Journal of Electronics, Electromedical Engineering, and Medical Informatics
Multidisciplinary : Rapid Review : Open Access Journal e-ISSN: 2656-8632

RESEARCH ARTICLE OPEN ACCESS

Manuscript received November 10, 2020; revised March 3, 2021; accepted April 21, 2021; date of publication April 28, 2021
Digital Object Identifier (DOI): https://doi.org/10.35882/jeeemi.v4i1.5

The Effect of Inlet Notch Variations in Pico-hydro Power Plants with Experimental Methods to Obtain Optimal Turbine Speed

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ABSTRACT Energy is an important element in the continuity of human activities. Indonesia has the potential to produce 94.5GigaWatt of electricity in the hydropower sector, but only a few can be utilized, which is only 11%. This study aims to utilize renewable energy that has not been utilized optimally, especially in Indonesia. This study exploits the potential of water flow from the Coban Wonoasri River, Bangun Village, Munjungan District, Trenggalek Regency which has a low head but has a fairly heavy discharge. The basin cone for making vortex flow has a canal length of 1450mm, a canal width of 231.5mm, and a canal height of 500mm with a basin cone diameter of 560mm, a basin cone height of 700mm, and a water outlet diameter of 90mm. A vortex turbine with a diameter of 270mm and a height of 210mm with a total of 8 blades, a blade curvature of 30°, and a blade tilt of 22.5° was used for research on this low head river. The inlet notch variations that will be used are angles of 0°, 17.82°, 19.30°, and 19.98°. The method used in this study is the experimental method, where the best results are obtained from the results of tests carried out on variations in the inlet notch. The inlet notch with a width of 0° and a discharge of 8.81l/s cannot produce turbine rotation because the vortex flow is not formed properly. Inlet notch with a width of 17.82° and 19.30° produces an average turbine speed of 157.2 rpm and 159.2 rpm. The variation of the inlet notch with a width of 19.98° produces the best turbine speed of 162.7 rpm with a flow rate of 7.72l/s.

INDEX TERMS Inlet Notch, Pico Hydro, Turbine Speed, Vortex Flow.

I. INTRODUCTION

Energy is an important part of human life. The need for energy in the world will continue to increase along with the increasing population, economic growth, and the pattern of energy consumption itself which will continue to increase. Consideration to switch to renewable energy (renewable resources) is very necessary because non-renewable energy (unrenewable resources) will not always be available. Indonesia is a country that is rich in renewable energy resources. Based on the Indonesia Energy Outlook (2019), Indonesia has the potential to generate electricity of 94.3GigaWatt in the hydropower sector, but only a few can be utilized, namely only 4.2GigaWatt [1]. The potential of water that can be utilized is in the form of water flow. However, the utilization of low head water flow using turbines has not been optimized in Indonesia. One example is the Coban Wonoasri River, Bangun Village, Munjungan District, Trenggalek Regency, which has a low head but has the potential to become a small-scale power plant [2].

Previous research conducted by Sudrajat et al. (2019), which examined the effect of turbine diameter on turbine power and efficiency, showed that a diameter of 270mm produces the most optimal turbine power and efficiency [3]. Research conducted by Fitroh and Adiwibowo (2018) which examined the effect of the blade tilt on the turbine on turbine power and efficiency, showed that a turbine with a blade tilt of 22.5° produces the most optimal turbine power and efficiency [4].

Previous research conducted by Achmad & Adiwibowo (2017), which examined the effect of the guide vane angle (inlet notch) on the power and efficiency of the vortex turbine, showed that the optimal power and efficiency values were indicated by the guide vane angle value of 17.82° [5]. However, the drawback in this research is that the increase in the rotational speed of the vortex turbine with an increase in the inlet notch is more than 17.82° [6]. Therefore, in this study, an experimental method will be applied to the inlet notch with an increase in the angle of the turbine radius. The experimental angles used in this test are 19.30° and 19.98°. [7]. An increase in the inlet notch will cause the incoming water flow path to become narrower so that the water flow can form a vortex before driving the turbine [8]. The purpose of this study was to determine the effect of increasing the inlet notch angle on the rotational speed of the vortex turbine to be applied in the design of a vortex turbine pico hydropower plant [9]. In this study, there is no energy.

