Testing Simulation in the River of Archimedes Screw Turbine on the Cilember River in Bogor Using SolidWorks Software

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Abstract: In searching for a turbine suitable for microhydro power generation, it must align with the characteristics of the river flow, such as the river head, water discharge, and flow velocity. In this study, the Archimedes screw turbine was chosen because of its ease of manufacturing, high efficiency, and ability to handle appropriate loads. Its operating principle involves the flow of water from the bottom of the screw turbine, entering the space between the screw blades (buckets), and then exiting from the top of the turbine. The rotation of this turbine rotor powers the electric generator connected to the top of the screw turbine, producing electrical energy. Therefore, the design of the screw turbine and static load simulation using SolidWorks 2022 software are necessary. The research aims to determine the extent of strain and stress distribution on the screw blades when subjected to static loads. The design is based on calculations from literature and utilizes data collected from the Cilember River in Bogor using the float method. From this data, a flow rate of 0.460 L/s and a water head of 0.36 m are obtained. The calculated results also indicate a blade diameter of approximately 0.1866 m, a turbine shaft diameter of 0.1 m, a turbine length of 0.8086 m, a turbine pitch of 0.1863 m, with a total of 4 threads on the turbine. The estimated potential power generation is around 8624 kW. Through static load simulation, it is found that the maximum stress value reaches 3.59 x 10^6 N/m^2, and the maximum strain is about 7.88 x 10^{-3} mm at the examined node point, involving a total of 38871 elements.

1 INTRODUCTION

1.1 Electric Power Sources

In general, electric energy is defined as the primary energy required for an electrical device to drive other devices to function properly. Available energy is divided into two types: renewable energy and non-renewable energy. Renewable energy can be defined as potential energy sources derived from nature and can be continuously utilized for the sustainability of the future. Use and process extra energy to create new energy. Currently, renewable energy sources are still being developed and will continue to be developed to achieve efficiency.

On the other hand, non-renewable energy is energy that will be depleted once used, with sources that cannot be renewed, such as fossil fuels. Various research studies have been conducted to find electrical energy sources other than fossil fuels as renewable energy sources. Some renewable turbine power plants in Indonesia are Microhydro Power Plants (PLTMH). This power plant creates small-scale turbine generators that utilize the energy of flow as a source of motion, such as river flow or waterfalls, using the height of the waterfall, the amount of water discharged, and water pressure. A hydro turbine power generator is a device that converts the flow energy into kinetic energy, and this mechanical energy is then converted into electrical energy using a generator. The type of turbine suitable for PLTMH depends on the flow characteristics, including head, available flow, and river speed. The generator works by utilizing the waterfall height and flow rate in the river and waterfall. The flow rate drives the runner, causing mechanical energy that makes the turbine and generator rotate. One type of power generator that utilizes water flow is the Archimedes screw turbine, which converts mechanical energy from water into rotational motion in the turbine.

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This turbine has advantages over other turbine variations, including high efficiency, ease of maintenance, and minimal disruption to the river ecosystem. Therefore, it is necessary to design an Archimedes screw turbine and perform simulation testing. The author intends to conduct research by testing the Archimedes screw turbine with a turbine inclination of 25º and a blade angle of 24º. The design of this turbine is done using Solidworks software, and simulation testing is performed to study the optimal performance of the Archimedes screw turbine, including the magnitude and distribution of stress and strain in the turbine blades.

