

Hydrocoil Turbine Performance at 3 m, 4 m, and 5 m Head Analysis Using Computational Fluid Dynamics Method

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Abstract. Indonesia is a country which has abundant renewable energy resources, comprises of water, solar, geothermal, wind, bioenergy, and ocean energy. Utilization of water energy through MHP is widely applied in remote areas in Indonesia. This utilization requires a water-converting device known as a water turbine. Rosefsky (2010) developed a water turbine known as the Hydrocoil turbine. This turbine is an axial turbine which is a modification of screw turbine. This turbine has a pitch length that decreases in the direction of the water flow and is able to work at relatively low water flow and head. The use of Hydrocoil turbine has not been widely applied in Indonesia, therefore this research is focused on analyzing the performance of Hydrocoil turbine. The analysis was performed using Computational Fluid Dynamics (CFD) method. Hydrocoil turbine performance analysis was performed at 3 m, 4 m, and 5 m head respectively as well as rotational speed variations of 100 rpm, 300 rpm, 500 rpm, 700 rpm, 900 rpm, 1,100 rpm, 1,300 rpm, 1,500 rpm, 1,700 rpm, and 1,900 rpm. Based on simulation result, the largest power generated by the turbine at 3 m head is 1,134.06 W, while at 4 m and 5 m are 1,722.39 W and 2,231.49 W respectively. It is also found that the largest turbine's efficiency at 3 m head is 93.22% while at 4 m and 5 m head are 94.6% and 89.88% respectively. The result also shows that the larger the head the greater the operational rotational speed range.

1. Introduction

Indonesia is a country which has abundant renewable energy sources, comprises of water, solar, geothermal, wind, bioenergy, and ocean energy. According to the data from *Kementrian Energi dan Sumber Daya Mineral (ESDM) Republik Indonesia* in 2016, renewable energy utilized in Indonesia is only 1.1% of total renewable energy potential (there is 810 GW of renewable energy potential in Indonesia and only 8.78 GW that were utilized) [1]. The largest utilization in renewable energy is in water sector. There is 5.25 GW or approximately 28% of total water energy potential that were utilized. Utilization of water energy through Micro Hydro Power (MHP) is widely used in remote area in Indonesia. It is because MHP is a simple system so that it can be easily installed. This utilization requires a water-converting device known as water turbine. In 2010 Rosefsky developed a water turbine known as Hydrocoil turbine [2]. This turbine is an axial turbine which is a modification of screw turbine. It has pitch length that decreases in the direction of water flow and is able to work in relatively low water flow and head [2]. This turbine is not widely used in Indonesia, so this paper will focus on the analysis of this turbine performance to get information how good the turbine is. The analysis will be conducted by the use of *Computational Fluid Dynamic* (CFD) method which is simulation of fluid using computer. The software used in this research is ANSYS CFX 15.0. The aim of this research is to get a graph that shows power generated by the turbine and the turbine's efficiency



which is applied at 3 m, 4 m, and 5 m head as well as rotational speed variations of 100 rpm, 300 rpm, 500 rpm, 700 rpm, 900 rpm, 1,100 rpm, 1,300 rpm, 1,500 rpm, 1,700 rpm, and 1,900 rpm..

2. Methodology

Figure 1 shows the Micro Hydro Power system and its dimensions in this research. Figure 2 shows the geometry inserted to ANSYS CFX 15.0. The drawing of the geometry is conducted using Inventor 2013. According to figure 2, the inlet boundary of the system is the inlet of penstock, and the outlet boundary is the outlet of hydrocoil turbine.

