TURBO Vol. 13 No. 02. 2024
Jurnal Program Studi Teknik Mesin UM Metro

p-ISSN: 2301-6663, e-ISSN: 2477-250X
URL: http://ojs.ummetro.ac.id/index.php/turbo

Experimental Study of The Effect of Inclination Angle Variations of The Turbine Shaft on The Archimedes Screw Turbine Efficiency

Zainuri Anwar[1*], Muhammad Irfan Dzaky[2], Ahmad Imam Rifa'i[3], Baiti Hidayati[4], Edi Sunarso[5]

[1,2,3,4]Mechanical Engineering Department, Politeknik Negeri Sriwijaya, Jalan Srijaya Negara, Palembang 30128, Indonesia
[5]Mechanical Engineering Department, Sekolah Tinggi Teknologi Nasional, Muaro Jambi 36361, Indonesia
**Corresponding author*: zainuri.anwar@polsri.ac.id

Abstract

Archimedes Screw turbine is a type of turbine that can operate at low heads. One of the parameters that influences turbine performance is the tilt angle of the turbine shaft. This research aims to determine the effect of the turbine shaft tilt angle on the performance of the Archimedes screw turbine using experimental methods. The experiment was carried out in the river of Pematang Gajah Village, Jambi Province, by varying the tilt angle of the turbine shaft, namely 10°, 20°, 30°, 40°, and 50°. The test results showed that the highest turbine efficiency occurred at a turbine tilt angle of 30° with an average efficiency value reaching 78%. This condition occurs because the flow through the turbine blade is less compared to other turbine shaft tilt conditions so that the fluid force is completely converted into energy. The electrical energy produced by turbine generators can reduce dependence on electricity supplies from the central grid and become more energy-independent. In addition, stable and affordable energy sources can improve the quality of life and support the social and economic development of society.
***Keywords*: *Archimedes screw turbine, tilt angle, efficiency*.**

1. Introduction

The reduced of fossil energy sources and increasing environmental pollution have made researchers look for renewable energy sources as alternative energy sources [1]. Renewable energy such as solar energy, wind, geothermal energy and hydropower are types of renewable energy sources that are popular and easy to find in Indonesia [2]. The alternative energies, water energy has been widely used as a large-scale environmentally friendly hydroelectric power plant [3]. Small river flows that are often found in Indonesia can also be used as small-scale micro-hydro power plants. In Jambi province there are many small rivers that can be used as energy sources, such as tributaries of the Batanghari River [4].

Development of the type of turbine used is very necessary to utilize the energy potential of water with low head. Based on the turbine classification, the types of turbines that are suitable for low heads are crossflow turbines, kaplan turbines and Archimedes screw turbines. Of the several types of turbines, each has its own advantages and disadvantages, one of which is the Archimedes screw turbine. The Archimedes screw turbine has a larger bucket so that more energy is absorbed by the turbine blade. This shows that the Archimedes screw turbine is suitable for use in remote areas in Indonesia which have river flows with low heads and varying water discharge conditions [5][6].

The use of Archimedes screw turbines as microhydro power plants has been widely used [7]. However, until now there are no optimal design parameters for increasing turbine efficiency. This condition made researchers study modeling and carry out experimental tests to determine the relationship between the energy conversion process, turbine geometry, and turbine mechanical efficiency. Aspects of turbine geometry that influence the performance of an Archimedes screw turbine include the number of blades, pitch distance, and inclination of the turbine shaft. Several of these parameters affect the amount of fluid

DOI: http://dx.doi.org/10.24127/trb.v13i2.3692
Received September 29, 2024; Received in revised form December 09, 2024; Accepted December 13, 2024
Available online December 31, 2024

in the bucket so that the distribution of the fluid thrust force is uneven.

The turbine blade transmits the fluid thrust force to the turbine shaft. The more the number of turbine blades, the more energy absorbed by the turbine [8]. However, the greater the number of blades causes the pitch distance between the blades to narrow so that the bucket volume decreases. From these conditions, the determination of the number of blades depends on the design of the turbine length so that the pitch distance can be adjusted to the fluid energy requirements to be absorbed [9].