II. MATERIALS AND METHODS

A. MATERIALS

1) MECHANICAL PART TO CREATE VORTEX FLOW

The mechanical part of this study aims to create a vortex flow. There are three main mechanical parts to be made, namely the basin cone, water turbine, and variations of the inlet notch [10]. The material used to make the basin cone a galvanized plate with a thickness of 2 mm, and the design is based on previous research [11]. Several changes were made, such as the addition of structural legs to support the basin cone because this study applied directly to the river. Figure 1 shows the design of the basin cone that will be made in this study, while Figure 2 explains the sizes of the basin cone that will be used [12].

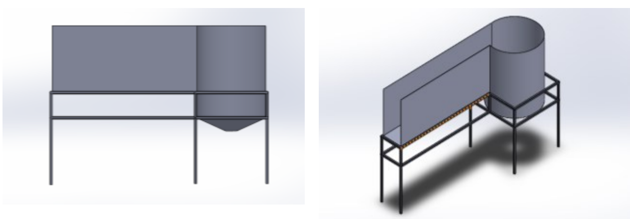

FIGURE 1. Basin Cone Design

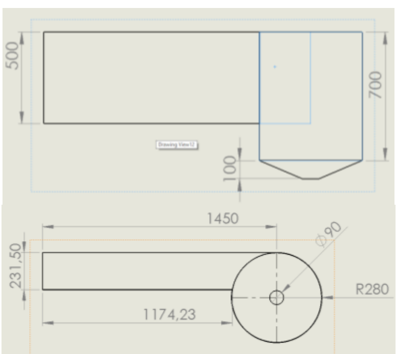

FIGURE 2. Basin Cone Size and Measurement [18]

The sizes of the designs that have been made are described as follows:
1. Inlet canal width = 230mm
2. Inlet canal length = 1450mm
3. Inlet canal height = 500mm
4. Basin cone diameter = 560mm
5. Basin cone height= 700mm
6. Outlet diameter basin cone = 90mm

The vortex water turbine used in this study is 270mm in diameter and 210mm in height which produces good power and efficiency [13]. This turbine has a number of 8 blades, a blade curvature of 30°, and a blade tilt of 22.5°, which can produce higher power and efficiency than other blade slopes [14]. The turbine design to be made is described in Figure 3 below.

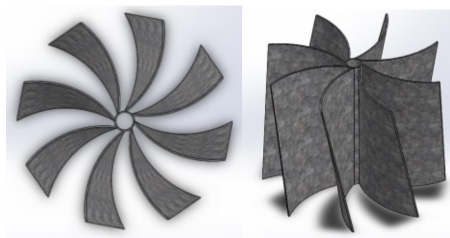

FIGURE 3. Vortex Turbine Design

Explanation of the sizes of the turbines to be used are as follows:
1. Turbine height = 21cm
2. Turbine diameter = 27cm
3. Blades = 8 blades
4. Blade curvature = 30°
5. Blade tilt = 22,5°

The inlet notch variation that will be made aims to determine the difference in turbine speed produced by different angles. The best inlet notch is the inlet notch which produces the best speed in the vortex flow turbine. The value of the inlet notch angle is determined by increasing the turbine radius and drawing a straight line with a distance of 400mm from the outer circle of the basin cone [15]. Figure 4 describes taking the value of the inlet notch variation angle.