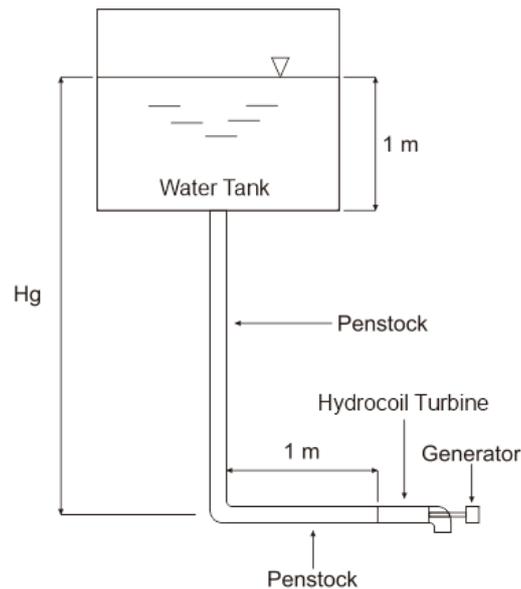


Figure 1. Schematic of Micro Hydro Power

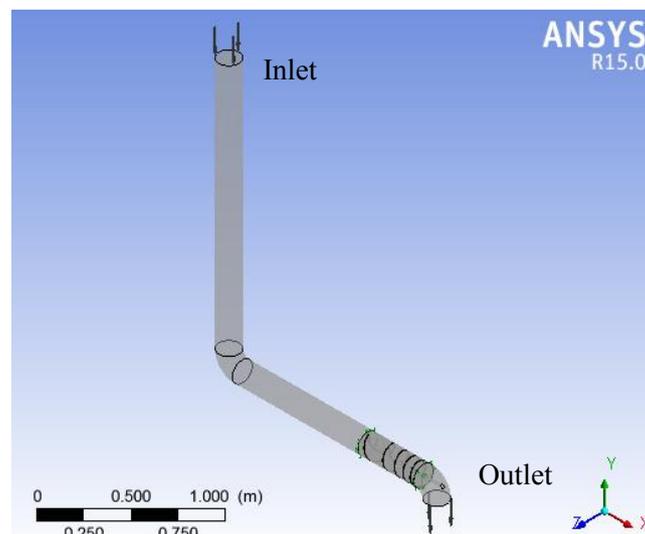


Figure 2. Geometry Inserted to ANSYS CFX 15.0

Figure 3 shows the research flowchart. According to the figure, before CFD can be done, parameters at boundary conditions of the system should be calculated.

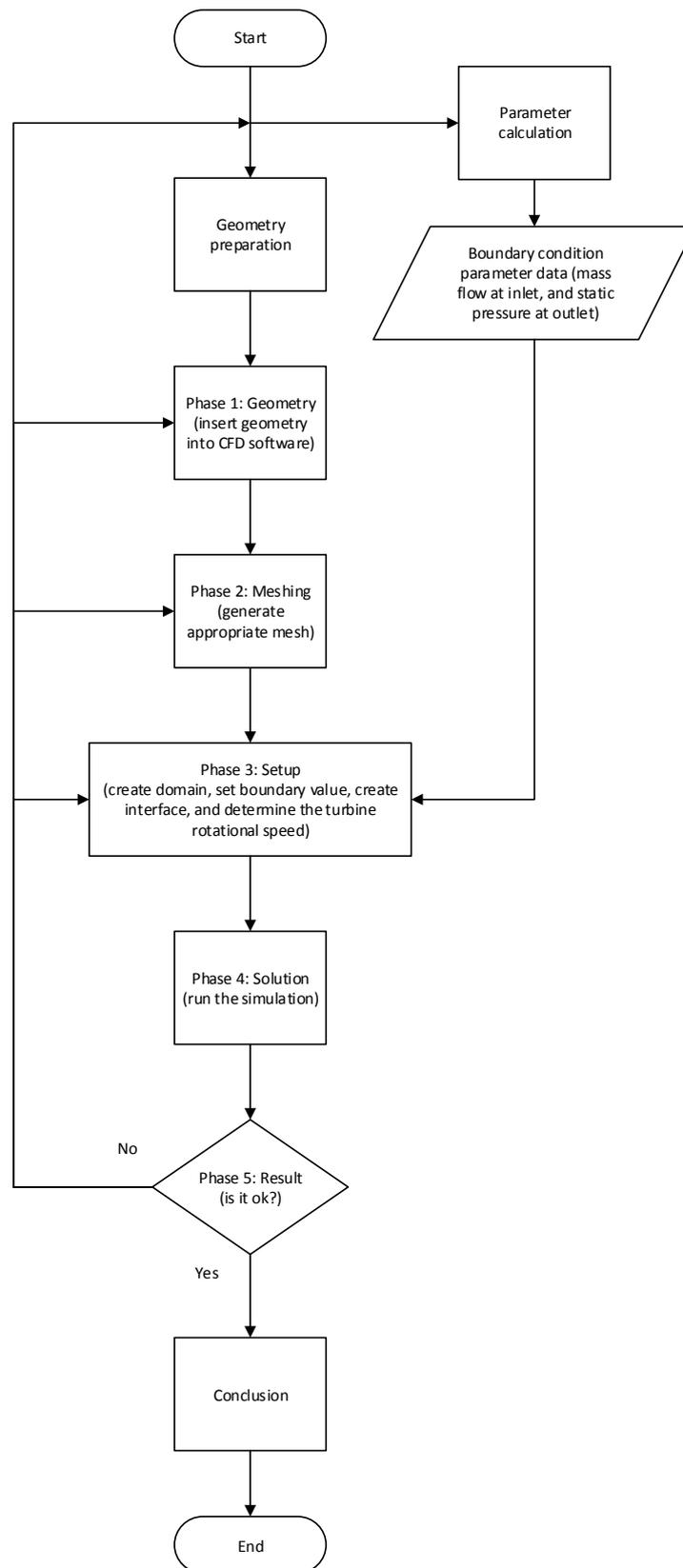


Figure 3. Research's Flowchart

2.1. Parameter Calculation

According to Figure 3, parameter at inlet boundary that need to be known is mass flow. Equation 1 shows the equation needed to calculate this parameter.

$$\dot{m} = \rho \cdot Q_{opt} \quad (1)$$

At Equation 1, ρ is water density, which is 1.000 kg/m^3 ; Q_{opt} is water flow through penstock. This parameter can be calculated using Equation 2 [3].

$$Q_{opt} = \frac{2}{3} A_p \sqrt{g \frac{7H_g}{10C_L}} \quad (2)$$

At Equation 2, A_p is cross sectional area of the penstock, H_g is gross head showed in figure 1, and C_L is losses coefficient that can be calculated using Equation 3 [3].

$$C_L = f \frac{L}{D_p} + \sum K_L \quad (3)$$

At Equation 3, L is total length of the penstock, D_p is penstock diameter, K_L is minor losses coefficient due to bend (the value is 0.3 for 90° flanged elbow [4]), and f is friction losses coefficient or Darcy-Weisbach friction coefficient that can be calculated using Swamee-Jain formula showed in Equation 4.

$$f = \frac{0,25}{\left[\log \left(\frac{\varepsilon}{3,7D_p} + \frac{5,74}{Re^{0,9}} \right) \right]^2} \quad (4)$$

At Equation 4, ε is pipe's roughness (0 if the pipe assumed to be smooth pipe), Re is Reynolds number that can be calculated using Equation 5. Swamee-Jain formula only valid if the Reynolds number is 5.000 to 10^8 . At Equation 5, ν is kinematic viscosity of water which is 1×10^{-6} at 25°C .

$$Re = \frac{\rho v D}{\mu} = \frac{v D}{\nu} \quad (5)$$

Another parameter should be known at boundary is static pressure at outlet. Due to the water will fall freely after passing the turbine, so the static pressure at outlet is 0 Pa relative to atmospheric pressure.

2.2. Hydrocoil Turbine

Hydrocoil turbine used in this research is showed in figure 4 [2]. According to figure 4, the pitch length of the turbine is decreases gradually and can be divided into 3 coils. Each coil has different length. Table 1 shows the dimension of the turbine, including the dimension of each coil.