Turbine blade soaking that exceeds the optimal limit will slow down the turbine rotation. In addition, the tilt angle of the turbine that is too high results in abundant fluid flow out of the tunnel and reduces the volume of water in the bucket so that the turbine power is not optimal. [10]. Previous research stated that the optimum turbine shaft tilt angle occurs between 25º-40º [11][12][13][14]. However, the best tilt angle cannot be determined depending on the turbine design parameters. So, based on this problem, we conducted research on the performance of the Archimedes screw turbine with variations in the inclination of the turbine shaft. The aim of this research is to find the best turbine shaft tilt parameters to increase the efficiency of the Archimedes screw turbine.

2. Methods

The turbine used in this research is a double blade Archimedes screw turbine with the turbine material made from 3 mm PVC plate. PVC material was chosen in making the turbine to avoid corrosion resulting from oxidation reactions, thereby making the turbine's lifespan longer. The Archimedes screw turbine was designed according to the design results which has dimensions of 1200 mm in length with a thread diameter of 210 mm and a pitch distance of 120 mm [2]. The double blade Archimedes screw turbine has the advantage of having a larger number of buckets compared to single blades so that it can absorb fluid energy as a whole.

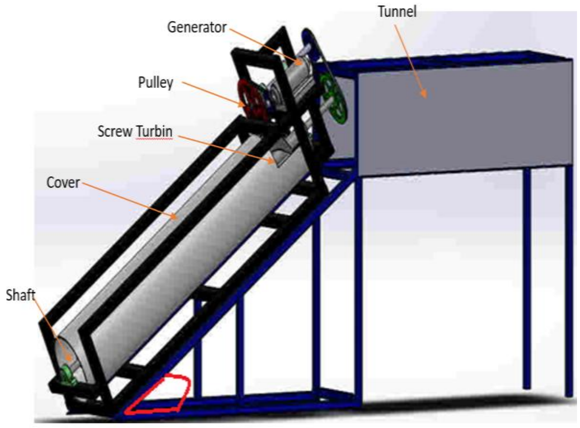

Figure 1. Design of Archimedes Screw Turbine

Turbine testing was carried out in a small river in Pematang Gajah Village, Jambi Province, which has a constant flow rate with a water fall height of around 1.5 m. The test was carried out by varying the tilt angle of the turbine shaft, namely: 10°, 20°, 30°, 40°, 50°. This condition was carried out to determine the effect of the shaft tilt angle on the performance of the Archimedes screw turbine. Apart from that, the electrical energy produced by this generating system can be used by food as a free and environmentally friendly energy source

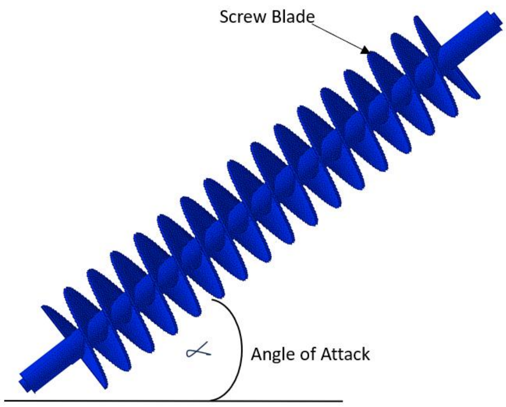

Figure 2. Tilt angle of turbin blade

When testing a turbine, a load is placed on the turbine shaft to determine the mechanical power of the turbine. To maintain a constant inflow to the turbine, water is directed through a tunnel which has a sluice gate which functions to regulate the flow of incoming water. Test data was collected three times, including data on tilt angle, turbine shaft rotation and inlet fluid velocity. The measuring instruments used in this test include a tachometer, flowmeter, and spring balance. From the parameters obtained, the test result data is then processed to obtain the best turbine efficiency value.

2.1 Energy equations

Several data are measured during testing such as turbine shaft rotation and fluid velocity passing through the tunnel. By using the equations for hydraulic power, turbine power, torque and flow capacity we can find out the efficiency of the turbine [15].