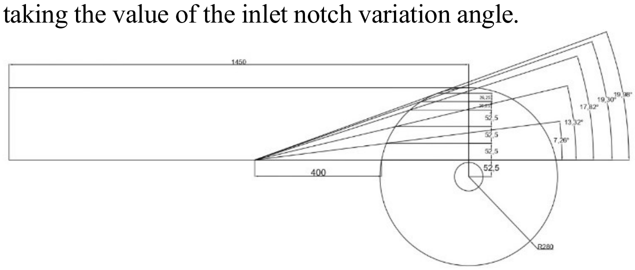

FIGURE 4. Inlet Notch Angle Value Taking

In previous studies, the highest power and efficiency was at an angle of 17.82° (3 times half turbine radius) [16]. In this study, two variations of the wider angle will be made, namely by adding an increase of quarter turbine radius and half radius from the inlet notch of the previous study (3 times half turbine radius). Thus, four variations of the inlet notch angle that will be tested are with wide angles of 0°, 17.82°, 19.30°, and 19.98°. Figure 5 shows four variations of the inlet notch that will be tested in this study.

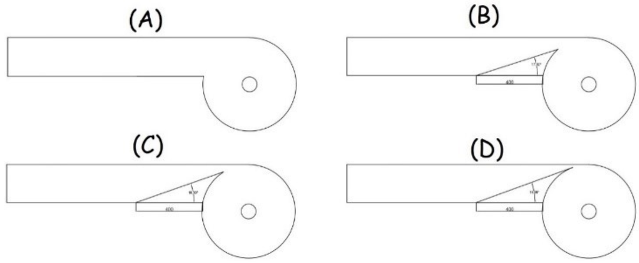

FIGURE 5. Inlet Notch Variation

2) ARDUINO UNO

Arduino is a microcontroller. We need Arduino IDE software to upload the program to Arduino [5] to program and run Arduino. The Arduino programming language is relatively easy because libraries have simplified and assisted. Time-based operations can be carried out precisely due to the presence of a microprocessor and completeness with a 16MHz oscillator and a regulator or supply of 5 volts.

3) OPTOCOUPLER SENSOR AND WHEEL ENCODER

An optocoupler is an electronic component that consists of a transmitter and a receiver separated by a small gap. This sensor can be used to detect rotational speed by calculating the wheel encoder hole. The wheel encoder consists of a disc that has holes in the circumference of the disc. If an object that is impermeable to infrared light is inserted into a small gap, the light emitted by the infrared LED cannot reach the photodetector, and the signal is logic low (0). Vice versa, this photodetector will be active if there is a light that hits it and has a high logic (1) [6] (FIGURE 6).

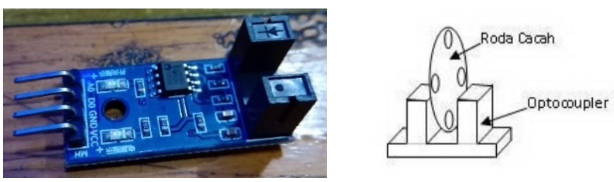

FIGURE 6. Optocoupler Sensor and Wheel Encoder

4) LCD WITH I2C

LCD uses a lot in designing a system using a microcontroller. LCD (Liquid Crystal Display) can function to display a sensor value, display text, or display a menu on a microcontroller application. In this study, the LCD used is a 20x4 LCD with I2C, which means the LCD can display 4 rows and 20 columns and I2C to save pins for connection to Arduino [7].

B. METHODS

1) HEAD AND FLOW CALCULATION

The principle of hydroelectric power is to utilize the difference in height (head) and the amount of water discharge (flow) that exists in irrigation canals, rivers, or waterfalls. The head or water drop pressure is the vertical distance between the water intake and the turbine rotation which is expressed in meters (m). From Figure 9, it is explained that the total head (Head Gross) is the difference in height between the surface between falling water and the turbine. Head gross can be calculated by equation one below [8].

