Dinamika Teknik Mesin 15(1) (2025) 18-26

Dinamika Teknik Mesin
Jurnal Keilmuan dan Terapan Teknik Mesin
http://dinamika.unram.ac.id/index.php/DTM/index

Effect of variations in the hitting point on the blade on performance of overshot water turbine

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ARTICLE INFO

Article History:
Received 19 September 2024
Accepted 24 March 2025
Available online 01 April 2025

Keywords:
Energy
Overshot turbine
Hitting point
Efficiency
Power

ABSTRACT

Water turbine is very important technology in producing electrical energy from renewable energy sources. Overshot turbine utilize specific gravity of water hit the blade and converts the potential energy of water into kinetic energy when the nozzle sprays water that hits the bucket and then passes it on to the transmission system becomes mechanical energy. This mechanical energy is converted into electrical energy by the generator. This research was carried out experimentally using five curved blades and an overshot turbine. The hitting point on blade distances are 0.13 m, 0.15 m, 0.17 m, 0.19 m, and 0.21 m and varying load, is 0.1 kg - 1.3 kg with constant discharge and head. The results obtained show that variations in hitting point on blades influence turbine power and turbine efficiency. The highest turbine power and efficiency for discharge of 0.0009 m^3/s was obtained at hitting point of 0.13 m with load of 1 kg which produces 3.7888 watts of turbine power and efficiency is 25.05 %.

Dinamika Teknik Mesin, Vol. 15, No. 1, April 2025, ***p. ISSN: 2088-088X, e. ISSN:*** **2502-1729**

1. INTRODUCTION

Water turbines are a very important technology in producing electrical energy from renewable energy sources, Basar et al. (2024). Most of the electricity consumed by the public is produced from coal and oil-fired power plants which are classified as non-renewable and produce quite high emissions, Siswadi et al. (2020). Based on Presidential Regulation of the Republic of Indonesia Number 22 of 2017 concerning the General National Energy Plan (RUEN) prioritizing the use of renewable energy with a target of at least 23% in 2025 and at least 31% in 2050, Taufiqurrahman et al. (2020).

Indonesia is a country rich in abundant water resources. The potential for water energy in Indonesia is estimated at 94,449 MW. The potential that can be utilized as PLTA is 75,091 MW, while that which can be utilized as PLTM and PLTMH reaches 19,358 MW, Dewangga et al. (2022). Based on the large potential for new and renewable energy, the government is committed to making plans and policies so that the use of new and renewable energy potential in Indonesia is more optimal while helping to reduce emissions from various sectors, Bachan et al. (2019).

https://doi.org/10.29303/dtm.v15i1.970

Water turbine is a driving machine or energy conversion machine that converts potential energy from falling water into kinetic energy when the nozzle sprays water that hits the bucket and then passes it on to the transmission system to become mechanical energy, Yasir et al. (2020). When the high-pressure water jet from the nozzle hits the turbine, it produces rotation of the shaft which is connected to an electric generator which then produces electrical power, Luther et al. (2020). The position of the waterfall can affect the power and efficiency of the turbine, where water that hits the outside of the blade can cause a reduction in turbine efficiency because only part of the water hits the turbine blade, Butera et al. (2020).

The blades in the water turbine are needed to capture kinetic energy from the water flow to make the runner rotate so that kinetic energy is converted into mechanical energy, Bilkova et al. (2023). The blades on the turbine can affect the performance produced by the water turbine. Several things about turbine blades that affect turbine performance are blade shape, number of blades, blade angle, blade size, material used, and hitting point on the blades. The curved blade shape has higher power and efficiency compared to the flat and bowl blade shapes, Gerard et al. (2023).

In previous research regarding the performance characteristics of Nest-Lie Turbines in Micro Hydro Power Plant Prototypes, based on the research, the maximum voltage and current values were obtained on nest-lie turbine blades with a nozzle position of 45° and a nozzle angle of 10°, namely 0.1824 Volts and 0. 84 Amperes. The highest torque value was also obtained at a nozzle position of 45° and a nozzle angle of 10°, namely 0.0076 Nm, Nyoman Wira Mastika et al. (2020)

Comparison of the performance characteristics of semicircular turbine blades with the NEST-LIE turbine on the PLTMH Prototype. This research found that the NEST-LIE turbine has better characteristics than the semicircular turbine. The NEST-LIE turbine produces the highest output power at the 45° nozzle position, with a turbine rotation of 342.4 rpm and an output power of 0.1802 VA, Paramitha et al. (2021).

Research on the position of the nozzle is designed with the water falling point at angles of 0°, 15°, 30°, 45°, 60° and 75°. Where the highest efficiency is obtained at the nozzle position at a 60° angle of 18% in the semicircular blade model. Previous researchers assumed that at a nozzle position at a 60° angle, the water falling from the nozzle would hit the most actively rotating area on the wheel (Vika et al., 2018).

2. METHODOLOGY

2.1 Design and Materials

This research was conducted using an experimental method. The blade model is curved blade made from 4-inch PVC pipe. The turbine runner has a diameter of 240 mm, length of 100 mm and width of 80 mm. Data collection was carried out with a load of 0.1 kg to 1.3 kg hanging vertically on a pulley with a radius of 0.045 m. Using variations in the hitting point from the shaft to the blade, namely 0.13 m, 0.15 m, 0.17 m, 0.19 m, and 0.21 m, with a head of 1.65 m and full valve opening for each variation hitting point. The experimental results calculated the water discharge, water speed, water power, torque, turbine power, turbine efficiency

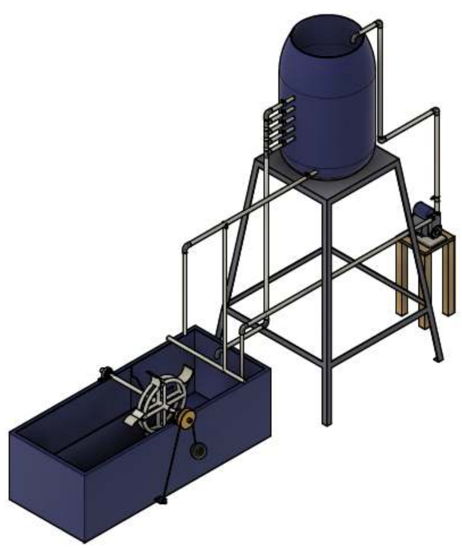

Figure 1. Design of Experiment Installation

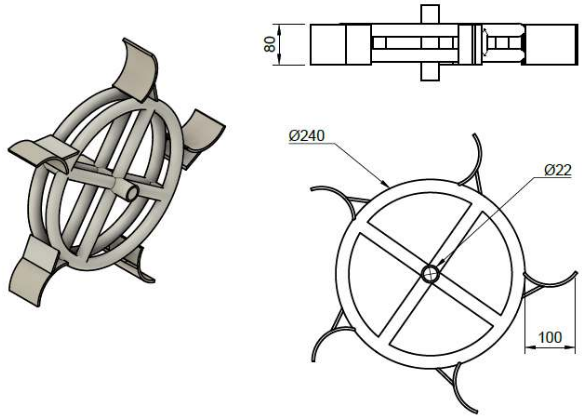

Figure 2. Design of Turbine

Figure 3. Experiment Installation

2.2 Method of changing the point of hitting on the blade

1. Hitting point 0.21 m (r_1)
   At an hitting point of 0.21 m, the position of the water falling from the nozzle is exactly on the outside of the blade on the x axis.
2. Hitting point 0.19 m (r_2)
   At an hitting point of 0.19 m, the position of the water falling from the nozzle is right between the outside (0.21 m momentum radius) and the middle (0.17 m momentum radius) of the blade on the x-axis.
3. Hitting point 0.17 m (r_3)
   At an hitting point of 0.17 m, the position of the water falling from the nozzle is exactly about the center of the blade on the x axis.
4. Hitting point 0.15 m (r_4)
   At an hitting point of 0.15 m, the position of the water falling from the nozzle is right between the middle (0.17 momentum radius) and the inside (0.13 m momentum radius) of the blade on the x-axis.
5. Hitting point 0.13 m (r_5)
   At an hitting point of 0.13 m, the position of the water falling from the nozzle is exactly on the inside of the blade on the x axis.

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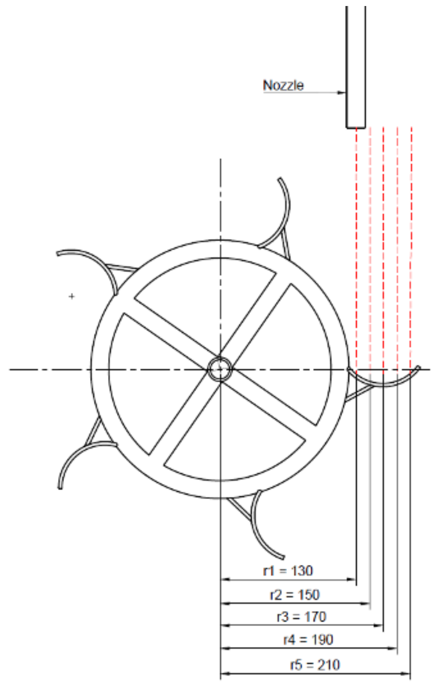

