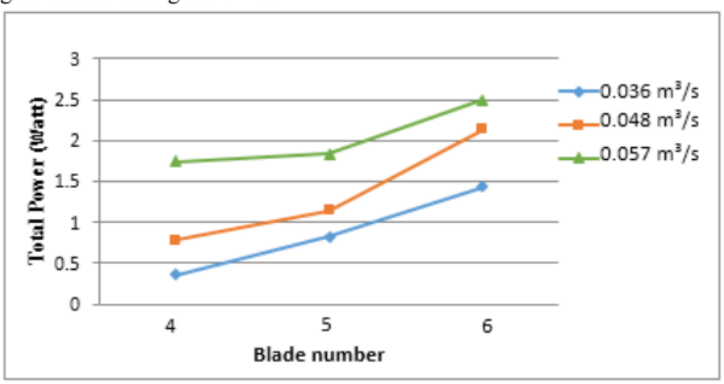

Figure 7. Total turbine power.

3.4. *Effect of number of turbine blades on the turbine efficiency*

From Figure 8 it can be seen that the highest efficiency in the turbine is 7.47% with a number of blades 6, at a discharge of 0.036 m³/s, while the lowest efficiency is 1.9% at a flow of 0.036 m³/s with a number of blades 4. The efficiency of the turbine is influenced by turbine power and water power. Where turbine power is implicitly affected by torque and rotation speed, while water power is affected by water discharge. The greater the turbine power, the efficiency will increase. But inversely proportional to water power, the greater the water power the smaller the efficiency. Efficiency has decreased due to the limited ability of the blade to receive large amounts of debit.

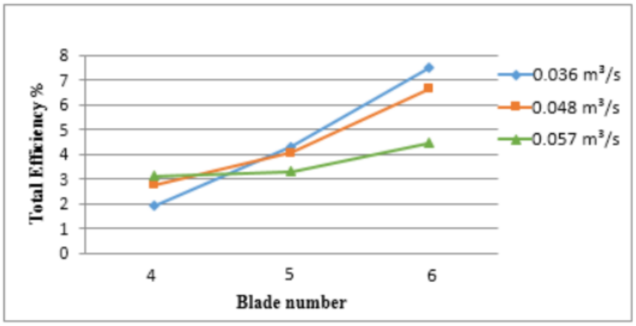

Figure 8. Total turbine efficiency.

4. Conclusion

From this study, it can be concluded that the more turbine blades the greater the torque and turbine power produced. Turbines four-blade on the second stage is more responsive to flowrate changes, but the fewer number of blades makes it less energy capture from the water.

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