1. Inlet velocity.

$$v = \sqrt{2.g.h} \quad (1)$$

Where: $v = inlet\ velocity\ (\frac{m}{s})$
$g = gravitation\ (\frac{m}{s^2}{}^2)$
$h = head\ (m)$

2. Capacity
By knowing the cross-sectional area of the tunnel and the fluid velocity, the water capacity can be calculated.

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

Where: $Q = Capacity\ (\frac{m^3}{s})$
$A = Area\ (m^2)$
$v = inlet\ velocity\ (\frac{m}{s})$

3. Inlet power

$$P_h = Q.\rho.g.h \quad (3)$$

Where: $P_h = Power\ hydro\ (Watt)$
$Q = Capacity\ (\frac{m^3}{s})$
$\rho = Density\ (kg/m^3)$
$g = gravitation\ (\frac{m}{s^2}{}^2)$
$h = head\ (m)$

4. Torsion

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

Where: $\tau = Torsion (Nm)$
$F = Force\ on\ shaft\ (N)$
$r = radius\ on\ shaft\ (m)$

5. Output power on turbin

$$P_{turbine} = \frac{\tau(2\pi.n)}{60} \quad (5)$$

Where:
$P_{turbine} = Mekanik\ power\ (Watt)$
$\tau = Torsion (Nm)$
$n = Rotation\ of\ shaft\ (Rpm)$

6. Turbine efficiency

$$\eta_{turbine} = \frac{Output\ power}{Inlet\ power}$$

$$= \frac{P_{turbine}}{P_{hydro}} x100\% \quad (6)$$

Where:

$\eta_{turbine} = Turbine\ efficiency$ (%)
$P_{turbine} = Mekanik\ power\ (Watt)$
$P_h = Power\ hydro\ (Watt)$

7. Force distribution on blade
The tilt angle of the turbine shaft results in changes in the fluid volume in the bucket resulting in differences in the force received by the turbine blade.

$$F_{hyd} = \frac{(do^2 + \Delta d^2) - do^2}{2} \rho.g \quad (7)$$

Where:
$F_{hyd} = hydro\ force\ (N)$
$do^2 = Water\ level\ inlet (m)$
$\Delta d^2 = Water\ level\ on\ blade\ (m)$
$\rho = Density\ (kg/m^3)$
$g = gravitation\ (\frac{m}{s^2}{}^2)$

8. Tangensial force hydrolic

$$F_{hydT} = F_{hyd} COS\ (\frac{\alpha+\beta}{2}) \quad (8)$$

Where:
$F_{hydT} = hydro\ force\ (N)$
$F_{hyd} = hydro\ force\ (N)$
$\alpha = tilt\ angle\ of$
$the\ turbine\ shaft\ (m)$
$\beta = tilt\ angle\ of$
$the\ turbine\ blade\ (m)$

3. Results and Discussions

Archimedes screw turbine testing was carried out in the Puri Kedaton river, Pematang Gajah Village, Jambi Province. This river has quite stable potential energy with a water fall of around 1.5 m. The slope of the turbine is varied to determine the best efficiency value during the process of installing the turbine in the turbine housing. Several equipment is prepared for the process of collecting data on turbine rotation and fluid velocity entering the turbine. At each turbine tilt condition, data collection was carried out three times with varying loads on the turbine shaft, namely: 30 kg, 40 kg, and 50 kg. Turbine testing can be seen in Figure 3.

Figure 3. Testing of Archimedes Screw Turbin

Table 1. Test result of data

No	Tilit Angel	Rotation (Rpm)	P In (Watt)	P Out (Watt)	Eff average (%)
1	10°	290	237.4	113.22	52.1
		250	237.4	128.48	
		201	237.4	128.96	
2	20°	700	420.6	273.28	71.9
		608	420.6	312.46	
		501	420.6	321.44	
3	30°	1458	744.6	569.21	78.1
		1123	744.6	577.12	
		934	744.6	599.26	
4	40°	1307	1082.5	510.26	49.1
		1104	1082.5	567.36	
		804	1082.5	515.85	
5	50°	1005	1390.7	392.36	30.9
		882	1390.7	453.27	
		690	1390.7	442.71	

The turbine blade cover was opened to see the flow phenomena that occurred in the turbine bucket. The fluid volume in the bucket changes with changes in the tilt angle of the turbine. A high tilt angle causes water in the bucket to overflow, resulting in energy loss. This condition causes a change in potential energy that drives the turbine blade, thus affecting turbine performance. Apart from that, the performance of an Archimedes screw turbine can be seen from the comparison between the fluid power entering the turbine and the mechanical power of the turbine. Table 1 is a table of test results and calculations to obtain turbine efficiency values.

