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Design and Manufacture of Portable Screw Turbine of Pico Hydro Power Plant for Road Lighting in Rural Area

Nofriadi [a], Azridjal Aziz [a] and Rahmat Iman Mainil [a*]

[a)] *Department of Mechanical Engineering, Faculty of Engineering, Universitas Riau, Indonesia*

*Corresponding author: rahmat.iman@lecturer.unri.ac.id

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ABSTRACT

This study aims to design and manufacture a portable screw turbine of pico hydro power plant for road lighting in rural area. The portable screw turbine has the specifications of a turbine diameter of 23 cm, length of 1 m, number of threads of 5, shaft diameter of 6 cm and pitch of 22 cm. This screw turbine was tested by varying several turbine tilts angles, namely 15°, 30°, 45° and 60° with a flow rate used of 0.0054 m3/s. In field test was carried out at an angle of 30° with a flow rate of 0.125 m3/s. The test results show the angle of inclination of turbine affects the mechanical performance. Testing the 45° angle produced a mechanical power of 18.857 Watts with an efficiency of 35.669%. In the field testing was produced a generator power of 4 Watts. This screw turbine is expected to be another alternative as a pico-hydro scale power plant.

KEY WORDS: *Portable screw turbine, Water flow, Turbine tilt angle.*

NOMENCLATURE

Q	*Discharge air flow rate*
A	*Flow cross-sectional area*
v	*Water flow rate*
ρ	*Density of water*
g	*Gravity acceleration*
H	*Falling water level*
η	*Efficiency*
τa	*Shear stress*
σB	*Material tensile strength*

1.0 INTRODUCTION

Electrical energy can be generated from several generating sources such as hydroelectric power plants, diesel power plants, hydroelectric power plants, and others. A power plant is a machine that works to generate electrical energy from various power sources such as air power, solar power, steam power, wind power and others. Air power plant is a change of energy source from air power to electric power which is influenced by air altitude and certain air flow. Now this is not just to meet the needs of daily life but has become a necessity of modern life, modern in this case is a requirement of society for a better standard of living and the development of large and advanced industries [1].

Water turbines have been widely used to generate electricity. Although it has represented an economical, technologically efficient and sustainable device, limited studies have been conducted to date. Theoretical approach is adopted to estimate the various types of power losses that occur in water turbines, to predict the mechanical power output. Theoretically the results are validated with experimental data on the turbine model. The characteristic curve of the experimental turbine is described, in the form of turbine efficiency and power output to the water flow rate, flow rate and turbine wheel speed [2].

Hydroelectric power plants can be generated from several machines such as turbines. A machine is a device that provides power to or that takes power from a fluid. For example, a pump whose function is as a machine that adds a certain amount of power to a fluid, while the turbine functions inversely from the function of the pump, namely the machine takes power from the fluid. So the turbine is a machine that functions to convert the potential energy of the fluid into mechanical energy to produce work in the form of shaft rotation [3].

In an energy turbine whose working fluid is gas, steam, and water, it is used directly to turn the turbine wheel. The rotating part of the turbine is called the rotor or turbine wheel, while the non-rotating part is called the stator or turbine housing. The turbine wheel is located inside the turbine housing and the turbine wheel rotates the power shaft which drives or rotates the load. The working fluid undergoes an expansion process, namely the process of decreasing pressure and flowing continuously [4].

A water turbine is a device for converting water energy into torsional energy. Water energy which includes potential energy

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including the pressure and flow velocity components of the water contained therein is converted into kinetic energy to rotate the turbine. The resulting torsional energy is then converted into electrical energy through a generator [5]. The first reference to low head turbines was presented by Leclerc (2007) who stated that low head turbines have great potential to develop renewable energy and this turbine is an environmentally friendly technology [6]. The Very Low Head (VLH) turbine is specially designed with a net head from 1.4 m to 3 m. The purpose of developing a low head turbine is to reduce civil works, simplify the installation system, and at an economical price. The development of the VLH concept is based on supporting technology, namely using a permanent magnet generator with varying speeds, a power system, electric power, and integrated with a control system [6].