The method for calculating the water discharge is the area and flow velocity method. In order to calculate the water discharge with this method, a light mass object, a meter, and a stopwatch are needed. In this method, measurements of river depth (H) and river width (B) are required first. Next, the light mass object will be floated as far as the distance you want to determine (L), and the time (T) will be calculated to reach that distance. If the condition of the riverbed is uneven, data can be collected in several parts of the river and then averaged in the hope of obtaining more accurate data (FIGURE 7).

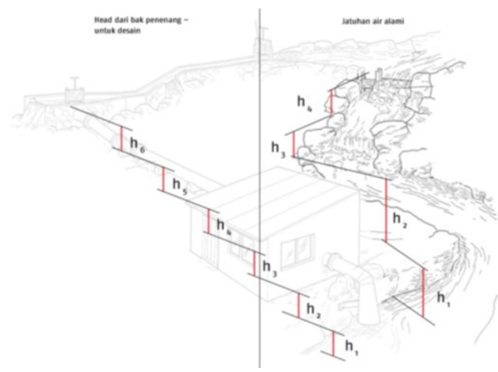

FIGURE 7. Head Calculation [8]

$$H_g = H_1 + H_2 + H_3 + H_n \tag{1}$$

where H_g , H_1 , H_2 , H_3 , H_n indicate head gross, head measurement 1, head measurement 2, head measurement 3, and head measurement n, respectively.

FIGURE 8 describes data collection using the area and flow velocity method, while equation 2 describes the calculation of water discharge using the area and flow velocity method [8].

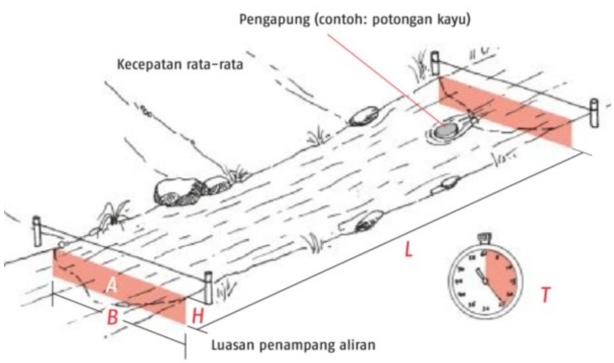

FIGURE 8. Flow Calculation [8]

$$Q = \frac{L}{T} \cdot B \cdot H \quad (2)$$

where Q indicates water discharge(m^3/s), L indicates distance (m), T indicates time (s), B indicates river width (m), and H indicates River depth (m)

2) EXPERIMENTAL METHOD

The experimental method will be applied in this study. The best results from testing on the inlet notch variation carried out will be used as the purpose of this study, namely to obtain the most optimal turbine speed.

3) SYSTEM WORKFLOW

The working principle in this study starts from the placement of the inlet notch variations that will be given to the water inlet basin cone. The inlet variations tested were angles of 0°, 17.82°, 19.30°, and 19.98°. The flow of water in the basin cone will form a vortex or whirlpool. In the center of the basin cone whirlpool is a vortex turbine. With the flow of water, the vortex turbine will rotate. The turbine speed will be read by the optocoupler sensor with the help of a wheel encoder as a high and low logic converter into speed data. The speed data will be sent to Arduino and will be displayed on the LCD. The selection of inlet notch variations will produce different speeds, so it is necessary to experiment with all variations of the inlet notch in the study to find out the highest rpm. Figure 11 shows the workflow of the system.

4) SYSTEM BLOCK DIAGRAM

The block diagram of the system in this study starts with a turbine that has been rotating with the help of water power, and the rotational speed will be read by the optocoupler sensor with the help of a wheel encoder as a high and low logic counter. The rpm data will be sent to the Arduino Uno with coding that has been embedded in the Arduino so that the high and low readings by the optocoupler sensor will be read as rpm data. Furthermore, the rpm data will be displayed by the LCD which has been integrated with the Arduino Uno. FIGURE 9 describes the system block diagram. FIGURE 10 shows the flowchart of the design system.

