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IDENTIFYING THE INFLUENCE OF BLADE NUMBER AND ANGLE OF ATTACK ON A BREASTSHOT TYPE WATERWHEEL MICRO HYDROELECTRIC POWER GENERATOR USING ANOVA

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This study focuses on optimizing the performance of micro-hydro power generation, specifically the breastshot type waterwheel. The limited availability of non-renewable energy sources and the high cost of developing renewable energy sources in the energy sector pose challenges, making it essential to find new energy sources and improve energy efficiency. The 2004–2022 national electricity plan aims to increase electricity access in rural areas, including remote regions like Bogor Regency, where access to electricity is limited. Many residents have constructed their own micro hydroelectric power generators, but their vulnerability to natural disasters is a concern. The study investigates the potential of breastshot waterwheel technology for micro hydroelectric power generation.

The study involved testing a micro hydro power plant with 6, 8, and 10 blades and blade angles of 0°, 30°, and 45°. The current research focuses on performance optimization, including the use of ANOVA analysis to know the significant impact of blade number and angle on the waterwheel's rotation.

The maximum rotational speed was achieved with 10 blades and an angle of attack of 0°, 30°, and 45°, with respective speeds of 153.59 RPM, 155.84 RPM, and 164.95 RPM. The study indicates that the higher the number and angle of attack of blades, the greater the rotation of the breastshot type waterwheel. ANOVA tests showed that the number of blades had a significant impact on the waterwheel's rotation, with an F-test value of 6.32 and a p-value of 0.012. On the other hand, the angle of attack of the blade had no significant impact, with an F-test value of 3.20 and a p-value of 0.067

Keywords: breastshot waterwheel, ANOVA analysis, blade number, angle of attack

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1. Introduction

One of the challenges in the energy sector is the limited availability of non-renewable energy sources and the high cost of developing renewable energy sources. Therefore, finding new energy sources and improving energy efficiency has become a priority [1]. One of the goals of the 2004–2022 national electricity plan is to increase access to electricity in rural areas, either by expanding the PLN network or by using alternative methods [2]. This is particularly important for remote areas, especially in Bogor Regency, where only half of the households have access to electricity. Many people in the area have built their own micro hydroelectric power generators, such as those that use simple waterwheels with a capacity of only around 100 watts. However, the simple construction and installation make the micro hydroelectric power generators vulnerable to natural disasters [3]. Research on micro hydroelectric power generators using the breastshot waterwheel is very promising because the technology is already widely known by the community [4].

The current research is focused on performance optimization, including optimization of runners such as blade number and blade angle using ANOVA. The significance of the study on the effects of blade angle and number on micro-hydro power generation lies in their potential to optimize the performance and efficiency of micro-hydro power generation. Studies [5–8] aim to determine the optimal angle and number of blades for maximum electrical power output, which can result in more efficient and cost-effective micro-hydro power generation. The study by [9] also highlights the importance of turbine design in micro-hydro systems. By optimizing the turbine design, micro-hydro power generation can produce more electricity with less water, making it a more sustainable and environmentally friendly source of energy [10]. The results of these studies can be used to improve the performance and efficiency of existing micro-hydro power generators and to design new ones. This can provide significant economic and environmental benefits, especially in remote areas with limited access to electricity.

Therefore, research on micro hydroelectric power generators using the breastshot waterwheel and focusing on performance optimization, including the optimization of runners such as blade number and angle of attack, is highly relevant. The focus on optimizing runners, through studies experiment and ANOVA, is significant. As a result, improving energy efficiency has become a priority. The increase in electrification ratio is expected to help PLN in improving the electricity supply for rural communities.

2. Literature review and problem statement

Many previous researchers also discussed modeling micro hydro power generation. The investigation related to the effect of the included angle of V-shaped blades on the performance of a simplified Pico-hydro system [7]. These findings underscore the importance of selecting smaller included blade angles, corresponding to deeper blades, for optimizing the performance of the Pico hydro turbine. However, the different runner sizes did not explore the potential impact on the performance of the Pico-hydro system.

The research focused on studying the performance and efficiency of a Pelton turbine prototype for micro-hydro power generation was reported [11]. The effect of blade angle on a simplified Pico hydro system was discussed. The investigation showed that the optimal number of blades for a water turbine is 16, overshot type which affects the turbine rotation speed and power output, resulting in 573.9 rpm and 14.7 watts of electricity.