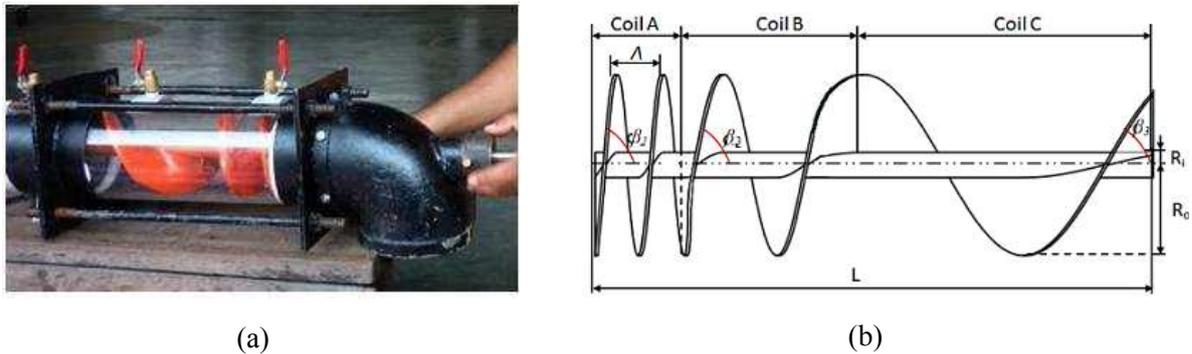


Figure 4. Hydrocoil Turbine

Table 1. Dimension of Hydrocoil Turbine

No	Specification	Value
1	Length Coil A	0.085 m
2	Length Coil B	0.095 m
3	Length Coil C	0.12 m
4	β_1 in Coil A	83°
5	β_2 in Coil B	79°
6	β_3 in Coil C	71°
7	D_i ribbon drive	0.019 m
8	D_o ribbon drive	0.108 m

The performance of the turbine can be seen from turbine's power generated and turbine's efficiency. Equation 6 shows the formula to calculate optimum power that can be generated by the turbine with γ is weight of fluid per volume [3]. This is the highest power possibility that can be generated by the turbine due to losses in the system.

$$P_{opt} = \frac{76}{135} \gamma H_g A_2 \sqrt{g \frac{7H_g}{10C_L}} \quad (6)$$

3. Results and Discussions

Graph in figure 5 shows torque values of the turbine at different head and different rotational speed. According to the graph in figure 5, torque will decrease as rotational speed increases. This pattern is natural pattern of any turbine [2]. This graph also shows that the highest torque is gained at 5 m head. This is due to water velocity will increase if head applied is increases. The higher the velocity, the higher the torque gained.

Graph in figure 6 shows turbine's power. This graph shows that the power rises until a certain value at a certain rotational speed and then decreases as the rotational speed keeps increasing. According to Aprilliyanto's work, this pattern is also natural to turbine's performance [2]. Based on this graph, the largest power generated by the turbine at 3 m head is 1,134.06 W, while at 4 m and 5 m are 1,722.39 W and 2,231.49 W respectively. So the highest power is generated at 5 m head. This is due to the higher the torque, the higher the power generated.

