Effect of Boss Runner Diameter on Laboratory Scale Vortex Water Turbine Performance Efficiency

DHEMAS OKTO JAKA PANGESTU[1], DODDY IRAWAN[1✉], GUNARTO[1], FAINO[1]
[1]Department of Mechanical Engineering Study
Universitas Muhammadiyah Pontianak
Jalan Ahmad Yani No. 111, Pontianak,
INDONESIA
*irawan.doddy@unmuhpnk.ac.id (corresponding author)

Abstract: One of the renewable energy sources that can be utilized is water. Due to Indonesia's potential for very big river flows, which makes it easier to conduct studies, the need for energy is growing, and renewable energy sources like hydropower have emerged as one of the most necessary energy sources. The search for and comparison of various boss runners with various diameters is the aim of this study. With the technique of removing pairs of runners, the research process is made more effective and efficient where the boss runners have a diameter of 15 mm, 30 mm, or 45 mm. The process involves measuring the elements that have an impact on the boss runner diameter's efficiency value. The torque applied has an impact on the runner's efficiency value. Additionally, the torque load provided affects the runner's rotational speed in a way that creates the perfect ratio for maximizing efficiency. The 45 mm runner with 0.18 (Nm) torque, 74.6% efficiency, and 151.8 (rpm) runner rotation speed has the maximum efficiency.

Keywords: renewable energy, hydropower, vortex turbine, runner, efficiency.

1 Introduction

Energy demand is rising, particularly in developing nations. Hydropower is one of the most essential forms of renewable energy today[1]. The development of renewable energy is the best way and solution for climate change in the world[2], Fossil fuels have historically been the primary source of energy, but their usage has various adverse effects, such as global warming and air pollution, necessitating the use of renewable energy sources[3] Large and small, hydropower continues to be the world's most significant "renewable energy" source for the generation of electric power[4], The world's concern over running out of energy supplies pervaded the 20th century. As a result, it is essential to develop renewable energy sources, one of which is water. When the needs for the available water resources are met, the design of a micro-hydro power plant becomes feasible[5], Indonesia is a maritime country where most of its surface area is water, so water energy is a field with great potential to be developed[6]. Hydroelectric power plants are one of the right choices at this time for utilizing renewable energy sources[7]. This type of hydroelectric power plant, often also called micro-hydro or often also called pico-hydro[8].

An electricity generating facility known as a micro-hydro power plant makes use of the potential of river flow as a source of power[9]. With a popularity of about 19 % and a very high efficiency, micro-hydro power plants currently contribute the most to satisfying the world's electricity needs[10]. Moreover, Indonesia has a large potential for hydropower, which is around 19.4 GW[11], Hydroelectric power generation is popular due to its low cost, ease of installation, mobility, efficiency, and maintenance requirements[12], but not all areas have river flow heights with large amounts of discharge, such as lowland rivers. Generator turbine power is affected by the difference in height (head)[1], This becomes a problem with the lowland river flow.

The Law of Gravity One of the turbines that performs well in low-head and low-flow situations is the Vortex Hydroelectric Power Plant (GWVPP)[13]. because channels and basins are key elements influencing GWVPP effectiveness[14].

Micro-hydro power plants are a subset of the environmentally favorable technology known as gravitational water vortex power plants. Due to the maximum amount of electricity that can be produced, which is currently 100 kWh, it is classified as a micro-hydro power plant[15]. This power plant's key benefit is that it can run at a low head[16], as well as environmentally friendly[17].

German scientist Viktor Schauberge is studying water engines based on whirlpools. This turbine uses a whirlpool, which is created by the spiral shape of the turbine basin. The water flows out of the basin and towards the outlet, which is below the basin. In Viktor Schauberger's study, he used an irrigation flow that was turned into a vortex flow and then used to drive turbine blades[18]. After that, Franz Zotloeterer, an Austrian researcher, developed it and asserted in his work that vortex turbines can operate with the smallest water fall height. From 0.7 to 3 meters is considered little. According to his studies, the conversion efficiency of the theoretical energy is 80%[17].