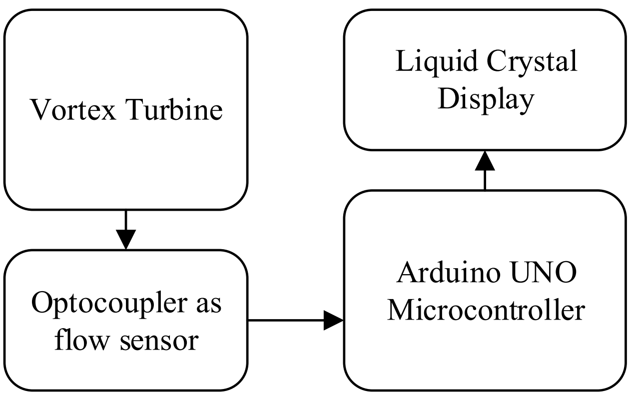

FIGURE 9. System Block Diagram

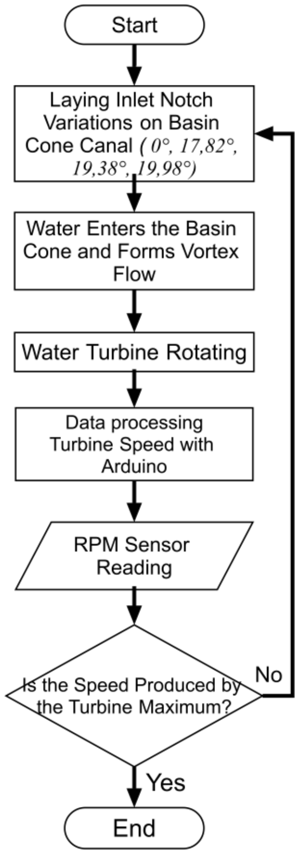

FIGURE 10. System Workflow

III. RESULTS

A. MECHANICAL PARTS MANUFACTURE

1) BASIN CONE

Basin cones are made according to the designs, sizes, and materials described previously. The material used to make the basin cone channel a galvanized plate with a thickness of 2mm. FIGURE 11 shows the making of a basin cone.

2) VORTEX TURBINE

Vortex turbines are manufactured according to the designs, sizes, and materials described previously. The material used to make the vortex turbine is a galvanized plate with a thickness of 2mm. FIGURE 12 shows the making of a basin cone.

FIGURE 11. Basin Cone Manufacturing

FIGURE 12. Vortex turbine manufacturer

3) INLET NOTCH VARIATION

Inlet notch variations are made according to the designs, sizes, angles, and materials described previously. The material used to make the inlet notch variation is a galvanized plate with a thickness of 2mm. FIGURE 13 shows the making of a basin cone.

FIGURE 13. Inlet notch variation manufacture

B. HARDWARE

The hardware consists of Arduino, an optocoupler sensor, and an LCD with I2C. The VCC on the optocoupler is connected to the 5V pin on the Arduino, and the GND of the optocoupler is connected to the GND pin on the Arduino. The D0 pin on the optocoupler will be connected to the Digital Input 8 pin on the Arduino. The 5V pin on the LCD is connected to the 5V pin on the Arduino, and the GND pin on the LCD is connected to the GND pin on the Arduino. While the SDA pin and SCL pin on the LCD is connected to the SDA pin and SCL pin on the Arduino. FIGURE 14 Explains the wiring hardware in this study.

