Manufacturing process and experimental study of a small scale archimedes hydro powerplant by varying the number of blade

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ABSTRACT
This study investigated the optimum value of Archimedes Screw Turbine (AST) performance by taking into account blades number. This paper also addressed the design approach based on a fixed incline angle of 30°, where the manufacturing and design steps were clearly explained as well. Variations of the single and double blades were experimentally carried out concerning the turbine power output, torque, and rotation speed. This study aimed to examine the optimum power output between two blade variations. The blade length dimension was 0.180 m and 0.269 m for the single and double blades. Furthermore, the overall turbine's length was 1.7m, and the inner and outer of the turbine's radius were 0.069m and 0.128m. Meanwhile, the manufacturing process began with turbine modeling, plate cutting, plate withdrawal (thread formation), welding, and attained finishing process. A double blade turbine generated turbine power by 48.8W at an average rotational speed of 115.3 rpm based on the experimental result. Moreover, a single blade turbine produced 37.5W, averaging a rotational speed of 109.8 rpm. It was obtained that the values of turbine efficiency were 42% and 38% for double and single turbine types, respectively. Based on this finding, it can be suggested that a double blade was more efficient than a single one. This study is beneficial for the design consideration of the AST system.

Keywords: Archimedes Screw Turbine, Blade, Power, HydroPower

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1. INTRODUCTION
Indonesia, composed of more than 17,000 islands, is emerging the challenge of energy distribution, especially in rural areas. In that case, small-scale renewable energy (RE) powerplant have been provided, such as solar and hydro energy. Among the mentioned resources, hydropower energy has been widely implemented and has many resources to exploit, such as rivers and irrigation systems. Accounted for nearly 94.3 GW energy potential in Indonesia, hydro energy has only slightly 5.3 GW been harnessed [1]. On the other hand, the national policy encouraged the use of renewable sources to fulfill the energy needs by more than 23% proportion in 2050 [1]. There are types of turbines used for electricity generation on hydropower, including Kaplan and Pelton turbines. Meanwhile, a rising interest in Archimedes screw turbine (AST) made it a popular electricity generation technology. AST has advantages on environmentally friendly, including not harming the ecosystem, which is necessary to consider during installation [2]. The annual capital cost was more affordable than the typical Kaplan turbine by 22% [3]. In terms of operation, AST was also suited for a low head that made it proper to be implemented in the rural area [4, 5]. Moreover, it also provided high efficiency (60% to 80%) over a wide range of flows, so it can be particularly advantageous in these regards [4, 6]. However, the design of AST highly depends on the location, and there is no general standard for the optimal hydraulic design [6]. Therefore, this study is proposed to enhance the knowledge of the optimal design of AST.
The AST is made by having an inner shaft, while the central shaft has an extension to both ends. It is utilized to place the turbine on the bearings and as a drive shaft connected to the generator. The helical planes are positioned to form a screw on the tube center, whereby the number of helical planes depends on the turbine’s position. The outer diameter of the screw considers the mass of water flow. The geometry of AST relies on environmental conditions such as water flow and the height of inclination angle [7]. The AST consist of concrete, which is often positioned next to the river. It also has an iron cover to prevent water losses between the inlet canal [8]. Rorres [7] obtained the empirical formula for design purposes where the description of mechanical, hydraulic, and water leakage losses has been explained. The simplified theory of AST has been entirely elaborated by [9]. The theoretical model was developed by considering geometrical parameters and idealized energy conversion and was then compared with the experimental results. The efficiency was found to be a function of the screw’s geometry [9]. Significant losses on efficiency were upon rotational speed, hydraulic loss, water leakage, and friction losses on the bearing [8]. The study of Brada, et al. [10] yielded that the variation of rotational speed and water flow in the range of >20% has no impact on the AST efficiency. It also revealed in the study that AST efficiency to be close to 80%. This finding allowed the benefits for implementation in the site, which has flow fluctuation with high seasonal variability. Usually, the efficiency of AST ranged somewhat between 80%-90% [11]. However, due to the ideal setup and losses, the mean operational efficiency was 69% to 75%, as reported in (Lashofer). Another finding in [4] suggested that the optimum efficiency was reached when the turbine was close to the stall rate of the system. The turbine bucket was filled; hence most torque can be generated. It was also noteworthy that the turbulence losses within the turbine were smaller at a low rotational speed. Moreover, it also have examined that a greater number of screws around the turbine means higher efficiency as the reduction of the head difference between each turn [4]. However, some compromises found in the study of the optimum number of blades was two [13]. Therefore, there is a restriction on finding the optimum design of AST.

The main objectives of this paper are to conduct the experimental assessment of AST. The practical test is performed on the natural river with a simplified setup; therefore, it is considerably suited to be applied to the rural area. The effect of a number of blades is examined while the inlet water flow keeps remained constant. However, some assumptions were made due to the environmental condition, such as the steady water flow, no major water leakage, and changes in physical properties were neglected. This paper organizes as follows: the design and experimental setup are elaborated in Sec.2, the results are discussed in Sec.3, and the conclusion is presented in Sec.4.

