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Experimental study of small hydro turbine propeller performance with a variety of blade angles of attack

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Abstract
The availability of non-renewable energy has recently been running low and so impacts electrical energy. Renewable energy is converted from natural sources to kinetic energy. The Double Propeller Water Turbine is a water turbine that is suitable to be applied using a small flow head. This research is a development of previous research by changing the degree of inclination of the blade angle on the turbine, which is used to determine changes in the power and efficiency of the Double Propeller turbine at various speeds. The results showed that the Double Propeller turbine rotation's performance was directly proportional to the slope of the turbine blade angle. The optimum angle of attack on the hydro turbine affected the lift force and the ability of the water flow to capture water power. At the lowest blade angle, which is 20 degrees, the highest rotational speed is obtained with a value of 335 rpm. The turbine generates the most significant power with a blade angle of 20º, with a value of 4.81 watts, and the highest efficiency is 24%. The degree of blade angle affects the performance of the Double Propeller turbine.

Keywords:
Angle of attack;
Double propeller;
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INTRODUCTION

The amount of non-renewable energy such as oil and coal is decreasing and impacts the high price of electrical power. Most power plants in Indonesia use non-renewable fossil energy sources [1]. Therefore, efforts to use renewable energy must be made to overcome the scarcity of fossil energy. Renewable energy is converted from natural sources to kinetic energy, such as hydrokinetic [2]. A water turbine is a machine that rotates due to the mechanical energy of the water current. The rotation energy of the turbine rotates the shaft to be transferred to turn the generator. Hydro-turbines were developed in the 19th century to facilitate work in industry before the electric grid. Until now, the utilization of wind turbines in Indonesia has not been carried out on a large scale. Some turbines that are widely applied in Indonesia include propeller turbines [3], Turgo [4], Crossflow [5], Pelton [6], and Savonius [7]. The type of water turbine selection depends on the number of potentials in the surrounding environment, such as the potential for discharge, speed, and head of water flow. This different performance of hydro-turbine is because each turbine model can only rotate at a specific speed and head.

The feasibility diagram of the hydro-turbine, as presented in Figure 1, can be used to determine the type of turbine that may be applied to an area. The optimum power produced by each turbine model is also different. According to the power produced, water turbines are classified into large hydro, medium hydro, small hydro, mini-hydro, micro-hydro, and pico-hydro [8]. Details of the energy produced by the turbine are shown in Table 1. The multi-stage radial flow Pump as Turbine (PAT) turbine can rotate at high flow heads with low flow rates.

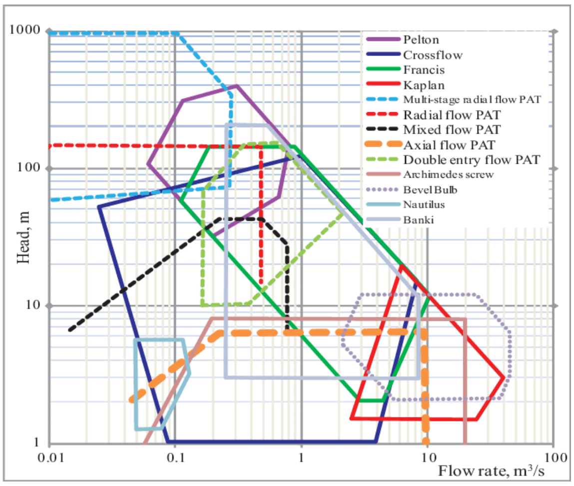


Figure 1. Turbine feasibilities diagram based on head and flow rate

Table 1. Classification of turbines based on the power generated

Hydro Turbine Classification	Power Output
Large-hydro	≥ 100 MW
Medium-hydro	15 – 100 MW
Small-hydro	1 – 15 MW
Mini-hydro	100 kW - 1 MW
Micro-hydro	5 kW – 100 kW
Pico-hydro	< 5 kW

The development of water turbines in Indonesia must be developed, especially in areas outside Java with many rivers and waterfalls.

The potential of marine biota, which is relatively abundant in Indonesian rivers, causes large-scale water turbines to be carried out. The development of each micro-hydro is possible in Indonesian waters, especially in remote areas. However, the utilization of water turbines in Indonesia is still very low, around 10% [9]. Several studies on hydro turbines have been carried out to increase the power of the electricity, including modifying the shape and size of the turbine [10], combining the turbine model [11], and designing the electrical power storage system [12].