Hydroelectric power plants are still being produced through innovation and research as the need for electrical energy continues to rise.

2 Formulation of the problem

2.1 Turbine performance measurement

In finding the performance efficiency value of a water turbine, there are several methods used; in this experiment, I used the following method:

One of the ways to measure how well a water turbine works is by how efficient it is. Efficiency is the ratio of how much power is made (output power) to how much power is needed (input power) (Pin). Then the efficiency η can be calculated by the equation:

$$\eta = \frac{Pout}{Pin} \quad (1)$$

Where :
η = Efficiency (%)
P out = Mechanical power (Watts)
P in = Water power (Watts)

For water turbines, the input power (P in) can be calculated from the hydraulic power (Pa). In a gravity system with a water turbine utilizing the difference in water level, hydraulic power can be obtained by measuring the flow rate or discharge (Q) and the difference in water level with the bottom of the basin (Hv). If the density of water is expressed by ρ and the acceleration due to gravity is expressed by g, then the hydraulic power is calculated as follows:

$$Pa = \rho.\ g.\ Hv.\ Q \quad (2)$$

Where :
Pa = Water power (Watts)
ρ.s = Density of water (kg/m^3)
g = Gravity (9.81) (m/s^2)
Hv = water level (m)
Q = water discharge (m^3/s)

The angular velocity (ω) is often referred to as the rotational speed, and the scalar quantity is the rotational speed, which depends on the rotation of the turbine (n). If n is expressed in revolutions per minute (rpm) then the angular velocity (ω) can be found as follows:

$$\omega = \frac{2\pi n}{60} \quad (3)$$

Where :
ω = Angular speed (rad/s)
n = Rotation (rpm)
π = Phi (3,14)

When you multiply the braking force (F) by the distance between the shaft axis and the point where the braking force is measured, you get the torque (t). If the distance between the shaft axis and the braking force measurement point is expressed in L, then the torque (T) can be found as follows:

T = F. L (4)

Where :

Q = Torque(N.mm)

F = Force (N)

L = braking distance (mm)

The turbine output power can be calculated from the turbine mechanical power (Pt). Where the mechanical power (Pt) is the product of the angular velocity (ω) times the torque (T). From equations 3 and 4, the turbine mechanical power (Pt) can be calculated by the following equation:

Pt = ω. Q (5)

Where :

Pt = Power (Watts)

ω = Kangular speed (Rad/s)

Q = Torque (N.mm)

3 Problem solution

3.1 Results and Discussion

Tests were carried out in real time using a laboratory-scale vortex water turbine with the following data calculations:

a. Runner diameter = 120 (mm)
b. Basin inlet diameter = 300 (mm)
c. Basin output diameter = 120 (mm)
d. Braking arm (l) = 90 (mm) = 0.09 (m)

From laboratory scale vortex turbine data collection, which includes flow rate (Q), vortex height (Hv), applied braking force (F), and turbine rotation speed (n), the following data is obtained:

No	Runner 15mm Q = 240 [l/min]			Runner 30mm Q = 240 [l/min]			Runner 45mm Q = 240 [l/min]		
	n (Rpm)	F (N)	Hv (Cm)	n (Rpm)	F (N)	Hv (Cm)	n (Rpm)	F (N)	Hv (Cm)
1	324,6	0,000	9,0	308,0	0,000	9,0	293,4	0,0	9,0
2	210,5	1,028	9,5	221,1	1,029	9,5	259,9	1,0	9,5
3	147,5	1,976	9,5	156,1	1,970	10,0	151,8	2,0	10,0
4	27,0	3,020	10,0	49,6	2,968	10,0	70,0	3,0	10,0
5	0,0	3,275	10,0	0,0	4,000	10,5	0,0	4,0	10,5

Table 1. Data collection with boss runner diameters of 15 (mm), 30 (mm) and 45 (mm).