The Archimedes screw is a type of screw that has been known since ancient times and was used as a pump for irrigation in the hanging gardens of Babylonia [7]. Formerly this pump was very familiar among Roman engineers. Archimedes created this pump to take and move water from a low stream to a higher place for irrigation purposes. Along with the energy crisis that is happening in the world and the limited potential of water energy sources that have high heads, starting in 2007, an engineer put forward the idea that if the screw pump rotates upside down it can function as a turbine. The pump is controlled by the flow of water so that the pump can rotate. Then at the top of the pump is installed a generator, where the generator will produce electrical energy caused by the rotation of the screw shaft of the pump [8]; [9]. This reverse-functioning Arhimedean screw pump is known as a screw turbine [7]. So, in principle a screw turbine is a reversal of the function of the screw pump itself [8]. Turbine screw illustration is depicted in Figure 1.

Figure 1: Screw Turbine

The screw turbine is a reversal of the screw pump function. The screw pump itself was invented by a Greek scientist, which is more than 21 centuries ago and until now this pump is still in use. At first Archimedes created this pump with the aim of removing water from the inside of the ship. Then Archimedes himself redesigned this pump for use in raising water from rivers [9].

This paper proposes to design and manufacture a portable screw turbine of pico hydro power plant for road lighting in rural area.

2.0 METHODOLOGY

The design and installation of this portable screw turbine tool has stages of work as shown in the Figure 2.

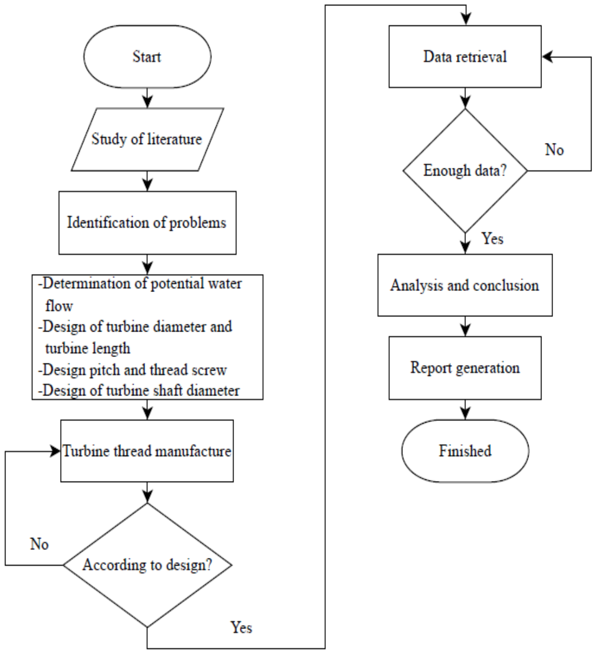

Figure 2: Research flow chart

2.1 Tools and Materials

The tools used in this research include:

a. Multimeter
This multimeter is needed to measure the current and voltage obtained from the generator when the test was carried out.

b. Wattmeter
This wattmeter is needed to measure power, volts, amperes when testing was carried out.

c. Tachometer
This tachometer is needed to measure the turbine rotation rate produced when the test was carried out.

The materials were used:

a. The iron hollow
This hollow iron is needed as the framework of the portable screw turbine.

b. PVC pipe
This PVC pipe is used as the shaft and blade of the portable screw turbine used.

c. Threaded axle iron
Threaded iron is needed as the axle of the turbine shaft so that it can be combined with the 8mm KP08 bearing.

d. Bearing KP08 8mm
Bearings were needed as bearings when the turbine screw rotates.

e. Dexton steel glue
This dexton glue is used as an adhesive between the turbine blade screw and the turbine shaft screw.

f. Aluminum plate
As a cover that is used to direct water into the turbine and not a lot of water was wasted.

g. Drum tank
This drum tank was used as a water reservoir to carry out tests on a laboratorium scale.

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h. Iron elbow

This elbow iron was used as a foot and as a support for drums used in lab-scale testing.

2.2 Design Process

1) Determination of water discharge [10]:

To obtain supporting data, it is necessary to determine the flow rate that will be used in the scheme. To find water discharge (Saefudin et al., 2018):

$$Q = V\,A \tag{1}$$

2) Hydraulic power

A water turbine is a device for converting water energy into mechanical energy, then mechanical energy is converted into electrical energy by a generator. The amount of energy used to convert water energy into electrical energy depends on the amount of water discharge (Q) that hits the turbine blades, the cross-sectional area of the blade that is exposed to water (A) to produce power (P) that can be utilized [10]:

$$P = \rho\, g\, Q\, H \tag{2}$$

Table 1: Thread constant value [10]

	22°		26°			30°	
d/D	1.0 D	1.2 D	0.8 D	1.0 D	1.2 D	0.8 D	1.0 D
0,3	0.331	0.335	0.274	0.287	0.286	0.246	0.245
0,4	0.35	0.378	0.285	0.317	0.323	0.262	0.271
0,5	0.345	0.38	0.281	0.317	0.343	0.319	0.287
0,6	0.315	0.351		0.3	0.327		0.273

Table 2: Screw turbine operation rotation [10]

Speed	Turbin Revolution Per Minute (Rpm)
Slow	20-23
Medium	25-26
Fast	29-31

3) Calculating turbine diameter [10]:

After knowing the water discharge from the ditch, the diameter of the turbine can be designed. Turbine diameter can be calculated by the following equation:

$$D = \sqrt[3]{\frac{Q}{k\,n}} \tag{3}$$

4) Calculating shaft diameter [10]:

The first step in calculating the diameter of the turbine shaft is to calculate the power produced by the turbine (P) with the following equation:

$$P = V\rho g H \eta_T \tag{4}$$

Shaft design power (Pd) can be calculated using the equation:

$$Pd = Fc.P \tag{5}$$

Torque can be calculated by the following equation:

$$T = 9{,}74x10^5 \frac{Pd}{n} \tag{6}$$

The shear stress that occurs can be calculated by the equation:

$$\tau_a = \frac{\sigma_B}{Sf_1 Sf_2} \tag{7}$$

Shaft diameter can be calculated by the following equation:

$$d = \left[\frac{5{,}1\,.\,K_t\,.\,C_b\,.\,T}{\tau_a}\right]^{\frac{1}{3}} \tag{8}$$

5) Calculate the length of the turbine:

After designing the shaft length, then the turbine length can be calculated by the following equation [11]:

$$\mathrm{L} = \frac{H}{\sin\theta} \tag{9}$$

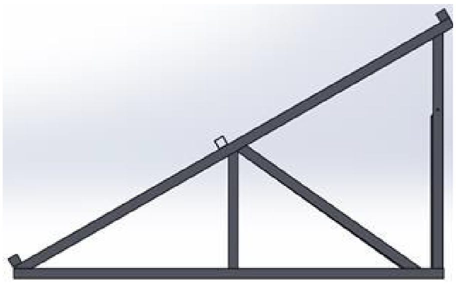

Figure 3: Tilt angle and length

6) Turbine blade design

Calculating pitch/distance between screws [12]:

Calculate screw pitch/distance:

If the turbine angle ≤ 30° , then S = 1.2 . D

If the turbine angle = 30° , then S = 1.0 . D

If the turbine angle ≥ 30° , then S = 0.8 . D

Since turbine angle = 30°, then S=1.0 D

7) Turbine efficiency:

Turbine efficiency can be calculated by the following equation [13]:

$$\eta = \frac{P_{out}}{P_{in}}\,100\% \tag{10}$$

2.3 The Manufacture of Portable Screw Turbine

Next is the construction phase, namely the process of making components or manufacturing the screw turbine. The automatic control system machine can produced the accuracy and precision of work-piece compoenets [14-16]. Manufacturing of screw turbine can used manual machines and computer numerical machines [17-20].

In this research, the manufacture of the portable screw turbine starts by cutting 6 pieces of PVC pipe according to the design results to form a turbine blade according to the

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dimensions of the design results as shown in the Figure 4.

Figure 4: The cutting pipe into sections

After the pipe is cut, the pipe is heated using a heat gun so that the pipe can be shaped like several sheets before being cut into a circle like a circle, as shown in the Figure 5.

Figure 5: Pipe softening using a heat gun

After the pipe is heated using a heatgun, the next step is to cut the pipe that has become sheets to form a circle in general according to the dimensions that have been determined according to the design, as shown in the Figure 6.

Figure 6: Pipe is shaped and cut like a circle

The next step after the pipe is cut to form a circle, the pipe is shaped and cut according to the grooves that have been made so that it forms like a cassette can be seen in Figure 7.

Figure 7: Cutting the pipe section for easy pulling

The next stage is to unite the blade and shaft components to form a turbine screw as shown in Figure 8.

Figure 8: Blade and shaft union

After the blade on the screw turbine is complete, the next step is to make the screw turbine frame, as shown in the picture:

Figure 9: Making the frame

After the manufacture of the turbine screw frame and blade has been completed, the next step is to make a testing scheme on a lab scale, as shown in Figure 10.

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Figure 10: An overall view of the screw turbine test

3.0 RESULT AND DISCUSSION

The design has been carried out to produce several specifications for the Portable Screw turbine. The specifications in question can be seen in Table 3, which was the result obtained from the design calculations.