2. METHODOLOGY
2.1 Design and Experimental Setup
In the design process, the complex trade-off between the performance and cost must be involved [4]. Generally speaking, AST begins with water flowing into the screw making it rotates while the water is falling down as the length of the screw. This rotation is due to the hydrostatic pressure of the water which then is able to generate electricity as the shaft is connected by generator. In this study, the design was based on Rorres [7] to obtain the optimal design of AST. Therefore, this study is only highlighted the main section of design whereby the steps of design was fully explained in Rorres [7]. The initial inputs for design parameter are head 2\( m \), max AST length is 2\( m \), slope is 30° while the number of turbine blade is varied by 1 and 2. The calculation was initiated by determining the shaft length shown in Eq. 1 where (\( H \)) is the head (\( m \)) and \( K \) is the slope (Eq. 2). \( R_i \) and \( R_o \) are the inner and outer blade radius (\( m \)) (Eq. 3) while \( \rho \) is the water density (\( kg/m^3 \)). \( \Delta \) is the pitch length (\( m \)) (Eq. 4). The \( \alpha \) and \( \beta \) are the outer and inner blade angles. The water debit (\( Q \)) is 0.011 (\( m^3/s \)).
2.2 Data Collection
The mechanical power of AST output \( P_m \) can be determined from torque \( T \) which corresponds with the angular speed \( \omega \). The torque is measured by using a Pony Brake (Fig. 2) whereby tangential force is obtained by placing load and arm radius of pulley \( r \) is determined. The schematic layout of Pony Brake shows in Fig. 2a whereas the implementation is illustrated in Fig. 2b. The loads were 2kg, 3kg, and 4kg, respectively. In this work, the gravitation acceleration is assumed by \( 9.8 \, m/s^2 \). To measure the turbine’s rotational speed, Tachometer was utilized as shown in Fig. 3. The mechanical power output is described in Eq. 4 while input power comes from the potential energy of water \( P_w \) is described in Eq. 5. Furthermore, the total efficiency of AST system is determined by considering the mechanical power output and potential energy of water.

\[
\begin{align*}
L &= \frac{H}{K} \\
K &= \tan \theta \\
R_i &= \rho \times R_o
\end{align*}
\]

\[
\begin{align*}
P_m &= T \omega = F r \omega \\
P_w &= \rho g Q H
\end{align*}
\]

2.3 Manufacture
Manufacturing consists of preliminary design produced using CAD, preparation, and assembly process. In this study, the steps of AST manufacturing are briefly explained as well as its engineering consideration. The material selection, as well as construction, is then presented in the following chapter.
3. RESULT AND DISCUSSION
3.1 Design Result
Based on the calculation, the geometry of AST for the single and double blade is depicted in Table 1. Meanwhile, the models are in Figs. 4(a) and 4(b) for the single and double blades, respectively. It can be seen that with respect to the same length single blade has fewer helical turns than that of the double blade by 3. The maximum volume of the bucket on the double blade is massively higher than on the single blade, which later affects the generated power. The pitch of each blade on a single blade was nearly half in size of a double one. The distinguishing parameters are pitch, maximum bucket volume, and several helices, while other parameters have remained the same. The generated model shows that a double blade offers more blade angle than a single blade, which allows more water to flow, resulting in higher hydrostatic power.

Table 1. Calculation result of AST geometry

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Single blade</th>
<th>Double blade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope of screw</td>
<td>°</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Total length</td>
<td>m</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Screw inner radius</td>
<td>m</td>
<td>0.069</td>
<td>0.069</td>
</tr>
<tr>
<td>Screw outer radius</td>
<td>m</td>
<td>0.128</td>
<td>0.128</td>
</tr>
<tr>
<td>Pitch of one blade</td>
<td>m</td>
<td>0.180</td>
<td>0.256</td>
</tr>
<tr>
<td>Bucket maximum volume</td>
<td>m³</td>
<td>0.0026</td>
<td>0.00367</td>
</tr>
<tr>
<td>Turns of helix</td>
<td></td>
<td>10</td>
<td>13</td>
</tr>
</tbody>
</table>

On the other hand, elements of the AST system are described in Fig. 5(a) and 5(b) for the 3D model and actual implementation, respectively. The turbine’s blade is covered and mounted using an aluminum frame. The upper side is then connected with a generator to produce electrical power and Pony Brake for measuring the torque. The actual implementation was in natural river flow. The water inlet was adjusted to produce constant debit before downwards inside the turbine. The reservoir was added to collect the water before flowing into the turbine system. This arrangement was made to aim fixed inlet condition.
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Figure 4. Geometry of (a) single blade and (b) double blade

Element of AST system:
1. Turbine’s framework
2. Turbine’s mounting
3. Back Leg mounting
4. Turbine’s cover
5. Turbine’s blade
6. Bearing
3.2 Manufacturing Process

The manufacturing process was firstly conducted by design which was explained in the preceding chapter. The aluminum sheet was cut in the cutting process using CNC Plasma cutting. The programmed CNC setup was adjusted, and its use was to result in better accuracy and precision rather than manual cut. CNC Plasma has numerous advantages: its straightforward operation and maintenance, more accurate and precise results, and low operating costs. The cutting process of the blade is depicted in Fig. 6.