3.2 Runners

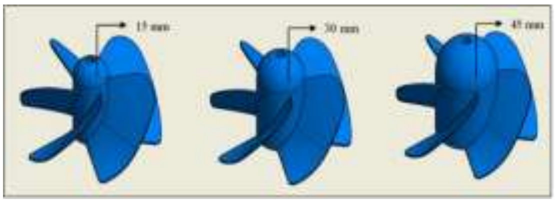

Fig.1 Runner with boss diameters of 15 (mm), 30 (mm) and 45 (mm).

Using a runner with PLA + filament material

3.3 Data from the test results of the effect of torque on efficiency

Table 2 of the effect of torque on runner efficiency 15 (mm)

No	Data Runner 15 mm	
	T (N.mm)	η (%)
1	0,00	0,0%
2	0,09	54,9%
3	0,18	73,9%
4	0,27	19,6%
5	0,29	0,0%

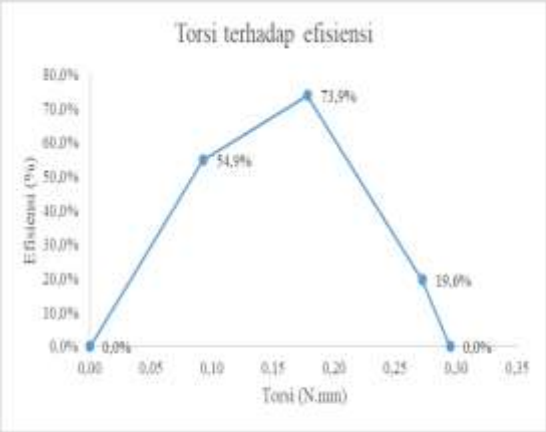

Fig.2 Graph of the effect of torque on runner efficiency 15 (mm)

Figure 2, a graph illustrating the effect of torque on runner efficiency with a boss diameter of 15 (mm), shows that the more torque applied, the greater the efficiency produced with an average runner rotation value of 147.5 (rpm).

Table 3 of the effect of torque on runner efficiency 30 (mm)

	Data Runner 30 mm	
No	T (N.mm)	η (%)
1	0,00	0,0%
2	0,09	57,7%
3	0,18	74,1%
4	0,27	35,5%
5	0,36	0,0%

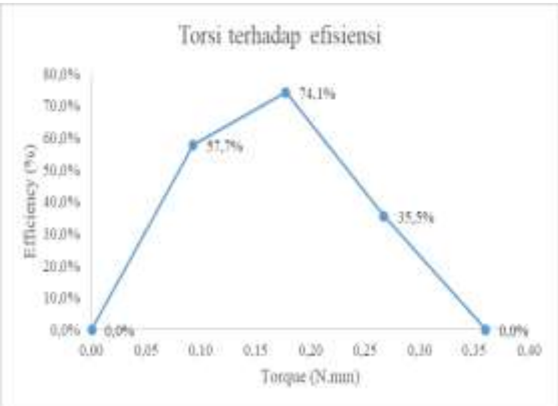

Fig.3 Graph of the effect of torque on runner efficiency 30 (mm)

Figure 3, a graph illustrating the effect of torque on runner efficiency with a boss diameter of 30 (mm), shows that the more torque applied, the greater the efficiency produced with an average runner rotation value of 156.1 (rpm).

Table 4 of the effect of torque on runner efficiency 45 (mm)

	Data Runner 45 mm	
No	T (N.mm)	η (%)
1	0,00	0,0%
2	0,09	64,1%
3	0,18	74,6%
4	0,27	50,9%
5	0,36	0,0%