Table 1 shows that there are differences in efficiency values as the turbine tilt changes. Increased efficiency occurs from a turbine tilt of 10º-30º, then decreases at a turbine tilt angle of 40º-50º. Changes in the angle of the turbine shaft result in differences in the height of the water fall, so that by using Toricelli's equation (1) we obtain differences in the value of the fluid velocity passing through the turbine. The higher the angle of inclination of the shaft, the higher the water fall. This condition causes the potential energy of the incoming fluid to increase at a shaft inclination of 50º, namely 1390 Watts. However, the mechanical power produced by the reactive turbine decreases. This is because the turbine rotation decreases as the angle increases so that the power produced by the turbine becomes small. The mechanical power generated by the turbine is influenced by the water passing through the turbine blades. If the blades are submerged too deeply, the turbine will rotate slowly. Conversely, if the blades are only slightly submerged, the turbine will also fail to rotate effectively. Therefore, the submersion level of the turbine blades and the water flow must be balanced, ensuring that the water precisely strikes the most active area of the blades.The amount of water in the bucket affects the fluid's potential energy, but it must be proportional to the fluid's kinetic energy. The balance between the potential and kinetic energy of the water leads to an increase in the turbine's mechanical energy. A decrease in turbine output power results in decreased efficiency. It can be seen in the table that the highest turbine power occurs at an angle of 30º with a maximum mechanical power produced by the turbine of 599 Watts. The mechanical power of the turbine is influenced by the torque on the turbine shaft. By using equation (4) the torque can be determined. The shaft is given a force to see the optimal load of the turbine. Next, by using equation (6) the highest turbine efficiency value is obtained. The highest average efficiency occurs at a turbine tilt angle of 30º with an efficiency value of 78.1%. Changes in efficiency values can also be seen in Figure 4

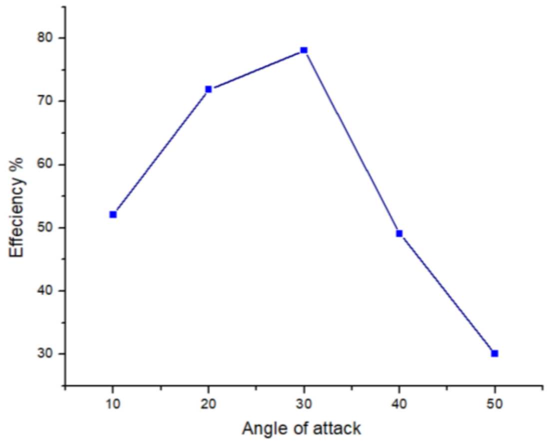

Figure 4. Tilt angle Vs Efficiency

Figure 4 shows the change in efficiency value with respect to the inclination of the turbine blade. The efficiency line forms a parabolic with the highest efficiency occurring at an angle of 30º and the lowest occurring at an angle of 50º. Under low tilt angle conditions, the fluid column in the bucket is relatively high, but the fluid flow speed is low due to the low potential energy so that the turbine rotation becomes slow. Meanwhile, under high tilt angle conditions, the turbine rotation becomes slow because a lot of fluid is wasted so that the fluid energy entering the turbine is not fully received by the turbine blades. Additionally, the fluid does not effectively push the turbine blades, resulting in the fluid force not being fully converted into the turbine's mechanical energy, which leads to energy losses. The fluid's potential and kinetic energy influence its total mechanical energy, requiring the turbine's angle of inclination to be adjusted for balance. To deepen the analysis, the forces acting on the turbine blades need to be studied, as shown in Figure 4.

