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The effect of blade angle on two-stage water turbine against power and efficiency

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Abstract. The Indonesian region has abundant alternative energy sources that can be used to meet electrical energy needs. One potential alternative energy source is water energy that can be converted into electrical energy with a water turbine. Water turbines are generally one stage, whereas water energy on the output side is still quite large. In this study, experiments were made using a two-stage micro water turbine model with blade angle variations on the second stage turbine. The type of turbine used in this study is a crossflow turbine with a vertical shaft. The results show that the 45° blade angle on the second stage turbine can increase the second stage turbine rotational speed, and also increase the power of second stage turbine. The total power of the turbine increases up to 29% compared to 15° blade angle. This indicates that the appropriate selection of the second stage turbine blade angle will significantly affect the total turbine power and its efficiency.

1. Introduction

Electrical energy has a very important role for society. The electricity situation in Indonesia is alarming because it still depends on oil, coal and natural gas, which is 89%. Even though the availability of fossil fuels in Indonesia is limited, and one day it will run out. Therefore, various studies were conducted to find renewable alternative energy sources including to meet the needs of electrical energy. One of the renewable energy sources in Indonesia is water energy which has the potential for a Hydroelectric Power Plant and a Micro Hydro Power Plant of 75,000 MW. However, its utilization is still around 11% of the total potential [1].

Changing water energy into electrical energy can use a conversion engine such as a water turbine [2–4]. Cross-flow turbines are one of the water turbines of the impulse turbine type, it has characteristics that are suitable for low to medium head ranges [5–7]. The results of research conducted by Yesung, et al [8], stated that the use of crossflow turbines is very suitable for the potential of water energy available in the surrounding environment which is dominated by river flow. The working principle of this turbine was first discovered by an Australian engineer named A.G.M. Michell in 1903. Then this turbine was developed and patented in West Germany by Prof. Donuts Banki so this turbine named Turbine Banki, it is sometimes called Turbine Michell-Ossberger [9]. The use of cross-flow turbine types is more profitable than using waterwheels or other types of micro-hydro turbines [10,11]. The working principle of a vertical shaft cross flow turbine is that river water flowed through the guide vane so that it precisely hit the turbine blade in the direction of rotation. This water collision will make the turbine rotate and produce mechanical energy in the shaft [12,13].



Installation of multistage vertical shaft crossflow water turbines can maximize total output power [14]. However, the optimal blade angle in the second stage turbine needs to be investigated, because it will affect the water flow and the total power produced.

2. Method

This research was carried out by direct experiments by making a water channel made of 1 cm thick wooden board, making two turbine runners, and two frame turbine holders. Then the main components are assembled according to the design made before.

The water turbine used is a two-stage crossflow water turbine with a vertical shaft. Two turbines are arranged in series in one channel, as shown in Figure 2. The second stage turbine blade angle is varied by: 15°, 30°, and 45° (Figure 1). The flow guide angle is installed on the inlet with a slope of 40°. The source of water flow uses the river flow and fluid discharge is varied with the opening of the lid: 3 cm, 6 cm, 9 cm.

The rotation speed of the water turbine is measured using a digital tachometer. While the output power is converted using a mini generator into electrical energy. The current and voltage generated are measured using a digital multimeter.

To calculate the power of water flowing in a certain cross section, the following equation is used in the calculation [6]:

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

where: P_w = water power (Watt)
 ρ = water density (kg/m³)
 V = water velocity (m/s)

To calculate the turbine power generated, the equation is used:

$$P_t = \frac{V \cdot I}{\eta_{gen}} \quad (2)$$

where: P_t = turbine power (Watt)
 V = voltage (V)
 I = current (A)
 η_{gen} = generator efficiency, 0.25 [15]

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 [2]:

$$\eta = \frac{P_t}{P_a} \times 100\% \quad (3)$$

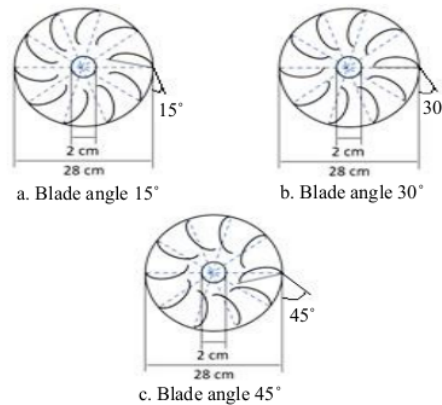


Figure 1. Rotor design with blade angle variations.