Figure 4. Variations of hitting point on the blade

Table 1. Materials

Name	Specifications
Runner	Plastic
Shaft	PVC ½ inch, length 765 mm
Blade	PVC 4 inch, length 100 m, width 80 mm, curved blade
Reservoir	200 l
Pulley	0,045 m
Pipe	PVC ¾ inch
Load	Cement and stone
Tachometer	Digital tachometer

2.3 Equations

Water discharge (Q) is the volume of water that can be flowed per unit of time. Water discharge can be used to calculate the flow rate in each experimental pipe, where the water discharge can be determined by the following equation (Gerard, 2023):

$$Q = V/t \quad (1)$$

Water flow rate (v) is the amount of water flowing at a certain speed per unit time. The flow rate can be determined using the following equation (Luther, 2023):

$$v = Q/A \quad (2)$$

Water power (P_w) is the power that enters the nozzle, the amount of which can be obtained by the following equation (Luther, 2023):

$$Pw = Q \times \rho \times g \times H \quad (3)$$

Torque is the rotating force generated by the turbine shaft or the turbine's ability to do work. Torque is usually given the symbol τ. To find the torque value, the following equation can be used (Gerard, 2023):

$$\tau = F \times r \quad (4)$$

The turbine power (P_t) generated by the turbine is obtained by the following equation (Luther, 2020):

$$Pt = \tau \times \omega \quad (5)$$

$$\omega = (2 \times \pi \times n)/60 \quad (6)$$

https://doi.org/10.29303/dtm.v15i1.970

Turbine efficiency is the ratio between the power generated on the turbine shaft and the power provided by the fluid (water). Turbine efficiency states the turbine's ability to convert fluid energy into useful energy on the turbine shaft. The following equation can be used to determine the turbine's efficiency (Luther, 2020).

$$\eta = \left(\frac{Pt}{Pw}\right) \times 100\% \quad (7)$$

3. RESULTS AND DISCUSSION

Data on the relationship between load and turbine power at varying hitting point obtained from calculation results in testing an overshot water turbine with five blades can be seen in table 4.

Table 2. Hitting point on turbine power

m (kg)	P_w(watt)	P_t (watt)				
		r_1 0.21 m	r_2 0.19 m	r_3 0.17 m	r_4 0.15 m	r_5 0.13 m
0.1		0.52	0.56	0.57	0.61	0.62
0.2		0.96	1.04	1.07	1.15	1.19
0.3		1.33	1.46	1.52	1.62	1.72
0.4		1.64	1.77	1.90	2.05	2.18
0.5		1.87	2.03	2.24	2.45	2.56
0.6		2.02	2.19	2.50	2.77	2.94
0.7	15.12	2.10	2.30	2.68	3.07	3.23
0.8		2.14	2.37	2.85	3.33	3.47
0.9		2.04	2.37	2.91	3.49	3.66
1		1.89	2.31	2.96	3.56	3.79
1.1		1.73	2.24	2.90	3.51	3.76
1.2		1.55	2.11	2.83	3.38	3.60
1.3		1.26	1.86	2.70	3.18	3.4238

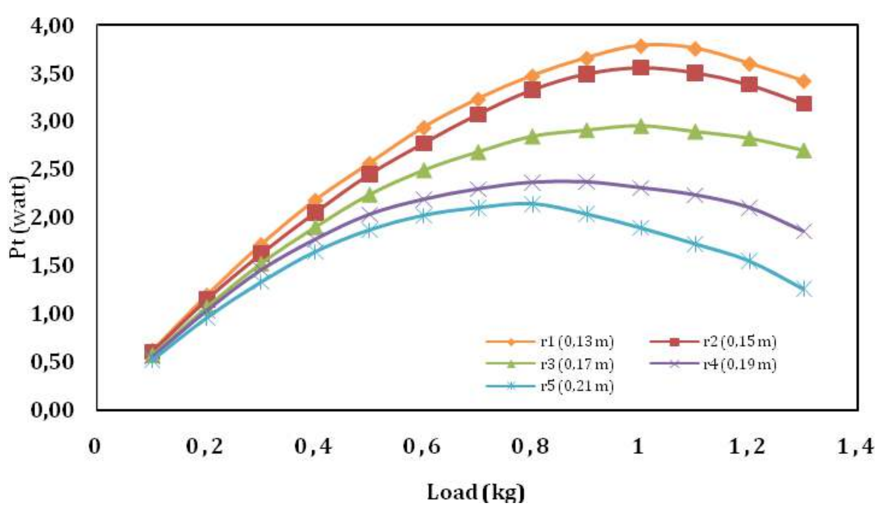

Figure 5. Relation between load and turbine power at varying hitting point

In figure 5, it can be seen that for each variation in hitting pointwith a constant discharge, the relationship between load and turbine power produces different values. At a hitting point of 0.21 m, the resulting turbine power value increases from a load of 0.1 kg to 0.8 kg, then decreases at a load of 0.9 kg to 1.3 kg. At an hitting point of 0.19 m, the resulting turbine power value increases from a load of 0.1 kg to 0.9 kg, then decreases at a