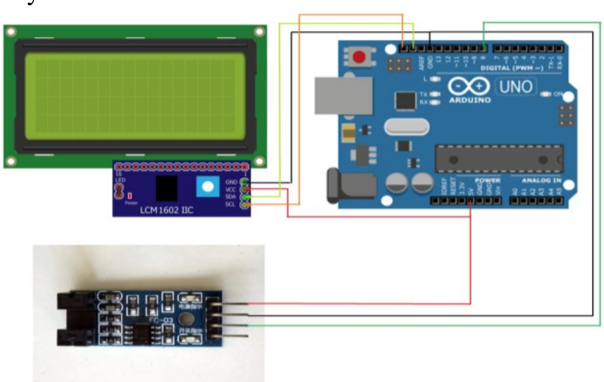

FIGURE 14. Hardware Wiring

C. TESTING

The test begins by placing the variation of the inlet notch to be tested to obtain the turbine rotation speed. The wheel encoder is placed on the turbine shaft so that it allows the optocoupler to read the turbine speed. After the hardware has been assembled with wiring, coding will be embedded for the rpm reading so that the turbine speed will be read on the LCD. The results of the rpm reading will be displayed on the LCD as shown in FIGURE 15.

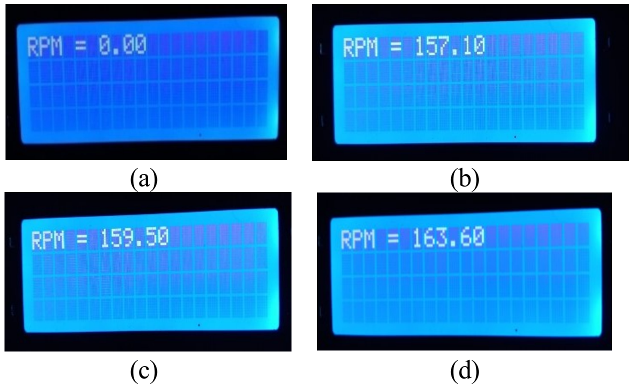

FIGURE 15. RPM Reading Test on (a) 0°, (b) 17,82°, (c) 19,30° and (d) 19,98°

D. RESULT

The results of the required tests are channel width measurement data (B), channel depth measurement (H), the specified floating object distance (L), time to reach the distance (T), so that discharge data is obtained using equation 2. What is needed is the turbine speed reading at each variation of the inlet notch so that the influence of the angle used can be seen (TABLE1).

TABLE 1
Test Result on Inlet Notch 0°

B (m)	H (m)	L (m)	t (s)	Q (l/s)	Turbine RPM
0,23	0,28	0,76	6,04	8,10	0
0,23	0,27	0,76	5,98	7,89	0
0,23	0,28	0,76	4,79	10,22	0
0,23	0,27	0,76	5,43	8,69	0
0,23	0,26	0,76	4,98	9,13	0
	Average			8,81	0

From the data above, it is shown that with an average discharge of 8.81l/s at the inlet notch 0° it cannot produce turbine rotation because the whirlpool flow is not formed properly. The water streams collide with each other so that they are not strong enough to turn the water turbine (TABLE1).

TABLE 2
Test Result on Inlet Notch 17,82°

B (m)	H (m)	L (m)	t (s)	Q (l/s)	Turbine RPM
0,23	0,29	0,76	6,82	7,46	156,5
0,23	0,27	0,76	4,9	9,7	157,1
0,23	0,26	0,76	4,4	10,33	157,7
0,23	0,27	0,76	7,23	6,53	157,6
0,23	0,26	0,76	4,93	9,36	156,9
	Average			8,68	157,2

From the data, it is shown that with an average discharge of 8.681/s at the inlet notch 17.82°, it can produce an average turbine rotation of 157.2 rpm (TABLE 3).

TABLE 3
Test Result on Inlet Notch 19,30°

B (m)	H (m)	L (m)	t (s)	Q (l/s)	Turbine RPM
0,23	0,26	0,76	5,73	7,93	159,5
0,23	0,27	0,76	4	11,93	158,8
0,23	0,27	0,76	5,7	8,4	159,5
0,23	0,27	0,76	6,1	7,82	159,5
0,23	0,27	0,76	5,85	8,19	158,7
	Average			8,85	159,2

From the data, it is shown that with an average discharge of 8.851/s at an inlet notch of 19.30°, it can produce an average turbine rotation of 159.2 rpm (TABLE 4).