1.2 Electric Power Potential from Water

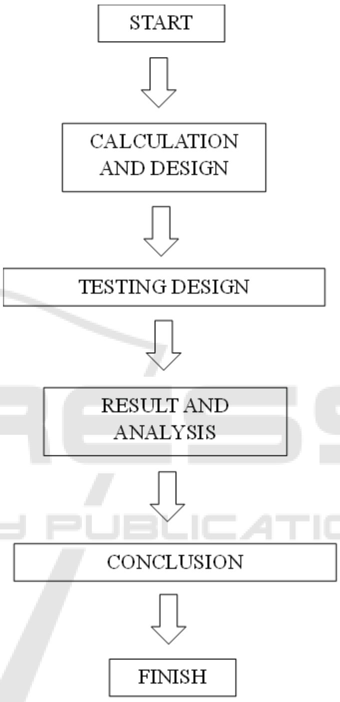
The appropriate utilization of this electrical resource can be an effective tool for advancing economic growth in a country. Therefore, it is not surprising that the demand for electrical energy has been increasing worldwide in recent times. In this context, several countries around the world are making efforts to harness and manage economically viable renewable energy resources, and one of these resources is the processing of high-flow water resources. For example, Hydroelectric Power Plants (PLTA) are often a preferred option. PLTA offers the advantage of being an economical, abundant, and environmentally friendly source of electricity. In Indonesia, the wealth of water resources holds significant potential for energy generation. For instance, PLTA has been in use since 1882 to power industrial machinery for tea production. Several PLTA facilities, including the one in the Cisalak area built in 1909, continued to operate until 1910.

In addition to PLTA, there are also Micro Hydro Power Plants (PLTMH) that successfully generate medium-scale hydroelectric turbines by harnessing the power of flowing water or water flow. PLTMH operates by utilizing the difference in water elevation (head) from the surface and the volume of water flow. Although the energy generated by PLTMH is smaller compared to large-scale PLTA, PLTMH has advantages in terms of relatively simple equipment and a smaller installation and operational area requirement. The primary advantage of PLTMH is its ability to provide access to electricity in remote and rural areas. In various remote regions of Indonesia, PLTMH serves as a significant alternative energy source. While other energy sources are dwindling and negatively impacting the environment,

water resources offer a promising solution because they can be relied upon as a clean and affordable source of electrical energy. PLTMH typically has a capacity of less than 101 kW, making it suitable for remote areas near river streams that allow small-scale electricity generation. In the future, the utilization of PLTMH potential in these remote areas can help meet local energy needs, mitigate rising energy costs, and address national electricity network challenges.

2 METHODS

2.1 Research Process Flow Chart



2.2 Location and Time of Research Implementation

The research will be conducted at Cilember River in Bogor, at coordinates -6.66121087443231, 106.94579520859499, in the Megamendung area in April - May 2023.

2.3 Research Procedure

The research procedure will be used to determine the distribution of strain and stress on the screw turbine blades, as explained below:

- Literature Review, through extensive literature study, plays a crucial role in strengthening the analysis of strain and stress in the Archimedes screw turbine. It serves as an application of literature that enhances this research.

- Consultation, involving discussions with the supervising professor or other faculty members to gain a better understanding of the research and analysis of the screw turbine's performance.

2.4 Testing Procedure

Testing is conducted to obtain data and visualize the distribution of strain and stress on the turbine blades using SolidWorks software.

2.5 Research Variables

The data used in the research is generated to calculate the dimensions of the helical turbine and includes control, dependent, and independent variables.

a. Independent Variables - These are the factors that will be chosen to investigate their influence. In this research, the independent variables are: Turbine inclination angle of 25°, Blade turbine inclination angle of 24º.
b. Dependent Variables - These are the outcomes connected to other variables, also known as responses. In this research, the dependent variables are related to the issues under discussion, which are strain and stress.
c. Control Variables - These are elements kept in a stable or unchanged condition. Some examples of control variables in this research include: River flow rate of 0.46 (m3/s), Waterfall drop height of 0.36 m.

3 RESULTS AND DISCUSSION

This involves data from the simulation testing of the Archimedes screw turbine blades using SolidWorks software. The testing is conducted by applying static loads to obtain the distribution and magnitude of stress as well as the distribution and magnitude of strain in the screw turbine.

3.1 Calculation of Helical Turbine Dimensions

The data obtained through calculations using the formula based on the concept of Chriss Rorres theory enables researchers to easily understand the dimensions of the helical blades and shaft in the Archimedes screw turbine by applying the Chriss Rorres equation theory. The calculation formula is as follows:

1) Calculation of Shaft Length L = H/K
With:
L=Shaft Length (m), H=Head (m), K=Tan θ

Table 1: Calculation of Shaft Length.