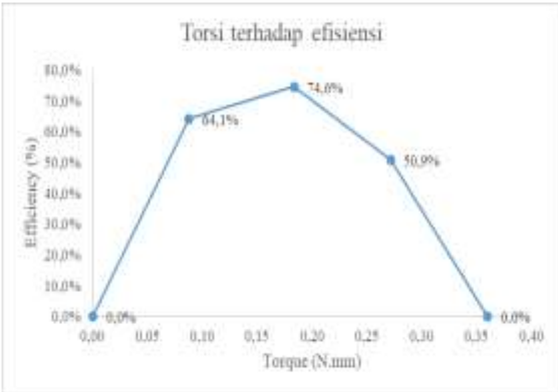

Fig.4 Graph of the effect of torque on runner efficiency 45 (mm)

Figure 3, a graph illustrating the effect of torque on runner efficiency with a boss diameter of 45 (mm), shows that the more torque applied, the greater the efficiency produced with an average runner rotation value of 151.8 (rpm).

3.4 Overall runner efficiency data

Fig.5 Graph of runner overall efficiency data

The highest efficiency resides on the 45 mm runner with a torque of 0.18 (N.mm) and an efficiency value of 74.6% with a runner rotation speed of 151.8 (rpm) and the second highest efficiency value on the 30mm runner with a torque of 0.18 (N.mm) and a value efficiency of 74.1% with a runner rotation speed of 156.1 (rpm) and then the efficiency value is the lowest for the 15mm runner with a torque of 0.18 (N.mm) and an efficiency value of 73.9% with a resulting runner speed of 147.5 (rpm).

4 Conclusion

Based on data analysis conducted on differences in the diameter of the boss runner on a laboratory scale vortex water turbine, several conclusions can be drawn as follows:

The effect of braking on runner rotation is closely related and inversely proportional, when braking is increased, the runner rotation decreases, and this is the ideal ratio to achieve the highest efficiency value.

The highest efficiency obtained is 74.6 % on a runner whose boss diameter is 45 mm, and the resulting turbine power is 2.92 (Watt) at 151.8 (rpm) rotation with a torque of 0.18 (N.mm).

References:

[1] S. Dhakal *et al.*, “Comparison of cylindrical and conical basins with optimum position of runner: Gravitational water vortex power plant,” *Renew. Sustain. Energy Rev.*, vol. 48, pp. 662–669, 2015, doi: 10.1016/j.rser.2015.04.030.

[2] “E. B. K. Signe, B. Bogno, M. Aillerie, and O. Hamandjoda, ‘Performance in feasibility studies of micro hydro power plants. New software development and application cases in Cameroon,’ Energy Procedia, vol. 157, pp. 1391–1403, 2019. - Penelusuran Google”, Accessed: Dec. 27, 2022. [Online]. Available: https://www.google.com/search?client=firefox-b-d&q=E.+B.+K.+Signe%2C+B.+Bogno%2C+M.+Aillerie%2C+and+O.+Hamandjoda%2C+“Performance+in+feasibility+studies+of+micro+hydro+power+plants.+New+software+development+and+application+cases+in+Cameroon%2C”+Energy+Pro

[3] F. Martins, C. Felgueiras, and M. Smitková, “Fossil fuel energy consumption in European countries,” *Energy Procedia*, vol. 153, pp. 107–111, 2018, doi: 10.1016/j.egypro.2018.10.050.

[4] O. Paish, “Small hydro power: technology and current status,” *Renew. Sustain. Energy Rev.*, vol. 6, no. 6, pp. 537–556, Dec. 2002, doi: 10.1016/S1364-0321(02)00006-0.

[5] “L. Jasa, A. Priyadi, and M. H. Purnomo, ‘Experimental Investigation of Micro-Hydro Waterwheel Models to Determine Optimal Efficiency,’ Appl. Mech. Mater., vol. 776, pp. 413– 418, 2015. - Penelusuran Google.” https://www.google.com/search?client=firefox-b-d&q=L.+Jasa%2C+A.+Priyadi%2C+and+M.+H.+Purnomo%2C+“Experimental+Investigation+of+Micro-Hydro+Waterwheel+Models+to+Determine+Optimal+Efficiency%2C”+Appl.+Mech.+Mater.%2C+vol.+776%2C+pp.+413–+418%2C+2015. (accessed Dec. 27, 2022).