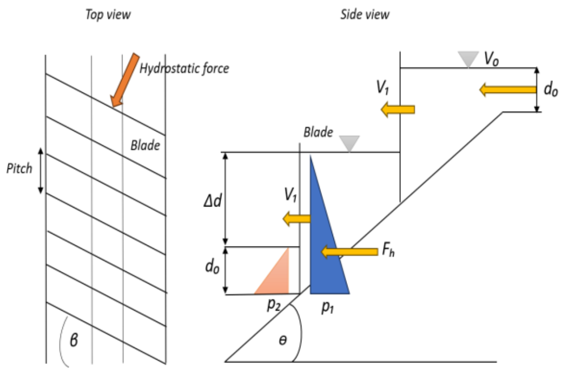

Figure 5. Force distribution on the turbine blade

Variations in the turbine shaft inclination angle (α) affect the hydraulic force that drives the turbine blades. In Figure 4 it can be seen that the slope of the turbine blade affects the tangential hydraulic force. By using equation (7.8), the distribution of fluid pressure received by the blade can be known. The greater the change in the turbine blade, the less fluid in the bucket, resulting in reduced hydraulic force. The pressure distribution on the blade surface is influenced by the height of the water column in the bucket. The higher the water column in the bucket, the higher the fluid pressure received by the blade. Vice versa, the higher the inclination of the turbine shaft causes the volume in the bucket to decrease which results in the height of the water column decreasing so that the hydraulic pressure pushing the blade becomes smaller. From the tests that have been carried out, it is known that the turbine shaft slope of 30 produces the highest turbine efficiency value of around 78.1%. Under these conditions, the fluid volume tends to be stable, with no fluid leaving the bucket or decreasing, so that the fluid energy received by the blade is optimal. The fluid's mechanical energy is fully transferred to the turbine's effective blades, resulting in an increase in the turbine's power output. However, increasing the angle of inclination causes much of the fluid received by the blade to be wasted so that the fluid power decreases. The decrease in the height of the fluid column reduces the area of the blades receiving the hydraulic force from the fluid. This condition lowers the fluid's volumetric flow rate, resulting in a decrease in the fluid's mechanical energy. The fluid's mechanical energy is proportional to the velocity and mass flow rate of the fluid received by the turbine. Apart from that, the hydraulic force that pushes the blade is influenced by the β angle (pitch angle) where from previous research the best β angle ranges from 25º-30º. The turbine pitch affects the force received by the turbine blades according to the direction of the applied force. Changes in the pitch angle result in variations in the turbine's rotation and torque [12][16].

4. Conclusions

Based on the test results, the slope angle α affects the power produced by the turbine. In Figure 3 it can be seen that the turbine efficiency occurs at an angle of 30º and the lowest occurs at an angle of 50º. This condition occurs due to energy loss in the turbine blade. The increasing angle of inclination causes the fluid in the bucket to overflow so that the fluid thrust force decreases. Under conditions of low angle of inclination, the fluid volume is relatively high, but the incoming fluid velocity is low so that the fluid pushing force is small. So from the test results of the Archimedes screw water turbin it can be concluded that the best turbine angle for installation in the turbine house occurs at an angle of 30º with an average efficiency value of 78%.

Acknowledgments

The publication of this research article was supported by the mechanical engineering laboratory of the Politeknik Negeri Sriwijaya and the mechanical engineering laboratory of the Sekolah Tinggi Teknologi Nasional Jambi. The author also would like to thank the Pematang Gajah village government for supporting this research process.

References

[1] N. Kumar Thakur, R. Thakur, K. Kashyap, and B. Goel, "Efficiency enhancement in Archimedes screw turbine by varying different input parameters - An experimental study," *Mater. Today Proc.*, vol. 52, pp. 1161–1167, 2022, doi: 10.1016/j.matpr.2021.11.020.

[2] Z. Anwar, B. S. Parsaroan, and E. Sunarso, "Rancangan Bangun Turbin Mikrohidro Tipe Archimedes Screw Dengan Kapasitas Daya 560 Watt," *J. Electr. Power Control Autom.*, vol. 4, no. 1, p. 29, 2021, doi: 10.33087/jepca.v4i1.43.