K	H	L	Result
Tan 24°	0.36	L1	0.8086
Tan 24°	0.36	L2	0.8086
Tan 24°	0.36	L3	0.8086
Average			0.8086

From the table above, it can be seen that when seeking the flow head with a 0.36 m height in the inclined blade turbine variant, the average value is 0.8086 m or 80.86 cm.

2) Determination of Inner and Outer Diameter $Ri=\rho.Ro$
With:
Ri= Inner helical blade radius (m), ρ= Optimal radius ratio (m), Ro= Outer helical blade radius (cm).

Table 2: Calculation of Shaft Length.

Ri	ρ	Ro	Result
0.05	0.5358	Ro1	0.0933
0.05	0.5358	Ro2	0.0933
0.05	0.5358	Ro3	0.0933
Average			0.0933

(D) is equivalent to 10 cm, which is then converted to 0.10 m. Using the appropriate formula from the Rorres table, which involves dividing the outer diameter (Ro) by the optimal radian ratio, the average result is 0.0933 m. Therefore, the outer diameter becomes 0.1866 m.

3) Determining the Number of Helical Flights m =L/A
With:
m=Total helical flights, L=Shaft distance (m), A=Pitch Ratio (m).
Total Blade=N=1
Then, m=L/A=0.8086/0.1863=4.36

From the calculation results in determining the threaded blade, the final step is to find the number of blades, specifically 4.34 pieces.

3.2 Water Discharge Measurement Float Method

Measuring water flow using a digital water flow meter or buoy is also known as a way to measure the speed and cross-sectional area of water flow, because in this formula, what is calculated is data on flow speed and cross-sectional area of water flow.

$Q = A \times V$

With:

Q = Water Flow rate, in (m^3/s).

A = Cross-sectional area of the water flow, (m^2). V = Water flow velocity, (m/s).

Data on water flow speed can be obtained through measurement techniques involving the use of meters and floats. In this approach, the speed of water flow is measured by placing a buoy on the surface of the river, then recording the time (t) and distance (d) traveled by the buoy in meters and seconds. The water flow speed is calculated using the formula:

$v = c.(s/t)$ With:

v = Velocity (m)

s = Distance (m)

t = Time (s)

c = Correction factor, 0.75 or 0.95

Table 3: Measurement of cross-sectional area.

Point	Depth (m)	Width Point (m)	Cross-sectional area (m^2)
1	0.36	0.66	0.24
2	0.53	0.68	0.36
3	0.21	0.69	0.14
Average		1.09	

From the table, the cross-sectional area is 1.09 m^2 and it can be seen that point 2 has a large depth, width and cross-sectional area of the Cilember waterfall, while point 3 has a small depth, width and cross-sectional area.

Table 4: River Velocity Measurement.

No	Measurement point	Time (s)	Velocity (m/s)	Average Velocity (m/s)
1	1	1.79	0.56	0.61
	2	1.75	0.57	
	3	1.45	0.69	
2	1	1.64	0.61	0.62
	2	1.72	0.58	
	3	1.54	0.65	
3	1	1.59	0.63	0.63
	2	1.52	0.66	
	3	1.67	0.60	
Average				0.62

From the calculations presented in the table above, the average Cilember current speed is 0.62 m/s. In the Cilember waterfall speed measurement table above, it can be compared that the highest travel time occurs at point 1 of the 1st measurement, while the highest current speed occurs at point 1st measurement to 3rd.

Table 5: River Flow Rate Measurement.

No	Cross-sectional area (m^2)	Average flow velocity (m/s)	River flow rate (m^3/s)
1	0.24	0.61	0.15
2	0.36	0.62	0.22
3	0.14	0.63	0.09
Average			0.46

From the calculation graph above, the average Cilember river water discharge is 0.46 m3/s. In the table above it can be compared that the highest cross-sectional area is at point 2, the highest average speed is at point 3, and the highest river water discharge is at point 2. This indicates that point 2 has the highest variables in carrying out measurements and calculations on the Cilember river, Bogor.