The additional research focused on the design and modeling of a micro hydro power plant using an overshot wheel turbine, and the efficiency of the turbine was measured at different nozzle angles [12]. The result reported that the highest efficiency was achieved at a nozzle angle of 30 degrees with 25.5 % efficiency.

Another study discussed how to enhance the performance of a water turbine for generating hydroelectric power in the design process and testing of an L-type turbine rotor prototype with three different blade curve angles [13]. The research highlights that adjusting the blade arc angle significantly influences the Savonius water turbine’s performance.

The study focused on the optimization of geometric factors to maximize the efficiency of a Turgo turbine has been done [14]. The analysis of performance was carried out on the pico-hydro turbine and considered jet inlet angle, nozzle diameter, number of blades, and speed as factors. The nozzle distance was very close to the runner shaft, the angle of attack was lower, and the nozzle height was chosen to maximize energy transfer to the upper and lower blade profiles. These factors all contributed to the highest turbine performance as well [15]. The advantages of the breastshot type include higher efficiency compared to undershot type, shorter fall height compared to overshot type, and can be applied to a uniform flow of water sources [16]. However, the disadvantages of breastshot type include uneven blades similar to other types. All this allows us to argue that it is appropriate to carry out research aimed at finding out the breastshot waterwheel maximum rotation with variations in the number of blades and the angle of attack.

3. The aim and objectives of the study

The aim of the study is to determine the maximum performance of the waterwheel.

To achieve this aim, the following objectives are accomplished:

– to find out the maximum rotation from research, which shows that the number and angle of attack of the blades affect the rotation of the waterwheel;

– to determine the significant effect on the rotation of the waterwheel, whether the number of blades or the angle of attack, using ANOVA analysis.

4. Materials and methods of research

The object of the study is a breastshot waterwheel.

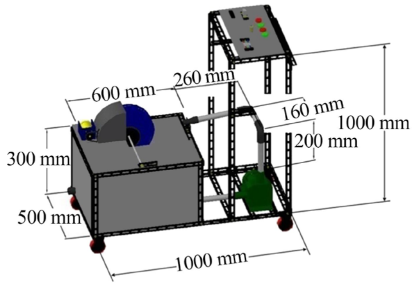
The hypothesis of this research posits that an increase in the number of blades and an augmentation of the blade attack angle will lead to higher rotations of the waterwheel. The rationale behind this is that a greater blade count results in more blades encountering the water, thereby intensifying the rotational motion of the waterwheel. Meanwhile, an increase in the blade attack angle is expected to enhance the thrust exerted on the wheel, consequently amplifying its rotation. Hence, it is crucial to ascertain the factor contributing to the escalation in the wheel’s rotation, whether it stems from the augmented blade count or the heightened blade attack angle.

The assumptions made for the purpose of facilitating this research are that the fluid flow velocity remains constant and is unaffected by time (steady state), in order to simplify the investigation of the fluid flow phenomena that occur.

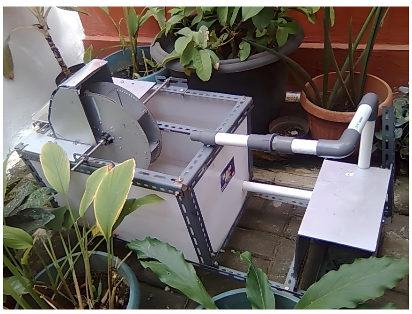
The simplification carried out involves scaling down from the existing dimensions to the dimensions of the testing apparatus, in order to observe the fluid flow phenomena where fluid velocity is transformed into fluid pressure capable of driving the waterwheel to increase its rotation.

The research process started with a community survey on the utilization of windmill-type Micro Hydro Power Plants. A model of the windmill-type micro hydro power plant was then created with 6, 8, and 10 blades. The performance of the turbine was tested by measuring the rotation speed. Afterwards, the blade angle was adjusted to 0°, 30°, and 45°, and the rotation speed was measured to determine the maximum rotation speed achieved with each blade angle adjustment.