[6] Gibran, Syahril Gultom, A. Z. Lubis, and Pramio G. Sembiring, “Rancang Bangun Turbin Vortex Dengan Casing Berpenampang Lingkaran Yang Menggunakan Sudu Diameter 46 Cm Pada 3 Variasi Jarak Antara Sudu Dan Saluran Keluar,” *Dinamis*, vol. 5, no. 2, pp. 36–46, 2017, doi: 10.32734/dinamis.v5i2.7049.

[7] M. M. Rahman, J. H. Tan, M. T. Fadzlita, and A. R. Wan Khairul Muzammil, “A Review on the Development of Gravitational Water

Vortex Power Plant as Alternative Renewable Energy Resources," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 217, no. 1, 2017, doi: 10.1088/1757-899X/217/1/012007.

[8] A. Assahab, "Seminar Nasional Teknologi dan Rekayasa (SENTRA) 2020 ISSN (Cetak) 2527-6042 eISSN (Online)."

[9] V. Rinanda and R. Permatasari, "Optimasi Desain Turbin Air Tipe Vortex Dengan 5 Variasi Jumlah Sudu Terhadap Efisiensi," *Semin. Nas. Cendekiawan ke 4 Tahun 2018 Buku 1 "Teknik, Kedokt. Hewan, Kesehatan, Lingkung. dan Lanskap"*, vol. 4, no. 4, pp. 785–790, 2018, [Online]. Available: https://www.event.lemlit.trisakti.ac.id/semnas/article/view/3543

[10] Y. Wu, W. Guo, and D. Yang, "Application of Neural Network Model Based on Multispecies Evolutionary Genetic Algorithm to Planning and Design of Diverse Plant Landscape," *Comput. Intell. Neurosci.*, vol. 2021, 2021, doi: 10.1155/2021/9031366.

[11] I. Renewable and E. Agency, *Renewable Energy Prospects: Indonesia*, no. March. 2017.

[12] S. J. Williamson, B. H. Stark, and J. D. Booker, "Low head pico hydro turbine selection using a multi-criteria analysis," *Renew. Energy*, vol. 61, pp. 43–50, Jan. 2014, doi: 10.1016/J.RENENE.2012.06.020.

[13] Y. Nishi, D. Sukemori, and T. Inagaki, "Performance and flow field of gravitation vortex type water turbine using volute tank," *Int. J. Fluid Mach. Syst.*, vol. 14, no. 3, pp. 229–246, 2021, doi: 10.5293/IJFMS.2021.14.3.229.

[14] S. Mulligan, G. De Cesare, J. Casserly, and R. Sherlock, "Understanding turbulent free-surface vortex flows using a Taylor-Couette flow analogy," *Sci. Rep.*, vol. 8, no. 1, pp. 1–15, 2018, doi: 10.1038/s41598-017-16950-w.

[15] S. Dhakal *et al.*, "Mathematical modeling, design optimization and experimental verification of conical basin : Gravitational water vortex power plant ," *World Larg. hydro Conf. Portl. or USA 2015*, no. August, 2015, doi: DOI:\t10.13140/RG.2.1.1762.0083.

[16] E. Del, R. Moreno, S. A. Zarate-Orrego, G. Andrés Torres-Casierra, E. Baldemar, and D. Risco-Moreno, "Horizontal vortex single chamber hydroturbine," *Rev. Fac. Ing. Univ. Antioquia*, vol. 2016, no. 79, pp. 150–162, Jun. 2016, doi: 10.17533/UDEA.REDIN.N79A14.

[17] "GRAVITATION WATER VORTEX POWER PLANTS." http://www.zotloeterer.com/welcome/gravitation-water-vortex-power-plants/ (accessed Dec. 27, 2022).

[18] Schauberger, *Turbin Air yang Berbasi pada Pusaran Air (Vortex)*. Jerman, 1936.