https://doi.org/10.29303/dtm.v15i1.970

load of 1 kg to 1.3 kg. At hitting point of 0.17 m, 0.15 m, and 0.13 m, the value of the power produced increases from a load of 0.1 kg to 1 kg, then decreases at a load of 1.1 kg to 1.3 kg. The maximum average turbine power for each hitting point was obtained at a load of 0.8 kg to 1 kg.

Based on research conducted by Gerard et al. (2023), it is known that the heavier the load given, the greater the turbine power produced until it reaches the optimal load to produce maximum power, then it will decrease as the given load increases. This can also be seen in equation (5), where the turbine power is obtained from the product of torque and angular speed. Based on equation (6), the amount of angular velocity is influenced by the amount of rotation produced, and in equation (4), the amount of torque is influenced by the amount of load applied. The amount of load and rotation has a negative correlation (if the load is higher, it creates a smaller rotation, or vice versa) so that at a certain point (maximum point) the amount of load and rotation is optimal to produce the highest power. Corvis et al. (2019) found that the greater load given, the turbine rotation decreases and if the lower load given the turbine rotation increases . The higher turbine rotation makes the higher turbine power. The slower angular velocity produces the force of turbine shaft is lower (Zain et al, 2022).

The maximum turbine power was obtained at a hitting point of 0.13 m with a load of 1 kg is 3.7888 watts, while the lowest turbine power with the same load was obtained at an hitting point of 0.21 m is 1.8944 watts. This is because the waterfalls at hitting point of 0.13 m directly onto the inside of the turbine blade so that the blade can utilize the maximum flow rate which produces high rotation and turbine power. Meanwhile, at hitting point of 0.21 m, the water falling from the nozzle does not completely hit the turbine blade so the turbine rotation and turbine power produced are smaller. So it can be said that the shorter hitting point , the higher turbine power produced, and vice versa.

Data on the relationship between load and turbine power at varying hitting point obtained from calculation results in testing an overshot water turbine with five blades can be seen in table 5.

Table 3. Hitting point on efficiency

m (kg)	P_w (watt)	η (%)				
		r_1 0.21 m	r2 0.19 m	r_3 0.17 m	r_4 0.15 m	r_5 0.13 m
0.1		3.45	3.70	3.79	4.00	4.09
0.2		6.36	6.85	7.09	7.58	7.88
0.3		8.80	9.63	10.08	10.73	11.37
0.4		10.88	11.73	12.59	13.57	14.42
0.5		12.38	13.45	14.82	16.20	16.96
0.6		13.38	14.49	16.50	18.34	19.44
0.7	15.12	13.90	15.19	17.75	20.32	21.39
0.8		14.18	15.65	18.82	22.00	22.98
0.9		13.48	15.68	19.25	23.10	24.20
1		12.53	15.28	19.56	23.53	25.06
1.1		11.43	14.79	19.16	23.19	24.88
1.2		10.27	13.93	18.70	22.37	23.84
1.3		8.34	12.32	17.88	21.06	22.64

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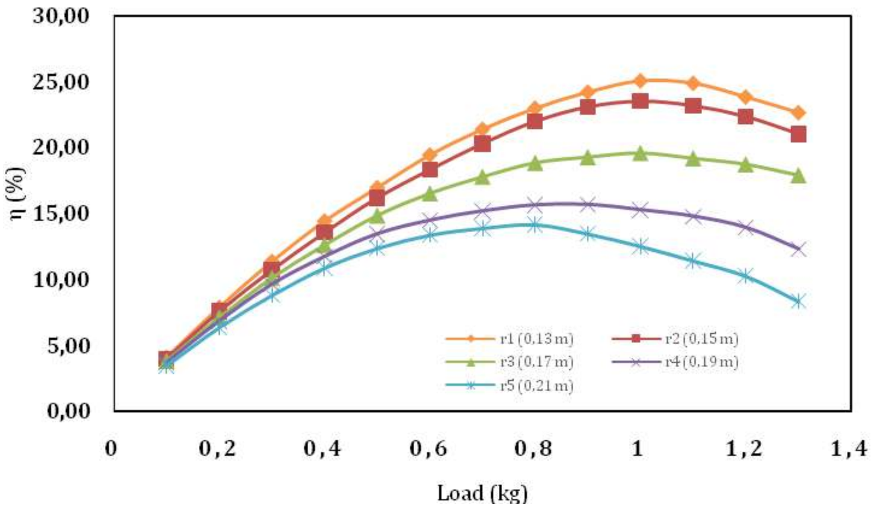