The purpose of creating a testing model for Micro Hydro Power Plants (MHPP) is to obtain initial data on the design of the turbine type before being tested using experiment and ANOVA analysis. Fig. 1 shows the design and implementation of Micro Hydro Power Plants that have been built.



a



b

Fig. 1. Breastshot-type Hydro Power Waterwheel: *a* — Design of a Breastshot type waterwheel; *b* — Implementation of a Breastshot type waterwheel

Next, a waterwheel model was built using 1 mm thick iron plate material with a diameter of 30 cm and a varying number of blades: 6, 8, and 10. The design of the Micro Hydro Power Plants (MHPP) of the breastshot type waterwheel can be seen in Fig. 2. The mechanism for constructing the waterwheel involved cutting the iron plates as the sides of the waterwheel and cutting galvanized plates as the waterwheel blades. Each side of the waterwheel was marked and drilled to hold connectors, which would then be fitted with bearings on both sides as the shaft support.

After the MHPP model was ready, the next step was to conduct testing on the MHPP model. The tools used in testing the breastshot waterwheel MHPP model consisted of: a digital tachometer used to measure the rotation speed of the waterwheel, a stopwatch used to measure the time of water flow measurement, and workshop support tools such as wrenches, pliers, screwdrivers, and others. The tested variable was a combination of 6, 8, and 10 blades with each blade angle of attack set at 0°, 30°, and 45°, resulting in a total of 15 performance tests.

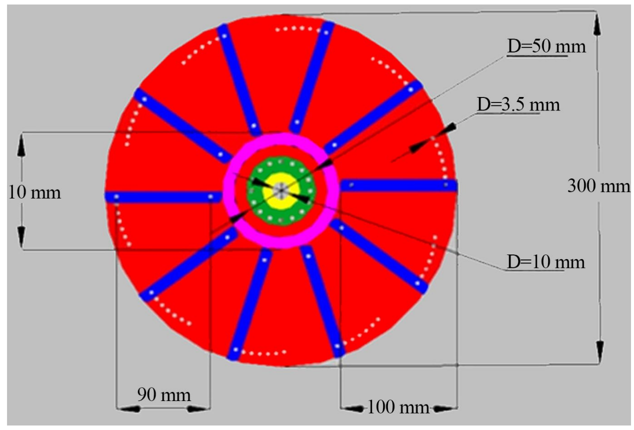


Fig. 2. Design of Waterwheel with 10 blades

5. Results of the study on the performance of a Breastshot Type Waterwheel

5. 1. Results of the maximum rotation

The information that was discovered during the testing of the breastshot type water mill is as follows:

– flow rate (Q):

$$Q=0.000436\ [\mathrm{m^3/s}]=0.436\ [\mathrm{L/sec}]=26.16\ [\mathrm{L/min}];$$

– mass flow rate ($\dot{m}$):

$$\dot{m}=Q\cdot\rho,$$

$$\dot{m}=\left(0.000436\ \mathrm{m^3/s}\right)\times\left(1000\ \mathrm{kg/s}\right),$$

$$\dot{m}=0.436\ \mathrm{kg/s}.$$

Table 1 shows the results of a breastshot waterwheel test with the number of blades (6, 8, and 10), and blade angle of attack (0°, 30°, and 45°).

Table 1

Results of a breastshot waterwheel

Run	Performance (RPM)								
	Number of blades, N=6 pcs			Number of blades, N=8 pcs			Number of blades, N=10 pcs		
	Angle of attack 0°	Angle of attack 30°	Angle of attack 45°	Angle of attack 0°	Angle of attack 30°	Angle of attack 45°	Angle of attack 0°	Angle of attack 30°	Angle of attack 45°
1	142.2	149.4	162.2	148.1	153.1	164.0	153.2	155.5	164.4
2	141.0	149.9	161.8	149.4	152.3	163.5	154.6	156.6	165.1
3	142.4	150.5	162.4	148.4	153.6	163.6	158.1	156.3	164.4
4	143.2	151.5	162.2	147.9	152.7	163.5	153.6	155.5	165.5
5	142.3	150.9	161.7	146.8	154.5	163.4	156.3	155.4	164.6
6	142.4	152.4	161.9	148.0	154.7	163.3	152.2	155.9	164.3
7	141.1	151.4	162.0	147.1	154.6	161.3	151.4	155.7	166.1
8	142.6	151.1	162.2	147.9	153.6	163.8	153.1	157.3	164.5
9	142.0	150.6	162.8	147.6	154.8	163.5	150.6	155.7	166.6
10	142.7	151.2	162.8	146.0	153.9	164.9	150.9	155.8	164.7
11	143.5	151.3	162.0	147.1	155.5	163.0	152.8	155.2	165.4
12	140.0	151.1	162.9	147.1	154.1	162.8	153.9	155.8	164.1
13	142.7	151.5	162.4	146.5	154.3	163.7	152.0	155.9	164.7
14	142.7	151.1	162.4	147.0	155.6	162.8	157.2	155.1	164.6
15	142.7	152.0	162.4	146.7	154.0	162.8	154.0	155.9	165.3
$\bar{X}$	142.23	151.06	162.28	147.44	154.09	163.33	153.59	155.84	164.95