The propeller turbine is a hydro-turbine suitable for low heads such as irrigation canals and rivers [13]. The efficiency of the power generated by the propeller turbine is about 40 - 60% of the input power used to drive the turbine [14][15].

Based on the feasibilities diagram shown in Figure 1, the propeller/Kaplan turbine can generate power in fluid flow with a low head and high flow rate. The power generated by the propeller turbine is determined by the shape and number of turbine blades. The turbine TSR value determines the shape of the turbine blades, the number of blades, and the turbine blade angle [16]. The blade of a suitable length must have a curved shape to obtain higher power. The most efficient number of blades used in propeller turbines is 3 [14]. If the number of blades increases, the turbine will experience an increase in drag due to the formation of water bubbles around the turbine blades. Propeller turbines can be used to generate electrical energy from fluid flow through a piping system. The turbine propeller installation can be done at the end of the piping system by utilizing the fluid flow that passes through the elbow at high speed. However, installing a propeller turbine near the elbow can cause vibrations in the piping system when the fluid flows at high speed [17].

Research on single propeller model turbines conducted on a laboratory scale by Samora et al. showed that single propeller turbines could produce up to 95% efficiency at a flow rate of 30 m^3/h [18]. This fluid flow discharge is obtained from a high flow rate river or a dam. The turbine is equipped with a guide vane or a double runner model for low-flow fluid flows. The application of a Double runner on a propeller turbine can increase turbine performance by between 15-100% [19].

However, applying a double runner on the turbine can cause cracks at the blade's tip. This condition enhances the force of the front blade to push the second runner at high speed. The use of guide vanes is more widely applied to the system because the power transmission system is simpler than the double runner application. The types of guide vanes used in propeller turbines are classified into two types. First, a simple guide vane is installed at the front of the propeller turbine to direct the fluid flow at a certain angle [20]. The second guide vane model is installed together with the turbine runner. The installation of the guide vane combined with the runner aims to increase the turbine rotation speed due to the addition of aerodynamic forces on the hydro turbine runner blade [21][22]. Installation of guide vanes on the runner blade can increase turbine performance by up to 5% compared to normal operating conditions [21].

This research was conducted to determine the performance of a propeller turbine at various angles of attack with a guide vane mounted on the runner. The research concept used is similar to the research conducted by Susanto [21] dan Borkowski [20]. However, both studies were performed using a simulation model to facilitate data collection on turbine performance. Numerical research has the disadvantage that the result depends on the number of meshing and iterations [7][23]. This research was directed experimentally to obtain valid data on of angle of attack effect on turbine performance. The turbine performance which is shown in this study is the power and torque turbine.

METHODS

This research was steered in a test section with a closed-loop form. A pump drives the fluid flowing in the close loop test section. The pump is operating on maximum performance 5 liters/second flow rate. A measurement cup and timer measure the flow rate of the working fluid. The turbine is mounted horizontally using a shaft that penetrates the elbow. The test section is depicted in Figure 2.

The turbine model used in this study refers to the contra-rotating hydro turbine experiment [24]. The study was conducted on variations of the front blade turbine with angles of attack (α) of 20°, 25°, and 30°. Rare rotor blade angle (β) has an angle of attack of 25°. The turbine blade angle model is presented in Figure 3. Before the experiment starts, the pump must be turned on for 5 minutes so that the fluid flow in the test section is uniform.

Angular velocity data retrieval is done using a tachometer to calculate the turbine shaft's rotation. Turbine torque is obtained by overloading the turbine shaft until the turbine stops rotating. The leaks at the pipe joints should be avoided to reach uniform flow conditions. In addition, the fluid storage tank must be ensured to be filled to prevent the appearance of air bubbles in the fluid flow.