TABLE 4
Test Result on Inlet Notch 19,98°

B (m)	H (m)	L (m)	t (s)	Q (l/s)	Turbine RPM
0,23	0,28	0,76	7,3	6,79	161,9
0,23	0,29	0,76	7,6	6,72	162,1
0,23	0,29	0,76	5	10,22	163,6
0,23	0,29	0,76	7,5	6,82	162,8
0,23	0,29	0,76	6,4	8,04	163,2
	Average			7,72	162,7

From the data as shown in TABLE 4, it is shown that with an average discharge of 7.721/s at the inlet notch 19.30°, it can produce an average turbine rotation of 162.7 rpm. This inlet notch produces the fastest rotation compared to other inlet notch variations.

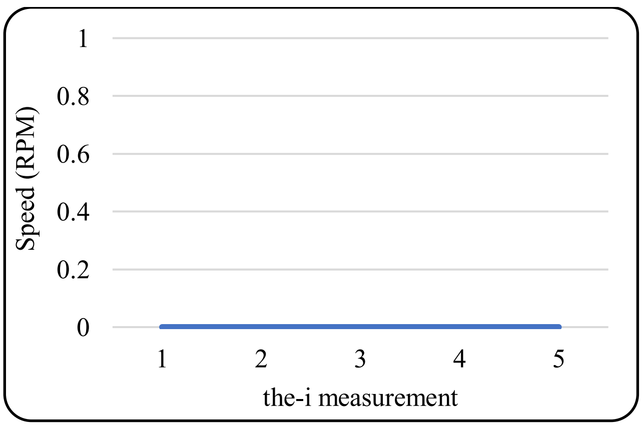

FIGURE 16. **Turbine Speed at 0° Inlet Notch**

From the graph FIGURE 16, it is shown that taking five times the rpm data at the 0° inlet notch cannot produce turbine rotation (0 rpm). 0° inlet notch angle cannot rotate the turbine due to the lack of efficiency in the vortex flow generator in the basin cone.

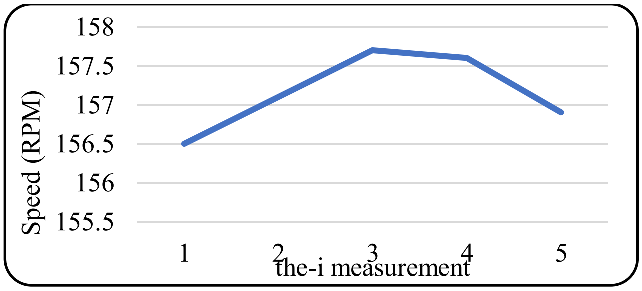

FIGURE 17. **Turbine Speed at 17,82° Inlet Notch**

From the graph FIGURE 17, it is shown that taking five times the rpm data at the inlet notch 17.82° can produce a turbine rotation between 156.5 RPM to 157.7 RPM.

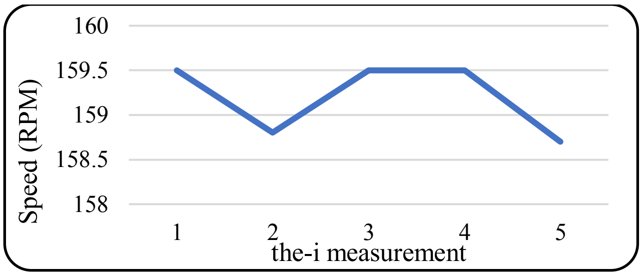

FIGURE 18. **Turbine Speed at 19,30° Inlet Notch**

From the graph FIGURE 18, it is shown that taking five times the rpm data at the 19.30° inlet notch can produce a turbine rotation between 158.7 RPM to 159.5 RPM.