The number of blades, $N=6$, and the waterwheel rotation at angles of attack (0°, 30°, and 45°) is (142.23 rpm, 151.06 rpm, and 162.28 rpm). The number of blades, $N=8$, and the waterwheel rotation at 0°, 30°, and 45° angles of attack is (147.44 rpm, 154.09 rpm, and 163.33 rpm). The number of blades, $N=10$, and the waterwheel rotation at 0°, 30°, and 45° angles of attack is (153.59 rpm, 155.84 rpm, and 164.95 rpm).

The performance of the breastshot type waterwheel in generating maximum rotations with variations in the number of blades and angle of attack can be seen in Fig. 3.

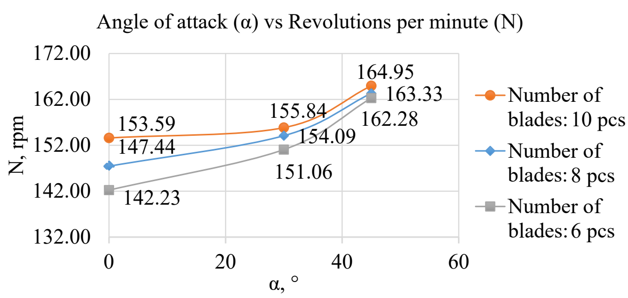


Fig. 3. Average results of measurements on blades 6, 8, 10 and water flow rate at 26.16 [L/min]

Fig. 3 shows that the maximum rotation is attained at a 45° angle of attack and the number of blades, $N=6$, 8, and 10, and is 162.28 rpm, 163.33 rpm, and 164.95 rpm, respectively.

Overall, the test results in Fig. 3 show that the breastshot type waterwheel rotates faster with the greater the blade angle of attack, and the more blades there are.

5. 2. Results of the significant effect on the rotation of the waterwheel (ANOVA analysis)

An ANOVA test was used to evaluate whether the angle or the number of blades has the greatest impact on how the waterwheel rotates. We can use statistical programs like R, SPSS, or Excel to run the ANOVA test on the table. However, I'll compute it using Excel in this case. The following is the ANOVA calculation table for the impact of the number of blades and angle of attack on the rotation of the waterwheel. Table 2 shows ANOVA test for waterwheel rotation [17].

Table 2

ANOVA test for waterwheel rotation

Source	DF	Sum of squares	Mean of squares	F-value	p-value
Number of Blades	2	6144.01	3072.00	6.32	0.012
Angle of Blade	2	3106.49	1553.25	3.2	0.067
Error	18	1912.64	106.26	–	–
Total	23	11163.14	485.87	–	–

A hypothesis test is also performed on each factor. The hypothesis tests for each factor are as follows:

a) Number of blades factor:

– null hypothesis (H_0): The average number of rotations of the waterwheel between each blade group is the same;

– alternative hypothesis (H_1): The average number of rotations of the waterwheel between each blade group is not the same.

The significance level (α) used is 0.05. Table 3 shows ANOVA test for the number of blades of the waterwheel [18].

Table 3

ANOVA test for the number of blades

Source of variation	DF	Sum of squares	Mean of squares	F-value	p-value
Between Groups	2	157.495	78.75	8.017	0.0001
Within Groups	42	650.322	15.48	–	–
Total	44	807.817	94.23	8.017	0.0001

b) Angle of attack of blades factor:

– null hypothesis (H0): The average number of rotations of the waterwheel between each angle of attack group is the same;

– alternative hypothesis (H1): The average number of rotations of the waterwheel between each angle group is not the same.