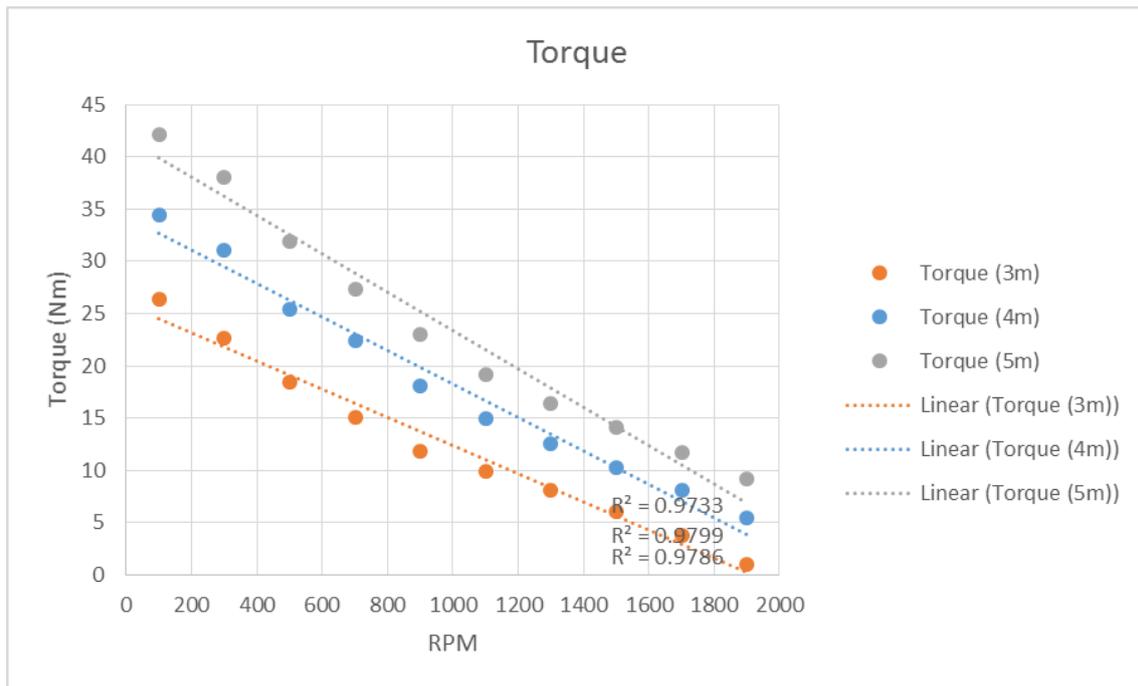


Figure 5. Turbine's Torque

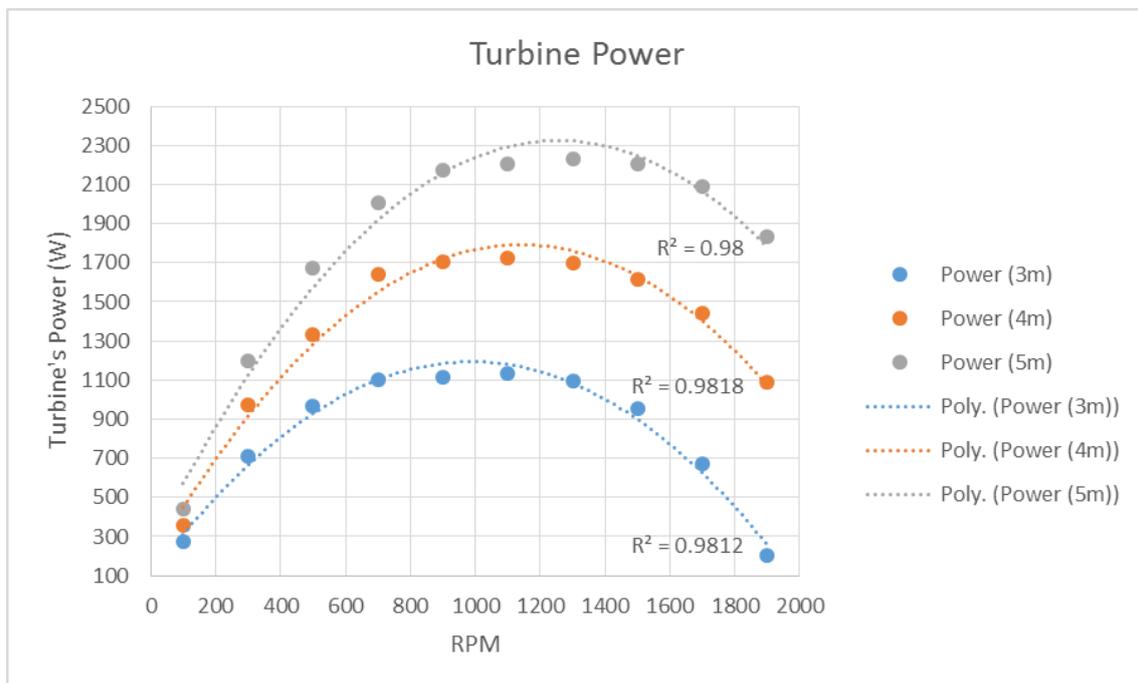


Figure 6. Turbine's Power

Graph in Figure 7 shows turbine's efficiency. The efficiency is calculated using the data given in figure 6 and the potential power generated according formula showed in Equation 6. The graph shows that the largest turbine's efficiency at 3 m head is 93.22% while at 4 m and 5 m head are 94.6% and 89.88% respectively. This result shows that higher head will not produce better performance, even though the torque and the power generated is higher. This should in consideration in designing micro hydro power using hydrocoil turbine.

The graph in figure 7 also shows that turbine's efficiency at 5 m head is the lowest until the rotational speed reach 1.700 rpm. After that, the turbine's efficiency become the highest among all variation. This is due to the higher the head, the greater the operational rotational speed range. So 5 m head will provide greatest rotational speed range among all variation. This mean