Performance of Single Screw Archimedes Turbine Using Transmission

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Abstract. Micro hydro electricity generation using Archimedes screw turbines has been developed in recent years in countries that have the potential for river flow. This turbine is applied to low water flow conditions and the head is smaller than 10 meter. One type of screw turbine commonly used is a single blade type. However, most of the research is carried out on a laboratory scale. The purpose of this study was to examine the performance of Archimedes single screw turbines using twice reduction gear transmission. The variables measured and observed are the flow rate, turbine rotation, torque and power generated. The test was carried out with two variations of flow discharge, 0.05 m$^3$/s and 0.0375 m$^3$/s. The Archimedes single blade turbine rotation testing defined that the gear transmission able to increase the turbine rotation from 236 rpm to 567.46 rpm. The best turbine performance using gear transmission is obtained at a flow rate of 0.05 m$^3$/s with an acquisition power of 15.38 W and a final rotation of 410.67 rpm.

1. Introduction

The electricity supply deficit in Indonesia has become a classic problem that has been chronic which difficult to be completely resolved. Every year, Indonesia's electricity consumption increased by 5,000 megawatts (MW). However, the demand for electricity consumptions always higher than supplied which lead to electricity deficit. Hence, some of rural area such Aceh still leak of electricity supplied.

One of the right efforts to reduce the impact of the electricity crisis in these areas is the use of small-scale renewable energy as well as small-scale hydropower with a power of 5-100 KW. Relatively low costs and consume minimized of water flows makes the micro hydropower generation system expected to be a solution to the electrical energy crisis in remote areas that have not been powered by electricity [1].

The development of this small-scale power plant usually utilizes the small flow of water and a certain flow rate that is converted to electrical energy through a rotating turbine. In the Aceh region, there are many water energy resources by river flows utilization, with an average height of water falling below 10 meters with moderate currents that can be used as energy generation. The type of turbine that is suitable for use can work at an altitude of <10 meters is Archimedes screw turbine. Water energy generation with the Archimedes Screw Turbine is a developing technology suitable for low-level hydraulic sites [2].

Recent years, several model of Archimedes screw turbines obtain the specifications and dimensions turbines that are able to work optimally. Rorreslays out an analytical method to optimize design an Archimedes screw geometry for pumping applications and states that the optimum pitch ratio depends on the amount blade and radius ratio (R1 / R0) equal to 0.54 [3]. Based on the study made by Rorres, Muller created a simplified model for Archimedes screw turbine that idealizes the turbine’s blades as
moving weirs. He identified that the efficiency of Archimedean screws is a function of geometry and losses. He also showed that efficiency dependable with number of turns [4]. Guilhem Delinger et al also did experimental research of Archimedes screw turbine. He successfully derived some formulas based on Rorres result. Their research shows both theoretical and experimental values of efficiency decrease when screw inclination increases [5]. Then, Lubitz proves that leakage and slope decrease will cause head differences between bucket declines as the amount of leak flow rate reduction is driven by pressure differentials. Thus, Archimedes screw efficiency will increase when the slope is set low (decrease) [6].

In this paper, we proposed a studied on the effect of blade numbers on pressure behavior in turbines using numerical methods with the k-epsilon turbulence standard model. We defined that turbines with different blade numbers have a clear pressure drop at a distance of one quarter of the suction side of the blade inlet and the single blade turbine shows a more even distribution of pressure drop across the blade [7].

In planning the power plant system using turbines, transmission losses to torque and power are of concern, because Archimedes Turbine Screw generally has a low rotation where the rotation must be increased. This research was conducted with an experimental method that is seeing firsthand on how the use of transmission gears that connects the turbine shaft and electric motor shaft to determine the optimum rotation and its effect on torque and electrical power produced.

2. Archimedes Screw Turbine

The Archimedes Screw turbine consists of a screw that rotates in a channel and utilizes the flow of water that is converted into electrical energy through a turbine on the generator. The geometry of an Archimedes screw turbine is determined by the outer dimensions and dimensions of the turbine (see figure 1). Calculation of the dimensions to be carried out refers to the method in the previous study by Chris Rorres [3].

\[ L = \frac{H}{K} \] (1)

Figure 1. Profile of Archimedes screw turbine [8]
Torres offers a formulation to determine the dimensions of the Archimedes screw turbine based on the calculation of the water volume in one round screw:

\[ V_T = \pi R_o^2 \Lambda v \]  

(2)

The inner diameter of the turbine is obtained using the equation:

\[ R_i = \rho R_o \]  

(3)

We define the range screw from the screw turbine blade using the following equation:

\[ \Lambda = \frac{2\pi R_o \lambda}{K} \]  

(4)

The pitch ratio of the screw turbine is equal to

\[ \lambda = \frac{K \Lambda}{2\pi R_o} \]  

(5)

Then, we have number of screw blades as much

\[ m = \frac{\lambda}{\Lambda} \]  

(6)

Equations (1) to (6) are used to determine the dimensions of the Archimedes screw turbine in this study.