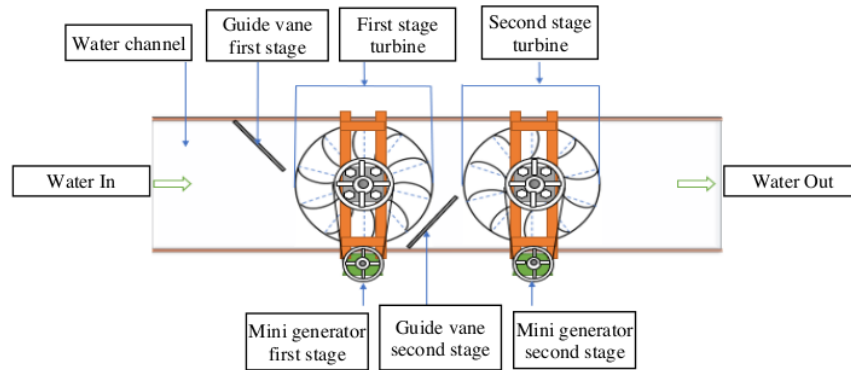


Figure 2. Testing installation.

3. Result and discussion

Data retrieval is done 3 times each variation. Then the results of data retrieval from the testing of a two-stage crossflow water turbine with blade angle variations are processed and set forth in Table 1 below. Data from Table 1 are then illustrated in several graphs to facilitate the process of discussion and analysis of results.

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

In Figure 3, it is known that the highest rotation value occurs at 30 L/s discharge with 480 rpm and the lowest rotation occurs at 10 L/s with a rotation value of 262 rpm. This is due to the influence of the flow of incoming water flow, the greater the water flow that enters, the greater the rotation produced. Likewise, vice versa, the smaller the flow of water entering the smaller the resulting speed rotation. The blade angle variation is only in the second stage of the turbine, and it does not affect the turbine speed rotation at the first stage.

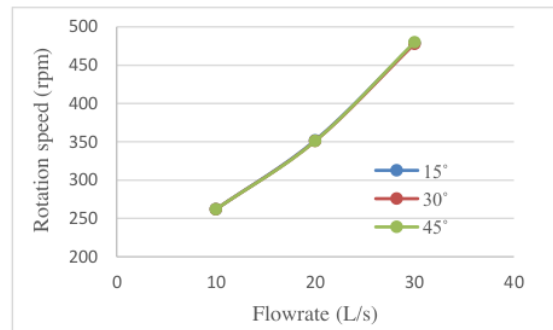


Figure 3. Graph of the effect of blade angle on the first-stage turbine speed rotation.

3.2. Effect of blade angle variations on the speed rotation of second-stage turbine

From Figure 4 it is known that the highest rotation value at 45° blade angle with 30 L/s water discharge produces 457 rpm rotation, at 30° blade angle with the same water discharge 30 L/s the lower rotation value is 447 rpm, while the lowest rotation is produced at 15° blade angle with the same water discharge 30 L/s resulting in a rotation value of 352 rpm. The greater the blade angle the larger the turbine rotation

is produced. This is because the greater the blade angle the greater the normal area of the flow direction so that the larger the water catch [5].

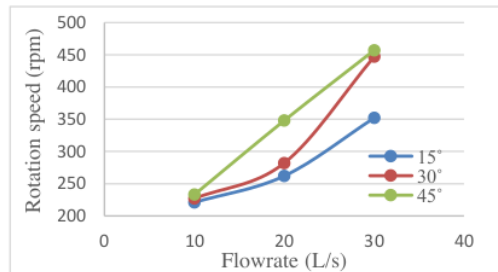


Figure 4. Graph of the effect of blade angle on the second-stage turbine speed rotation.

3.3. Effect of blade angle variations on the power of first-stage turbine

From Figure 5, it is known that the biggest power value is at the discharge of 30 L/s with a power value of 0.07 watts and the smallest power value is found in the discharge variation of 10 L/s with a power value of 0.012 watts. This is due to the influence of the water flow that enters the water flow, the greater the water flow that enters, the higher the rotation carried out by the turbine, the greater the power obtained. The blade angle variation is only in the second stage of the turbine, and it does not affect the turbine power at the first stage.

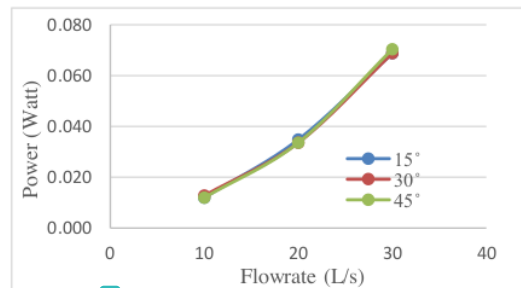


Figure 5. Graph of the effect of blade angle on the power of the first-stage turbine.