that the turbine's rotational speed can reach more than 2.000 rpm. Otherwise, 3 m head only provide rotational speed range from 0 rpm to around 1.900 rpm. This range should be a consideration in choosing appropriate generator. This is because every generator has minimum rotational speed required coupled to it.

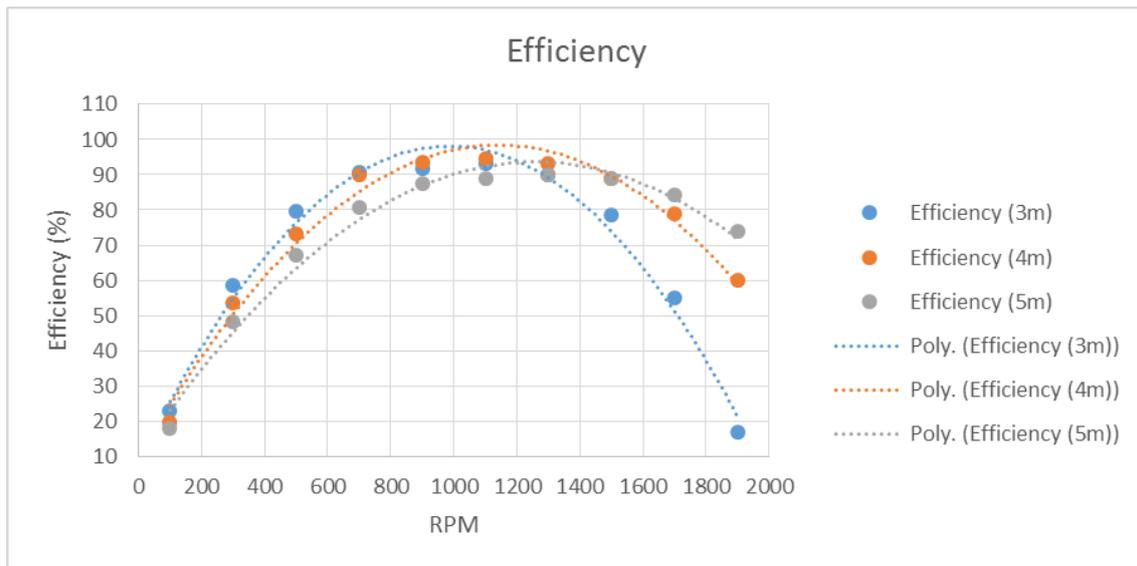


Figure 7. Turbine's Efficiency

4. Conclusions

The hydrocoil turbine power graph on head variations of 3 m, 4 m, and 5 m indicates that the largest power at 3 m head is 1,134.06 W, while the largest power at 4 m and 5 m head are 1,722.39 W and 2,231.49 W respectively. Turbine's efficiency graph shows that the largest turbine's efficiency at 3 m head is 93.22% while at 4 m and 5 m head are 94.6% and 89.88% respectively. This result shows that higher head will not produce better performance, even though the power generated is higher. This graph also shows that the larger the head, the greater the operational rotational speed range.

References

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