The significance level (α) used is 0.05. Table 4 shows ANOVA test for the angle of attack of blades factor of the waterwheel [19].

Table 4

ANOVA test for the angle of attack of blades

Source of variation	DF	Sum of squares	Mean of squares	F-value	p-value
Between Groups	2	173.19	86.60	0.802	0.456
Within Groups	12	1687.94	140.66	–	–
Total	14	1861.13	227.26	0.802	0.456

To perform a homogeneity test, the Levene's test can be used. Here are the results of the homogeneity test for the data in Table 1 with a significance level of α=0.05. Table 5 shows Levene's test for homogeneity of variance [20].

Table 5

Levene's Test for Homogeneity of Variance

DF		Sum of squares	Mean of squares	F-value	Pr (>*F*)
Group	3	0.050748	0.016916	1.257413	0.308761

Based on the result of the Levene test in Table 5, the obtained p-value is 0.308761, which is larger than the significance level of α=0.05, thus it is not strong enough to reject the null hypothesis. Therefore, it can be concluded that the data has homogeneity of variances.

6. Discussion of the results of the study on the performance of a Breastshot Type Waterwheel

Fig. 3 depicts the performance of the breastshot type waterwheel in generating maximum wheel rotations at 164.95 rpm and water flow rate at 26.16 L/min with 10 blades, and an angle of attack of 45°. The higher the wheel rotation, the greater the potential to generate more electricity. Therefore, the information obtained from the data can be useful in the planning and design of hydroelectric power generation systems. According to the research [21], the ideal design parameters were a waterwheel turbine with 6 blades, a convex blade form, and a water discharge of 50 L/min, and the research [22], small hydro turbine blade performance delivers the most significant power with a blade angle of 20° at the highest rotating speed of 335 rpm.

Based on the results in Table 2, the source of variation in the number of blades yielded an F-test of 6.32 with a p-value of 0.012, while the source of variation in the angle of blades yielded an F-test of 3.20 with a p-value of 0.067. Since the p-value from the source of variation in the number of blades is less than 0.05, it can be concluded that the number of blades has a significant effect on the rotation of the waterwheel, while the angle of attack of the blades does not have a significant effect.

In the ANOVA analysis in Table 3, the calculated F-value is 8.017 with a p-value of 0.0001. Since the p-value is smaller than α, it can be concluded that there is a significant difference between at least one pair of mean values of the number of blade groups. Therefore, the null hypothesis is rejected.

The calculated F-value for the ANOVA analysis in Table 4 is 0.802 with a p-value of 0.456. It cannot be said that there is a significant difference between at least one pair of mean angles of attack groups because the p-value is greater than. The null hypothesis is therefore accepted, and it can be said that the angle of attack of the blade component does not significantly affect the number of spins of the waterwheel.

There are several limitations of this study, one of which is the lack of computational testing using CFD (Computational Fluid Dynamics) to observe flow phenomena and the influence of increasing wheel rotation with changes in the number of blades.

The disadvantage in this study does not address the potential impact of environmental factors on the waterwheel's performance. This limitation may affect the generalizability of the findings to different environmental conditions.

Therefore, the next development that needs to be undertaken in this study is to employ computational modeling to understand fluid dynamics, analyze energy efficiency, and explore real-world applications. However, researchers will face challenges such as resource constraints, complex fluid dynamics analysis, and environmental influences. Despite these difficulties, this study provides valuable insights into waterwheel performance and paves the way for future investigations in the field of hydropower and fluid dynamics.

7. Conclusions

1. The study's results indicate that the rotation of the waterwheel is influenced by both the quantity and the angle at which the blades are set. This is shown in a test of a breastshot type waterwheel micro hydro power plant, where the maximum rotational speed was attained at 10 blades and blade angles of attack of 0°, 30°, and 45°, respectively, and was 153.59 rpm, 155.84 rpm, and 164.95 rpm.

2. The number of blades produced an F-test value of 6.32 with a p-value of 0.012 and the angle of attack of the blades produced an F-test value of 3.20 with a p-value of 0.067. The number of blades has a substantial impact on the waterwheel's rotation, however, the angle of attack of the blade has no significant impact, as shown by the p-value for the variation source of the number of blades being less than 0.05.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

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