3.4. Effect of blade angle variations on the power of second-stage turbine

From Figure 6 it is known that the value of the power produced at the 45° blade angle with a 30 L/s water discharge produces a power of 0.066 watts. While the 30° blade with the same water discharge 30 L/s, the power obtained is smaller at 0.058 watts. The lowest power is produced at the blade angle 15° with the same water discharge of 30 L/s, resulting in a power of 0.036 watts. Same with the turbine rotation speed. The bigger the blade angle the greater the turbine power produced [5]. This is because the greater the blade angle the greater the normal area of the flow direction so that the water catchment gets bigger so that the turbine power produced will be greater.

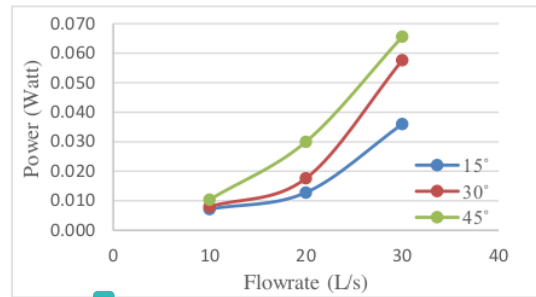


Figure 6. Graph of the effect of blade angle on the power of the second stage turbine.

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

From Figure 7 it is known that the total value of power produced in the blade angle is 15° with a water discharge of 30 L/s which is equal to 0.105 watts. At 30° blade angle with the same water discharge 30 L/s the value of the power obtained is still less than the maximum that is 0.126 watts, while the highest power is in the 45° blade angle with the same water flow of 30 L/s producing power amounting to 0.136 watts. Because the value of the power produced by the first stage turbine tends not to change with the variation of the second stage blade angle, so that the increase in the total power of the turbine is caused by an increase in the power of the second stage turbine.

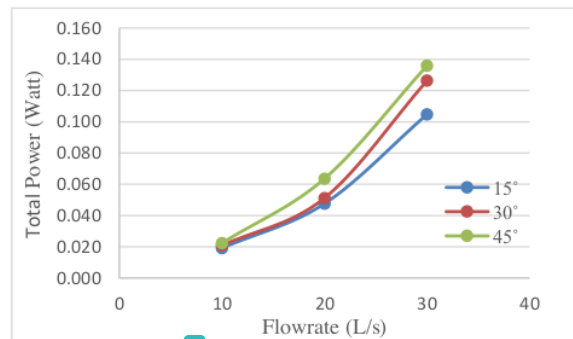


Figure 7. Graph of the effect of blade angle on total power of turbine.

3.6. Effect of blade angle variations on efficiency of turbine

From Figure 8, it is known that the greatest efficiency is formed at 45° blade angle at 10 L/s water discharge, which is 3.44%. At the same discharge of 10 L/s, the 30° blade angle produces an efficiency of 3.19%, while the blade angle 15° produces an efficiency of 2.95%. The lowest efficiency is produced at 15° blade angle at 30 L/s discharge which is 0.61%. The greater the water discharge the lower the efficiency produced, this indicates that not all water masses are captured by the turbine blade [5]. The bigger the water discharge, the faster the turbine turns so that it is more difficult for the turbine to catch the mass of water.

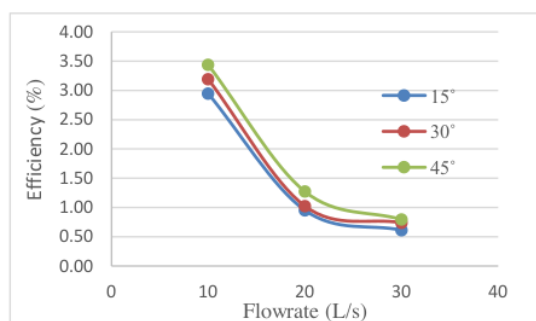


Figure 8. Graph of the effect of blade angle on total turbine efficiency.

4. Conclusion

Based on the results of the research that has been done it can be concluded that the greater the blade angle the greater the rotation and turbine power produced. The rotation and power generated by the first turbine stage tend not to be affected by the change of the second stage blade angle, so that the increase in total turbine power is generated by increasing the power of the second stage turbine.

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