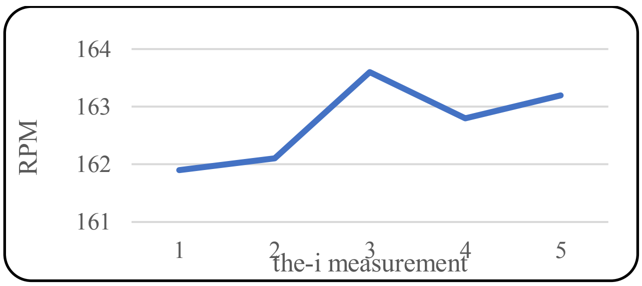

FIGURE 19. **Turbine Speed at 19,98° Inlet Notch**

From the graph FIGURE 19, it is shown that taking five times the rpm data at the 19.98° inlet notch can produce a turbine rotation between 161.9 RPM to 163.6 RPM.

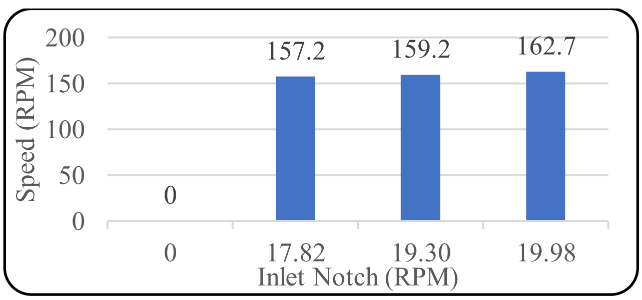

FIGURE 20. **Turbine Speed Comparison of Each Inlet Notch**

From the graph FIGURE 20, it is shown that of the four variations of the inlet notch, the best speed is obtained from the inlet notch 19.98° by producing an average turbine speed of 162.7 rpm.

IV. DISCUSSION

The results of this study indicate that the inlet notch angle affects the turbine rpm where the 0° inlet notch angle cannot rotate the turbine due to the lack of efficiency in the vortex flow generator in the basin cone. Meanwhile, at the 19.98° inlet notch, it can rotate the turbine with a maximum speed of 162.7 rpm with a flow rate of 7.72 l/s. This can happen because the vortex flow is well-formed in the basin cone.

This research proves that slightly widening the angle of the inlet notch can speed up the turbine rotation. In previous studies, the inlet notch 17.82° produced the fastest and most efficient turbine rotation, but with a new variation in this study, the inlet notch 19.98° can produce turbine rotation faster than the inlet notch 17.82°.

The limitations of this research are:

1) The inlet notch that will be tested in this vortex turbine has four inlet widths with a width of 0°, 17.82°, 19.30°, 19.98°.
2) The type of blade used in this vortex turbine is an eight-blade turbine with a curved blade of 30° and a blade tilt of 22.5°.
3) There is no conversion of mechanical energy generated from the turbine into electrical energy.

V. CONCLUSION

The purpose of this study was to determine the effect of variations in the inlet notch on the design of a pico hydropower plant on the Coban River Wonoasri, Bangun Village, Munjungan District, Trenggalek Regency, which has a low head but has the potential to become a small-scale power plant. There are four variations of the inlet notch tested, where the first variation is without the inlet notch, then the second variation is taken from previous studies that have good efficiency, and two additional variations from the researcher, namely the experimental method to find out whether widening the inlet notch can produce faster and more efficient turbine speed.

From this research, it is proven that widening the angle of the inlet notch from previous studies can increase the speed of the turbine produced. The 19.98° inlet notch produces the fastest rotation of the other variation, with an average speed of 162.7rpm. This can happen because the whirlpool or vortex flow is well-formed in the basin cone before driving the turbine so that the turbine can be driven by water power so that it can produce faster rotation.

Researchers hope that in the future, this research will be continued by adding a DC generator as a converter of mechanical energy produced by the turbine into electrical energy so that the goal of utilizing renewable energy can be achieved.

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