In calculating hydro turbine performance, several value indicators are taken from the measurement results, such as flowrate, power, torque, and rotational speed (rpm) produced by the turbine. The following equation shows turbine performance:

$$Q = vA = v\pi r^2 \qquad (1)$$

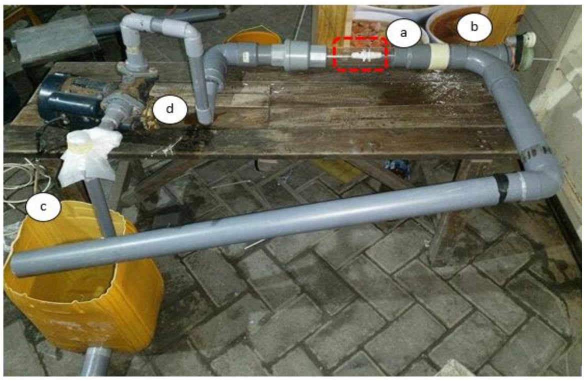
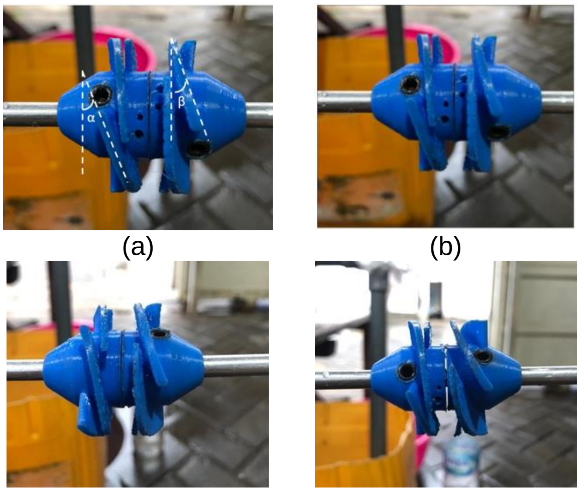


Figure 2. Experimental Setup (a) test section (b) generator (c) Reservoir (d) Centrifugal pump



(a) (b)

(c) (d)

Figure 3. Hydro turbine blades on the various angle of attack

Turbine performance is influenced by the flow rate and head of the fluid around the turbine. Turbine performance is determined by the flow velocity (v) and the diameter of the test pipe section (A) as (1). The calculated turbine performance result is the power generated by the turbine rotation. Power output is calculated using the torque (N.m) value and angular velocity turbine (rad/s) indicated by (2). Torque (Nm) is obtained through the force (N) produced by the turbine to rotate the shaft multiplied by the length of the force arm (m) as (3). The rotating of the hydro turbine results in voltage (V) and electric current (A). The efficiency value in this study is obtained from calculating the generator's electrical power output (W) generated compared to the turbine rotation power (W).

The formula used is shown in (4) and (5).

$$P = \tau \, . \omega \qquad (2)$$

$$\tau = F.r \qquad (3)$$

$$P_g = V.I \qquad (4)$$

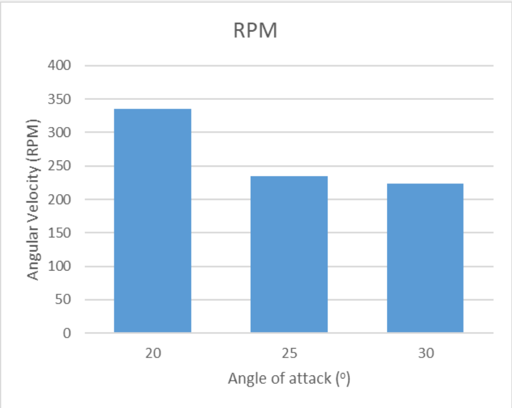
$$\eta = \frac{P_g}{P_t} \times 100\% \qquad (5)$$

RESULTS AND DISCUSSION

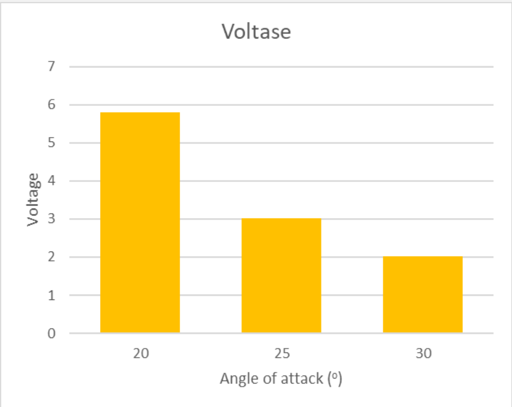
This research was conducted using a close loop test section where the fluid flow is circulated at a speed of 5 liters/s utilizing a pump. The variation of the angle of attack is affected by turbine performance, shown by the value of the angular velocity (rpm) and the voltage generated by the turbine in Figure 4. The angular velocity value is measured using a tachometer. The results showed that the highest angular speed was produced by the blade angle of attack (AOA) blade 20º. The increment of the AOA on the turbine causes a decrease in the angular velocity resulting from the turbine. This condition is caused by the Increment of AOA on the turbine blades, which causes a stall in the flow. The stall is a condition where there is no increase in turbine performance when the AOA increases. Changes in the angle of attack will cause a difference in the separation point on the turbine blade. This research is related to a previous study of contra-rotating turbines which are varied in the angle of attack blade [25].