[3] A. T. Piper, P. J. Rosewarne, R. M. Wright, and P. S. Kemp, "The impact of an Archimedes screw hydropower turbine on fi sh migration in a lowland river," *Ecol. Eng.*, vol. 118, no. April 2018, pp. 31–42, 2020, doi: 10.1016/j.ecoleng.2018.04.009.

[4] H. Matalata, "Listrik mikro hidro berdasarkan Potensi debit andalan sungai batanghari kota jambi," *J. Electr. Power Control Autom.*, vol. 1, no. 1, pp. 1–6, 2018.

[5] Z. Anwar, R. Siahaan, D. Ratnawati, and H. Azwan, "The Effect of Single and Double Blade on Archimedes Screw Turbine Performance," *J. Taman Vokasi*, vol. 11, no. 1, pp. 1–7, 2023, [Online]. Available: https://jurnal.ustjogja.ac.id/index.php/tamanvokasi/article/view/14632/6006

[6] C. Rorres, "The Turn of the Screw : Optimal Design of an Archimedes Screw," *J. Hydraul. Eng.* ·, pp. 72–80, 2000, doi: 10.1061/(ASCE)0733-9429(2000)126.

[7] K. Shahverdi, R. Loni, J. M. Maestre, and G. Najafi, "CFD numerical simulation of Archimedes screw turbine with power output analysis," *Ocean Eng.*, vol. 231, no. February, pp. 1–8, 2021, doi: 10.1016/j.oceaneng.2021.108718.

[8] E. K. Yulyawan, I. Wicaksono, I. N.

D. K. Dewi, A. Ahlan, and W. N. Achmadin, “Pengaruh Jumlah Ulir Pada Prototipe Turbin Archimedes Screw Untuk Pembangkit Energi Hijau dan Terbarukan,” vol. 12, no. 2, pp. 9–16, 2022.

[9] D. Adanta and M. H. G. Syafei, “Development of Archimedes Turbine Research : Review Article,” pp. 177–181, 2017.

[10] H. B. Harja, H. Abdurrahim, S. Yoewono, and H. Riyanto, “Penentuan Dimensi Sudu Turbin Dan Sudut Kemiringan Poros Turbin Pada Turbin Ulir Archimedes,” vol. 36, no. 1, pp. 26–33, 2014.

[11] Amir, “Kemiringan Optimum Model Turbin Ulir 2 Blade,” *J. Tek. Mesin Univ. Muhammadiyah Tangerang*, vol. 2, no. 1, pp. 1–8, 2018.

[12] A. Havendri and I. Arnif, “Kaji Eksperimental Penentuan Sudut Ulir Optimum Pada Turbin Ulir Untuk Data Perancangan Turbin Ulir Pada Pusat Listrik Tenaga Mikrohidro (PLTMH) Dengan Head Rendah,” in *Seminar Nasional Tahunan Teknik Mesin*, 2010, pp. 13–15.

[13] A. . Siswantaraa, W. Warjitoa, B. Budiarso, H. Rudias, M. . Gumelar, and A. Dendy, “Investigation of the α angle’s effect on the performance of an Archimedes turbine,” in *International Conference on Power and Energy Systems Engineering*, 2019, vol. 156, pp. 458–462. doi: https://doi.org/10.1016/j.egypro.2018.11.084.

[14] G. R. Cahyono, A. Amrullah, P. R. Ansyah, and R. Rusdi, “Pengaruh Sudut Kemiringan Terhadap Putaran Dan Daya Hidrolisis Pada Turbin Archimedes Screw Portable,” *J. Rekayasa Mesin*, vol. 13, no. 1, pp. 257–266, 2022, doi: 10.21776/ub.jrm.2022.013.01.25.

[15] Y. A. Çengel and J. M. Cimbala, *Fluid Mechanics Fundamentals and Applications*, 4th ed. 2018.

[16] A. T. Saputra, A. I. Weking, and I. W. Artawijaya, “Eksperimental Pengaruh Variasi Sudut Ulir Pada Turbin Ulir (Archimedean Screw) Pusat Pembangkit Listrik Tenaga Mikro Hidro Dengan Head Rendah,” *Maj. Ilm. Teknol. Elektro*, vol. 18, no. 1, p. 83, 2019, doi: 10.24843/mite.2019.v18i01.p12.