The power that works in the working system of the Archimedes screw turbine consists of the theoretical power of the fluid (P input) and the power of the turbine shaft (P output). The theoretical power provided by the Archimedes screw turbine is given by:

\[ P_{\text{input}} = \rho g Q H \eta \]  

(7)

Where: \( \rho \) = the density of water (kg/m\(^3\)), \( Q \) = the flow rate (m\(^3\)/s), \( g \) = the Gravitational constant (m/s\(^2\)), the system head (m), \( \eta \) = the efficiency of the whole system (%).

By using the values of friction force (F) and rotation (n), the torque acting on the turbine is the multiplication of the frictional force with the pulley radius [15].

\[ T = F \times r \]  

(8)

Turbine power obtained by multiplying the torque by angular velocity, ie:

\[ P_{\text{output}} = T \times \omega \]  

(9)

Angular velocity (\( \omega \)) is obtained by the equation:

\[ \omega = 2 \pi n / 60 \]  

(10)

Where: \( T \) = Torque (Nm), \( F \) = friction (N), \( r \) = pulley radius (m), \( \omega \) = angular velocity (rad/s), \( n \) = rotation (rpm)

Turbine dimensions used in this study are presented in Table 1 below.

**Table 1.** Turbine dimensions
3. Experimental Methods

3.1. Gear Unit System
A gearbox is usually used in a water turbine to increase the rotational speed of a low speed turbine shaft to a higher speed electric generator. The expected ratio in this study is 2:1, with an expected rate of 750 rpm input from the turbine shaft to the output of 1,500 rpm for the generator. The gears used to make transmissions in Archimedes screw turbines are straight gear models. The specifications of the gears used are as shown in Table 2 and Figure 2 below:

| No | Gear diameter | Gears wheel number | Laying position                       |
|----|---------------|--------------------|---------------------------------------|
| 1  | 160 mm        | 57                 | Located on the turbine shaft          |
| 2  | 88 mm         | 42                 | Located between the turbine shaft and the generator shaft |
| 3  | 44 mm         | 20                 | Located on the generator shaft        |

![Figure 2. Gears Design Sketch](image)

3.2. Data collection Method
There are two variables in the testing of the Archimedes screw turbine experiment, which are independent variables such as flow discharge and dependent variables which include rotation, torque, power and efficiency. Data retrieval is divided into two stages: field data collection related to rotation.

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| Head turbin | 1 meter |
|-------------|---------|
| Flow capacity, $Q_1$ | 0.05 $m^3/s$ |
| $Q_2$ | 0.0375 $m^3/s$ |
| Turbine length | 2 meter |
| Pitch Distance | 0.287 m |
| Tilt angle | 30° |
| Outer radius of the turbine | 0.167 meter |
| Inner radius of the turbine | 0.089 meter |
| Turbine blade thickness | 0.002 meter |
| Turbine material | Stainless Steel ASTM 201 |
and torque, and calculations through computing devices. The tool used to measure turbine shaft rotation is a speed sensor that is connected to Arduino Mega 2560. Speed sensor, a magnetic sensor that can calculate the number of turbine shaft rotations. Load cell is a test tool that can measure the load (force) that is converted into an electrical signal. Both devices will be connected to the Arduino Mega 2560 to defining the rotation and torque during the testing process. Data from the testing process will be collect by PC using PLX-DAQ software.

Tests were also carried out to analyze the mechanical strength of a turbine by measuring torque (T). Torque measurement is carried out using a disc brake dynamometer method that uses load cells. When the turbine rotates, the load will be carried out and the frictional force will work on the turbine, which is defined as the resultant between the loads that added to the force read on the sensor.

All data retrieval is carried out in two stages, ie without gears and after being speeded up using a gear system. This analysis is important because many water turbine gearboxes have basic design problems such as ineffective interference that results in undesired movement and wear, ineffectiveness of the internal lubrication pathway and decrease in torque so that power is not reached. Increased rotation, which is capable of producing sufficient torque and power, is the key to the right transmission system in the water turbine plan.

4. Result and Discussions

The flow rate of the water under test conditions is measured in real time by using 90-degree V-notch weir discharge at the height of falling water directly to the turbine. The flow rate is measured at full flow conditions and about 50% of maximum flow capacity. At the flow rate below, the resulting rotation is very small, so it is not possible to increase the rotation using the gear.

From the measurement results obtained the highest water discharge of \( Q_1 = 0.05 \text{ m}^3/\text{s} \) and the lowest water discharge where half of the turbine inlet submerged in water \( Q_2 = 0.0375 \text{ m}^3/\text{s} \) as presented in Figure 5 below.