In the previous study, the angles of attack used were 18°, 20°, and 25° [25]. The increment of the AOA turbine leads to a decrease in turbine electrical power. While in this study, the angles used are 20°, 25°, and 30°. The stall effect on hydro turbine causes this condition. The decrease in turbine rotation impacts the power produced by the turbine, especially the voltage value shown in Figure 4b.

Increasing the angle of attack causes a reduction in the angular velocity of the turbine and generator rotation. This condition causes the voltage generated by electricity to decrease.



(a)



(b)

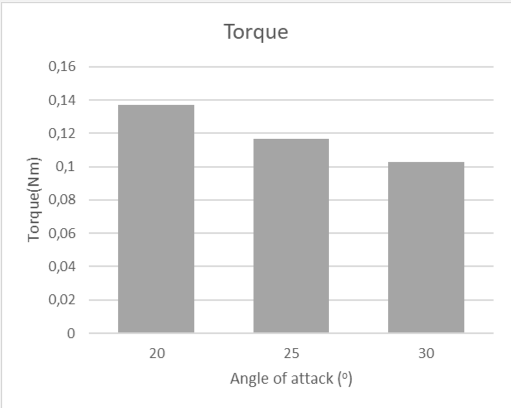
Figure 4. Turbine performance is shown by graph a) angular velocity b) voltage as a function of angle of attack

At AOA 20°, the turbine produces the highest voltage of about 5.79 V 0.2 A. This electric power can be used to turn on the LED lights.

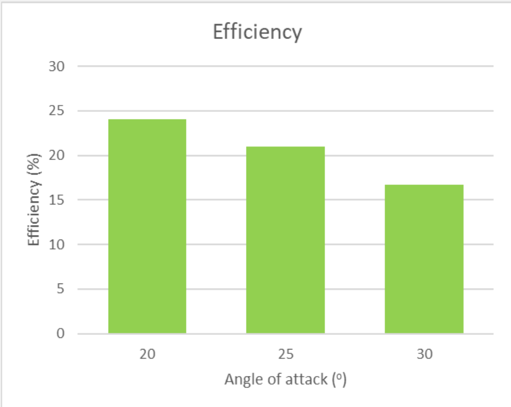
The torque and efficiency graph show the effect of the angle of attack blade on hydro turbine performance as in Figure 5. Graph 5a shows that the increment of the AOA turbine leads to a reduction in turbine torque. The decrease in turbine performance is indicated by the slower angular velocity produced by the turbine. This condition causes the force required to stop the rotation of the turbine shaft is lower.

This condition is caused by the Increment of AOA on the turbine blades, causing a stall in the flow [26][27]. The stall is a condition where there is no increase in turbine performance when the AOA increases. Changes in the angle of attack will cause a difference in the separation point on the turbine blade.

The force generated by the turbine is used as primary data to calculate the turbine torque using (2). The turbine mechanical power calculated by (3) is based on the rotation and force generated by the hydro turbine.



(a)



(b)

Figure 5. Turbine performance is shown by graph a) Torque b) Efficiency as a function of angle of attack

Turbine efficiency calculates by comparing the electrical power generated by the turbine compared to turbine mechanical force in (5). The highest efficiency of the turbine is produced by AOA 20°, which almost reaches 25%. Graph 5b shows that the increment of the AOA turbine leads to a reduction in turbine efficiency.

CONCLUSION

The Double Propeller Water Turbine is a water turbine that is suitable to be applied using a small flow head. This research is a development of previous research by changing the degree of inclination of the blade angle on the turbine, which is used to determine changes in the power and efficiency of the Double Propeller turbine at various speeds. This condition is caused by the Increment of AOA on the turbine blades, which causes a stall in the flow. A contra-rotating gearbox model can be applied for future work to increase electrical power.

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