Figure 6 . Relation between load and turbine efficiency at varying hitting point

In figure 6, it can be seen that for each variation in hitting point with a constant discharge, the relationship between load and turbine efficiency produces different values. At hitting point of 0.21 m, the turbine efficiency value increases until it reaches a maximum point at a load of 0.8 kg, then decreases at a load of 0.9 kg to 1.3 kg. At hitting point of 0.19 m, the turbine efficiency value increases until it reaches a maximum point at a load of 0.9 kg, then decreases at a load of 1 kg to 1.3 kg. At hitting point of 0.17 m, 0.15 m and 0.13 m, the turbine efficiency value increases until it reaches a maximum point at a load of 1 kg, then decreases at a load of 1.1 kg to 1.3 kg. The maximum average turbine efficiency for each hitting point is obtained at a load of 0.8 kg to 1 kg.

From Figure 6, it can be said that the higher load makes the higher efficiency until the peak point. Peak point is a state where efficiency is maximum but cannot increase again. After the peak point, efficiency decreases although the higher load given and efficiency can sometimes become zero. Peak point for r_1, r_2, r_3 are in load of 1 kg. Peak point for r_4 is on load of 0.9 kg and peak point for r_5 is on load of 0.8 kg. The decrease in the turbine efficiency value is caused by a reduction of the forces acting on the turbine blades so that the resulting rotation will decrease and automatically the turbine power will also decrease. Based on equation (2.10), it can be seen that determining the efficiency value is obtained from the ratio between turbine power (output power) and water power (input power), so that the greater the turbine power or closer to the water power, the greater the resulting efficiency value (Yasir et al., 2022). Increasing the output power of the turbine is related to increasing the kinetic and potential energy so that the efficiency of the turbine increases (Agato et al, 2023)

From the calculations, it is obtained that the highest efficiency occurs at hitting point of 0.13 m, then decreases sequentially at hitting point of 0.15 m, 0.17 m, and 0.19 m, and the lowest efficiency occurs at hitting point of 0.21 m. The highest efficiency was obtained at hitting point of 0.13 m with a load of 1 kg, 25.06%, while the lowest efficiency with the same load was obtained at hitting point of 0.21 m, 14.18%. This is because the turbine power decreases for each increase in the hitting point, thus affecting efficiency. In Figure 6 it can be seen that for each load, the hitting point of 0.21 m produces the lowest efficiency. This is to research conducted by Vika et al. (2018), when the water falls right on the outer edge of the blade, it produces small turbine rotation and power because the water no longer hits the most active area of the turbine, so the efficiency is smaller. So it can be said that the longer the hitting point, the smaller the efficiency, and vice versa.

4. CONCLUSION

For an overshot water turbine with a curved blade, turbine power can be affected by the hitting point, where the smaller the hitting point given, the greater the turbine power produced. This is because, at a small hitting point, the blade can utilize the maximum flow rate, producing large turbine power. The amount of turbine power is also influenced by the amount of rotation and the load given, where the load and rotation have a negative correlation (if the load is greater, the rotation is smaller, or vice versa) so that at a certain point (peak point) the amount of load and rotation is optimal to produce the highest turbine power. In this study, the highest turbine power was obtained at the hitting point of 0.13 m with a load of 1 kg at 82 rpm, which is 3.79 watts, while the lowest turbine power was obtained at the hitting point of 0.21 m with a load of 0.8 kg at 58 rpm, which is 2.14 watts.

ACKNOWLEDGEMENTS
All credits for Fluid Machines Laboratory, Department of Mechanical Engineering, Hasanuddin University

NOMENCLATURE

Q	: Discharge (m^3/s)
V	: Volume (m^3)
t	: Time (s)
v	: Velocity (m/s)
A	: Cross-sectional area (m^2)
Pw	: Water power (watt)
ρ	: Density (kg/m^3)
H	: Head (m)
τ	: Torque (N.m)
F	: Force (N)
r	: Hitting point (m)
m	: Massa (kg)
g	: gravitational acceleration (m/s^2)
Pt	: Turbine power (watt)
ω	: rotating speed (rad/s)
n	: Rotation (rpm)
η	: Turbine efficiency (%)

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