![Figure 3: The value of the incoming water flow rate](image)

By applying the equations(7) and (8) above, the torque and power produced by the Archimedes Screw turbine in conditions where the gear is not installed can be obtained. This result is a direct measurement of the main shaft of the turbine.

The results are as shown in Figure 4 and Figure 5 in the form of the rotational relationship to torque and the relationship between the rotation and the theoretical output power of the turbine. The highest rotational speed occurs at the turbine inlet flow rate of Q1 that is equal to 236.44 rpm and the lowest rotation occurs at the Q2 inlet flow rate of 94.44 rpm.
Both of these figures show that the turbine has a different torque and power because of the influence of the flow rate that enters it. The results of the performance of the turbine show that the turbine has the best performance when the flow enters the inlet of the turbine at maximum conditions.

The relationship between theoretical power outputs of Archimedes screw turbine calculated based on equation (9) to its rotation shows in Figure 5. These results also show that the best conditions, namely at the water flow rate of $Q_1$ is able to produce maximum torque of 0.5 Nm and the theoretical power output of 6.21 W. While at the $Q_2$ water flow rate, the maximum torque is only 0.17 Nm and the theoretical output power is 3.17 W. Furthermore, the turbine is connected to the gear system, which aims to increase the shaft rotation to match the available generator shaft rotation. The gear design used is a straight gear that refers to the design as previously explained. The results are shown in Figure 6 and Figure 7 below.
Figure 6 show the rotation generated at the same shaft loading before using the gear system (a) and on the second shaft after the gear system is installed (b). The test results show the same tendency in the flow rate conditions of $Q_1$ and $Q_2$. The resulting data shows that after the gear system is installed at the $Q_1$ water flow rate it can produce the highest rotation speed of 567.5 rpm and the lowest rotation occurs at the water flow rate of $Q_2$, which is 213.5 rpm. The new shaft rotation is still very low. The resulting rotation increase has only reached around 60 %.

Figure 7 describes the relationship between rotation and power that occurs in a system that uses gear transmission at a maximum turbine inflow rate ($Q_1$). This figure shows that after using the gear transmission, the highest power generated at the flow rate $Q_1$ of 0.05 m$^3$/s is 15.38 W at rotation of 410.66 rpm. While the highest power obtained on direct measurements on the turbine shaft is only 6.22 W when the rotation is 166 rpm.

Figure 7. The effect of the gearbox system on the rotation and the output power produced of the turbine for $Q_1 = 0.5$ m$^3$/s

When compared to the output power obtained by direct measurement on the turbine shaft without a gear system with the measurement after the installation of the gearbox system obtained an increase of 59.6 %.

So it takes a larger turbine dimension to achieve greater power increase. Increasing the gear ratio higher is not possible because there will be a large decrease in torque as shown in Figure 6. In this picture it is clear that with increasing rotation, the torque becomes smaller, so that the turbine shaft is no longer able to handle the generator load, at low torque. Similar conditions occur both before the installation of gearbox and afterwards.
The results of this experiment indicate that the performance of the screw turbine will be maximized if the inlet flow rate enters the optimum conditions. Using the gear system is able to increase the output power and rotation as long as the torque produced is still within the allowable limit to rotate the generator shaft. This condition shows that in an electric power plant installation using the Archimedes Screw turbine, a proper system is needed so that the flow rate is maintained at maximum conditions. Because the increase in rotation generally has to be done to achieve the generator rotation, even though it can produce an increase in power, it also results in lower torque, so that in the end the generator shaft is unable to handle the load in generating optimum electrical power.

5. Conclusion
From the result of this research could be drawn some following conclusions:
1. In the direct measurement of the turbine shaft, the highest rotation velocity is obtained at the turbine inlet flow rate $Q_1$ that is equal to 236.44 rpm and at 220.14 rpm inlet flow rate.
2. The highest rotation occurs in Archimedes single screw turbine at the maximum inlet flow rate ($Q_1$) of 0.05 m$^3$/s after the use of gear transmission is 567.46 rpm.
3. In direct measurements without a gear system, the greatest theoretical output power occurs at the flow rate of $Q_1$, i.e. at a rotation of 410.66 rpm, which reaches 6.22 W.
4. After installation of the gearbox system, Archimedes screw's highest turbine output power occurs in $Q_1$ conditions which is 15.04 W or has a 59.6 % increase from the direct measurement conditions on the turbine shaft.
5. Because the shaft rotation affects torque, from the experimental results it appears that the increase in torque in an Archimedes Screw turbine when given a load will result in a decrease in shaft rotation. Prudence is needed in using the gear system so that there is no significant reduction in torque due to loading.

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