After being cut, the blade was formed by pulling the steel on the shaft. It was impossible to manually arrange the blade since the blade’s thickness was 2.8mm. The pulley was utilized in order to adjust the blade, as shown in Fig. 7(a). It was worthy to note that the inner diameter of the blade must be perfectly laid on the shaft in order to avoid leakage and losses in operation. The next step was welding. The SMAW welding tool was used to attach the blade to the shaft. SMAW welding has lower operational costs than another welding. The benefits of using SMAW were its ability to weld various types of ferrous and its wide availability of electrodes. After being attached, the last stage of the manufacturing process was finishing. At this point, the thread was grinded to avoid any imperfect surface after being pulled. This process was intended to remove any wavy surface resulting in imbalance rotation during operation.
In addition, some design considerations were made. AST system was built to fulfill energy needs, especially in rural areas, so that simple design was considered. However, in this study, the design was carried out by the simplest possible construction without neglecting the function. The AST system was mainly used ASTM A36 steel which belongs to low carbon steel. It has the advantages of high ductility, availability, and ease to machine. Therefore, it suited the AST, which then was intended to be implemented in wide area including a rural area.

3.3 Experimental Result

The typical results of the experimental from the AST apparatus in terms of torque, rotation speed, and power output are explained afterward. Torque was measured using Pony Brake, and the result showed in Fig. 8. Based on the test result, the torque values tend to increase regarding the number of blades and given load. Firstly, it explains that the current AST is able to withstand the given load. The weight should be increased to examine the maximum torque produced by AST, whereby it is preserved for future study. The difference in value between blade variations was due to the volume of water that each turbine can accommodate. By considering the resemble design parameter but the number of the blade, a double blade has a higher bucket volume than a single one meaning that torque produced by a double blade is also higher [7]. However, the exceptional result was at a 3kg load which showed that a single blade was more superlative than a double one. Aside from the comparative result, the trend remained the same where the torque value increased in line with the additional load. Hence, it was due to the imperfect and arbitrary conditions related to the instruments and environment. In general, the torque value will nearly remain the same for each load [15]. But here, neither double nor single blade produced the same result. At the same time, the reasons for that were imperfect experimental setup and environmentally unstable in the actual natural river. Another argument was the instrument that produced discrepancy in high rotation conditions. Therefore, further study is proposed with regard to filling the drawbacks of the current study. However, aside from the drawbacks mentioned above, the AST in this study was able to generate average torque of 2.81Nm and 2.63Nm for, respectively, double and single blades.
The increase of load will affect lower turbine rotation speed, whereby it can be seen in Fig. 9 that a 4kg load has a smaller value of turbine rotation. Overall, the value of the double blade was again higher than the single one. Based on [16], a double blade has advantages in producing more axial force that influences the rotation of the turbine. Therefore, the results are in good agreement with the previous study. Moreover, the power output is given in Fig. 10. The maximum power generated by double and single blades was 48.8W and 37.5W. The average value of mechanical power was 38.07W and 34.25W for a double and single blade. The different pattern showed in the load of 3kg, whereby a single blade produced more power than a double one. The power relates to the torque, therefore, the reason for this distinction resembled that of the explanation mentioned earlier. Again, the discrepancy result between those was because of its bucket volume. The double one has advantages in its size to harvest more hydrostatic power than the single one. Therefore, the energy produced by the double blade configuration is better in terms of power output. In addition, compared to the previous study by [14], the current double blade study produced more power but more diminutive in size. This concludes that the current AST system is considerably more efficient than that of the previous study.
The overall efficiency regarding mechanical power and water energy was carried out. The input power of water was based on $0.011\ (m^3/s)$ in debits producing a total power of $90.5W$. It was assumed that no leakage occurred during the process so that the total input power remained the same. Based on the calculation, the overall efficiency of the double and single blades was 42% and 38%.

4. CONCLUSION

The experimental experience was elaborated whereby specific design considerations of the single and double blade were also addressed. The added value herein is the examination of manufacturing and design consideration as well as examination regarding power output. The blade length dimension was 0.180 m and 0.269 m for the single and double blades. Furthermore, the overall turbine's length was 1.7m, and the inner and outer of the turbine's radius were 0.069m and 0.128m. Meanwhile, the manufacturing process began with turbine modeling, plate cutting, plate withdrawal (thread formation), welding, and attained finishing process. According to the experimental result, it was found that a double blade generated more power than a single blade. The mechanical power of a double blade was 48.8W, while 37.5W was found on a single blade, which led to 23% less in terms of power output. In addition, the overall efficiency of the double blade was slightly higher by 9.5% than the single one, with 42% and 38% for double and single blade overall efficiency in comparison. Future research plans include adding more load and varying other design parameters are considered.

REFERENCES:


