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Experimental study of screw turbine performance based on different angle of inclination

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Abstract

Potential energy from fluid flow of small rivers or irrigations could be extracted become electricity by using screw turbine. This turbine is promising because the advantages of ultra-low head and fish friendly. Experimental performance of screw turbine for ultra-low head hydro resource is presented in this paper. The screw turbine with an outside diameter of 142 mm and the water flowrate of 1.2 l/s with the head of 0.25 m, can produce maximum power 1.4 W with 49% efficiency at 22^o angle of inclination. This turbine has one blade screw and screw turbine experiment apparatus is made by using locally available materials. The screw turbine has shown good potential to be used for low head micro hydro-electric installations. This paper reports on a performance analysis based on the experimental data collected from different performance tests carried out on some inclination angle position of screw turbine prototype.

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1. Introduction

Due to awareness about the importance of a sustainable environment, the role of renewable energy has been recognized as great significance for the global environmental concerns. One example of renewable energy is hydro power in which its potential application to future power generation cannot be underestimated. Particularly in lower head hydro resource, the cost of the commercially available low head water turbine is considerably high per kilowatt output, more research need to be done on lowering the cost of these low head hydro power systems. Depending on fossil fuel energy should be decreased and substitute with renewable energy resources. Any kind of green energy source becomes research object such as solar, wind, water, geothermal and biomass nowadays [1]. Any small contribution of renewable energy source will influence the percentage of energy mix that use around the world.

Among the renewable energy resources, energy from water in mini/micro hydropower has gained the highest attraction due to its environmental friendly operation. Water energy is of great importance for sustainable future because it is a clean, cheap and environmental friendly source of power generation [2]. Particularly in lower head, it can be the best economical option for remote area electrification in developing countries [3].

Around the world, there are many sources of hydro power in the form micro or pico hydro power from low head river or irrigation have not been exploited yet. In developing country such as Indonesia, from 400 MW potential capacity of micro hydro power, only around 1.8 % of potential micro hydro power which exploited for power generation [4], while many areas are still lack of electricity particularly in rural areas. Application screw turbine as micro or pico hydro power generation will solve that problem and it can increase electricity ratio around this country.

This paper highlights the development of screw turbine and present the experimental performance of screw turbine for ultra-low head hydro resource. This paper reports performance of screw turbine based on experimental data collected from some inclination angle position of screw turbine. Furthermore, discussion about the challenges and opportunities for promoting screw turbine as alternative renewable energy technologies is also included in this paper, followed by conclusion with recommendations for development of screw turbine.

2. Literature Review

Research on screw turbine has been started in Europe around the year of 2000s. Originally it was designed for pumping water from one location to another, the idea of modifying it for use as a turbine has been seen in the UK since 2004/2005. There are several advantages of screw turbine. It is known as one of the most environmentally friendly turbine in which fish and eels can pass through screw turbine while it operate without injured. It is remarkably cheaper among other kind of turbine, because it does not need guide vane or penstock, trash racks, screens and fish diversion systems. This turbine also known as very low maintenance turbine, that retipping is required every 20 years, with a minimum lifetime of 30 years. The main maintenance issue is the complicated gearbox required. The Archimedes screw turbine operates at low rotational speeds, which means a complex gearbox is required for connection to a generator [5].

Rorres (2000) lays out an analytical method to optimize design an Archimedes screw geometry for pumping applications. This problem is framed as maximizing the amount of water that can be lifted with each turn of the Archimedes screw pumps. He stated that the geometry of Archimedes screw pump consist of some external parameter which are usually determined by the location of the screw and how much water is to be lifted, and some internal parameter such as inner radius, number of blades and the pitch of the blades. In this research, he developed method to maximize the volume of water lifted in one turn of the screw by combination of inner radius and pitch of screw [6].

Muller and Senior (2009) created a simplified model for Archimedes screw turbine that idealizes the turbine's blades as moving weirs. Based on this idealization, a comparison is made to the hydrostatic pressure wheel. They concluded that Archimedes screw turbine efficiency is a function of both turbine geometry and mechanical losses, and that efficiency increases with an increased number of flights (N) as well as with decreased installation angle (β) [7].

Nurenberg and C. Rorres (2013) derived analytical model for water inflow of Archimedes screw turbine to get the optimal value of the inflow parameters. In this paper, they adopted some formulas of Archimedes screw pump that published by C. Rorres (2000), which are radius ratio, pitch ratio, volume ration and volume per turn ratio. For getting efficiency, they considered leakage between the flights and the trough and leakage from overflow. Their analytical model compared with experimental measurement. However, value of highest efficiency of screw turbine is still become a question [8].

In 2015, there was an article about compilation of Archimedes screw in application as a pump and as a turbine (S. Waters, G.A. Aggidis). They said there is currently a lack of research on the topic due to infancy of technology as a turbine. Screw turbine that was developed are visually similar to the inclined pump and often treated the same during the design. However, there are some key differences. When it comes to creating and optimizing a pump device, the key is to increase the amount of water moved during each turn of device. For the turbine, the maximum amount of energy in the flow needs to be extracted [9].

J. Rohmer et al (2016) did research about modeling and experimental results of an Archimedes screw turbine. Their model based on what C. Rorres (2000) did for Archimedes screw pump with some developments. Their research shows upstream level, mechanical efficiency and mechanical torque, as a function of the rotational speed and flow rate. Comparison between numerical and experimental data show the same trend and tend to slightly different [10].

Guilhem Delinger et al (2016) also did experimental research of Archimedes screw turbine. They derived some formulas based on C. Rorres (2000). Their research shows both theoretical and experimental values of efficiency decrease when screw inclination increases [11].

In the wide range of microhydro technologies, Williamson et al. discussed the relative advantages, includes a design approach for selecting an appropriate technology for particular site [12]. Compared to other generation technologies, screw turbine has greatest potential at low head site (less than 5 m), and unlike conventional reaction and impulse turbines, screw turbine has the potential for maintaining high efficiency even as the head approaches zero [12,13].

3. Methodology

Screw turbine works as follow; water flows into the top of the screw, make it turn while water keep moving down as the length of the screw. The hydrostatic pressure from water on the screw surface causes it to turn. Rotation of screw shaft can generate electricity by connecting to a generator. In this experiment, the screw turbine consists of a cylindrical shaft onto which one helical blade (N = 1) is wrapped orthogonal to the shaft with 12 revolutions. It has been fastened using glue and covered by cylindrical casing. Blade of screw turbine and casing were made of aluminum for easy machinability, and the shaft was made of PVC pipe. The size of diameter shaft, screw, and housing were selected according to available tools and materials. No attempt was made to balance the finished turbine. The turbine shaft supported directly by ball bearing at the top and bottom of turbine housing. Screw turbine dimensions are shown in Table 1.

Table 1. Lab scale screw turbine nominal parameters

Parameter	Variable	Value
Slope	B	22°, 30°, 40°
Outer diameter	D_o	142 mm
Inner diameter	D_i	32 mm
Pitch	P	54 mm
Number of screw	N	1
Gap width	G_w	5 mm
Screw length	L	646 mm
Flow rate	Q	1.2 l/s
Casing diameter	D_t	152 mm

Generally, the total extractable power of a water turbine can be found from [14]

$$Pw = \rho g Q h \tag{1}$$

In which ρ is the density of water, g is the acceleration due to gravity (9.81 m/s^2), h is the available head of water source (m) and Q is the volumetric water flow rate (m^3/s).

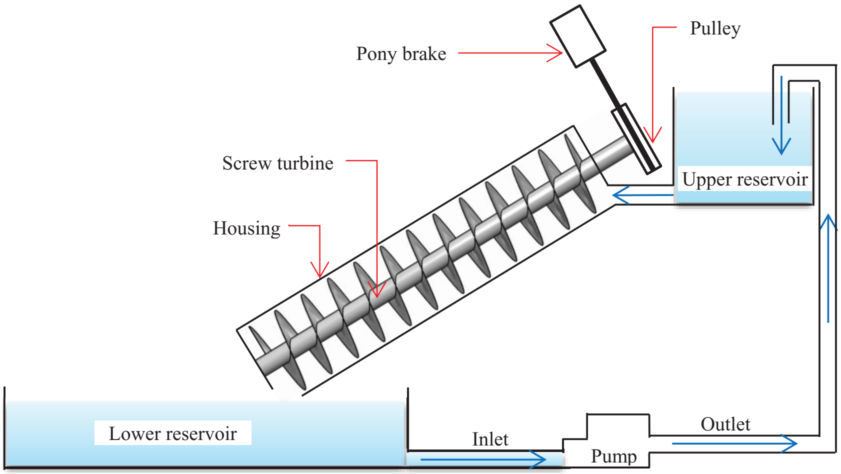


Fig. 1. Lab scale turbine screw experimental apparatus.

The mechanical power P_s available at the turbine shaft can be determined by measuring the torque T at a corresponding angular speed ω. The torque is found by measuring the tangential force F on a pony brake with moment arm radius of pulley r.

$$T = Fr \tag{2}$$

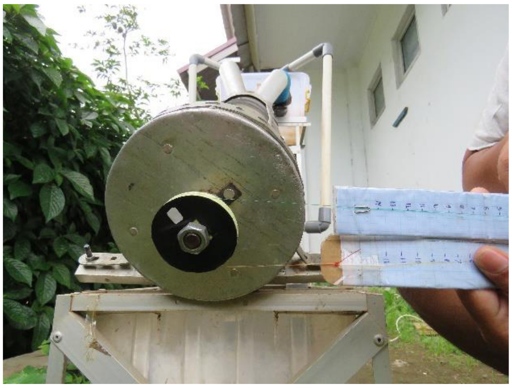
$$Ps = T\omega = T\frac{2\pi n}{60} \tag{3}$$

The mechanical efficiency of the turbine shows how effectively the available kinetic energy of the water is transformed into turbine motion and it becomes

$$\eta_m = \frac{Ps}{Pw} \tag{4}$$

In the experiment, water is supplied to the upper reservoir by electric pumps. Water flows to turbine through flexible tubing. After passed screw turbine blade and turn the shaft, water exits from turbine through a hole at the base casing to lower reservoir located under the turbine and flows back by pumps to upper reservoir. A pony brake is used to determine the torque on the turbine shaft. It is made from two springs, which fits on the pulley of turbine shaft, apply a frictional force on the turbine shaft as shown in Fig. 2 (a). Three different slope of turbine are made to show related connection with power produce and efficiency.

(a)



(b)

Fig. 2. (a) pony brake; (b) water fill level in experiment.

Table 2. Three slopes (β) used in the experiment, the corresponding maximum values of torque, power and mechanical efficiency.

	Inclination β (^{0})	Q (l/s)	Head (m)	n (rpm)	Torque (N.m)	Power (W)	η_m
1	22	1.2	0.25	106	0.13	1.4	0.49
2	30	1.2	0.38	146	0.09	1.3	0.30
3	40	1.2	0.41	225	0.06	1.4	0.30

4. Results and Discussion

Typical results of the experiment from apparatus of screw turbine made are shown in the following table and figures. Table 2 lists the slopes angle used, followed by corresponding head, torque and power. Maximum values of efficiency produced from this lab scale screw turbine is on the right side of the table. Torque and power of the turbine as a function of rotational speed are plotted in Fig. 3. Three different slopes of turbine position are plotted on that figure, show as maximum for slope (β) 22^o, medium for slope 30^o and minimum for slope 40^o respectively. Polynomial line for each slope show the leaning for each slope data.

It can be seen that different head gotten by different angle of inclination (slope) of screw turbine. Some significant values are collected from this experiment. Increasing slope and head turbine affect to rise the rotational speed of turbine, from 106 rpm to 225 rpm. In contrast, it tend to decrease the torque, from 0.13 Nm to 0.06 Nm respectively. From the experimental results, the turbine was found to have a maximum efficiency of 49% in producing 1.4 W power. This efficiency is reached as turbine operate in the slope of 22^o. Although number of blade of this turbine different from previous research done by Muller et al. [7] and Dellinger et al. [11], the trend is the same about decreasing values of efficiency when screw inclination increases.

The value of this efficiency is caused by several energy losses from this turbine. It can be seen from Fig. 2 (b) that fill level of water in this turbine is still under filling. Another factor is gap width between casing and screw diameter, 5 mm gap is too big for this small turbine. Improvement both of those factors will increase the efficiency of screw turbine.

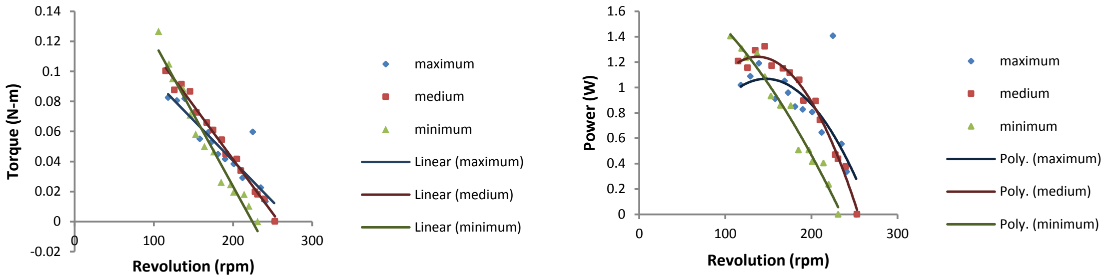


Fig. 3. Torque and Power of screw turbine as function of rotation speed for three different slope.

5. Conclusion

Valuable information about the performance characteristics of screw turbine was collected through the experiments. A lab scale screw turbine for hydroelectric generation has been constructed by using inexpensive and available materials and components. Among three selected angle of inclination, lowest slope has highest efficiency.

Future research plans include the impact of varying other parameters such as number of blade, pitch and more installed slope. Leakage and losses will also be investigated. Finally, the best result of propose model should be tested with a full size of screw turbine.

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