Table 3: Screw turbine specifications

No	Part	Parameter	Results
1	Blade	Thread slope	26°
		Diameter	23 cm
		Number of Threads	5 blades
		Pitch	22 cm
2	Spindle	Long	1 m
		Diameter	6 cm
3	Frame	Long	1.15 m
		Wide	40 cm

3.1 Result of Design and Manufacture the Screw Turbine

The portable screw turbine that has been designed and manufactured is as shown in Figure 11.

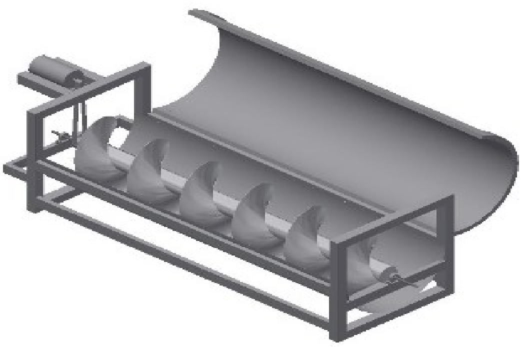

Figure 11: Results design and manufacture the portable screw turbine

3.2 Data Collection Test Results

The results of the data collection test were depicted in Table 4.

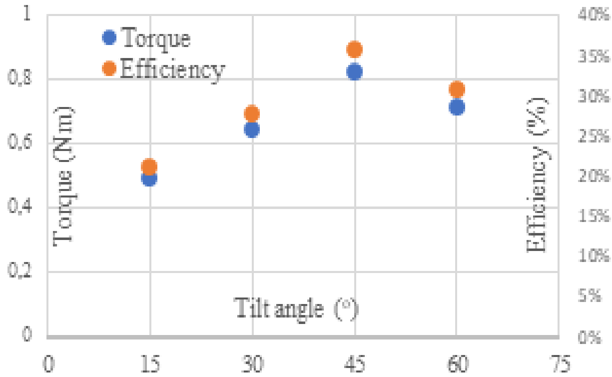

Figure 12: Characteristic between torque and efficiency with respect to the angle of inclination

Based on the graph shows the results of data processing that the highest torque is 0.827 Nm at an angle of 45^0, this is because when breaking the mass required is greater, which is 6.75 Kg compared to other angles. The higher the torque, the higher the efficiency produced.

Table 4: Processing results of screw turbine test data

Tilt angle (°)	P hydraulic (W)	T (Nm)	P mechanic (W)	Efficiency (%)
15	52.868	0.492	11.217	21.216%
30	52.868	0.643	14.653	27.716%
45	52.868	0.827	18.857	35.669%
60	52.868	0.717	16.357	30.939%

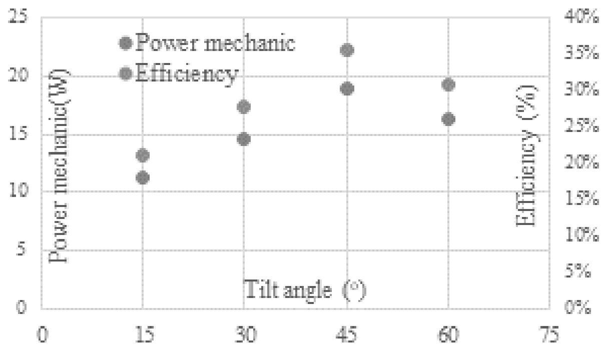

Figure 13: Graph of mechanical power and efficiency against angles

The highest mechanical power is produced at a tilt angle of 45° which is 18.857 watts with a torque generated of 0.827 Nm, while the highest efficiency is also produced at an angle of 45° of 35.669%, this is due to the power generated on mechanical power at an angle of 45° larger than the other angles. The greater the mechanical power, the greater the efficiency tends to be.

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4.0 CONCLUSION

The design and manufacture of portable screw turbine have the following conclusions:

1. The design and manufacture of a portable screw turbine has been carried out, with the specification of a turbine diameter of 23 cm, length of 1 m, number of threads of 5, shaft diameter of 6 cm and pitch of 22 cm.
2. The result of test the portable screw turbine has highest efficiency of 35.669% at an angle of 45^0.
3. The portable screw turbine that has been made, which has met the requirements for use as an alternative street lighting in rural areas that is still a lack of street lighting without having to use electricity from PLN.

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