3.3 PLTMH Electrical Power Potential

The potential electrical power from a PLTMH depends on the water flow, height and maximum efficiency of the water turbine. Therefore, the following is the calculation of Turbine Power (Pt):

Pt=ρ x g x Q x Hn x η With:

ρ = 1000 kg/m^3 g = 9,8 m/s^2

Q = 0,46 m^3/s=460 li H = 88%

Hn = 0.36 m

Pt = ρ x g x Q x Hn x η

Pt = 1000 x 9,8 x 0.36 x 88% = 8624 (W)

3.4 Design and Calculation Results

Based on the data that has been taken, after the data has been processed for the purposes of modeling the Archimedes screw turbine, the results can be presented in the table below:

Table 6: Archimedes Screw Specifications.

No	Calculation	Result
1	Shaft Length	0.8086 m
2	Inner Diameter	0.10 m
3	Outer Diameter	0.1886 m
4	Number of Threads	4.34
5	Thread Pitch	0.1863 m
6	Electrical Power Potential	8624 W

From the following table, it can be seen that the screw turbine design results produce a blade that uses one blade, is capable of flowing a water flow of 460 liters/s, has a blade angle of 24°, and a turbine tilt of 25°. then create a 3D shape using SolidWorks software, followed by static load testing to evaluate its magnitude.

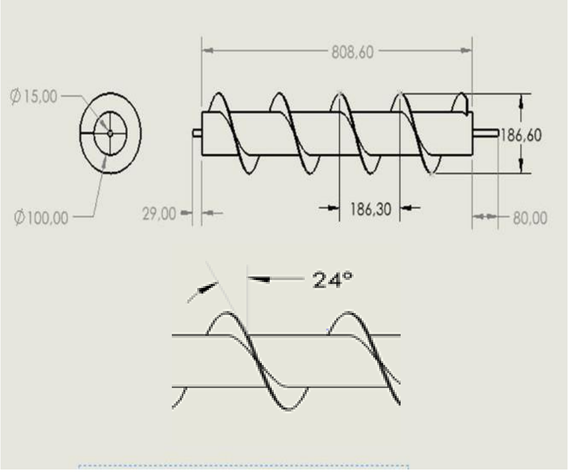


Figure 1: 2D Design of Archimedes Screw.

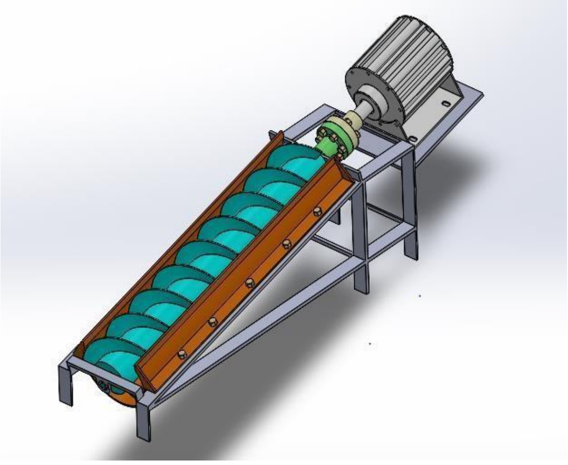


Figure 2: 3D Design of Archimedes Screw Turbine.

3.5 Test Simulation Steps

Parameters that lead to valuable constraints determine the shape and geometry of the turbine. Specifically, the test simulation stages using SolidWorks are:

1) The first step is to run the SolidWorks application using the shortcut provided. Once the application opens, then select the design file to be analyzed which can be accessed via the "File" menu or using the shortcut CTRL + O.
2) After opening the file, hover over the "SOLIDWORKS Add-Ins" view and select "SOLIDWORKS Simulation" until the "Simulation" menu appears to the right of the "SOLIDWORKS Add-Ins" view. The simulation display in question is shown by a cursor, as previously explained. This menu will appear once the "SOLIDWORKS Add-Ins" option is selected.
3) After the "Simulation" display opens, the cursor is directed to the top left. Select the "Study Advisor" display then 2 new menus will appear below it, to start the simulation, select the "New Study" menu.
4) After opening "New Study", then select the type of material that will be used in the simulation process. This step can be taken by selecting the "Apply Material" view. In this component, the material used is AISI 304, select the right material for testing by hovering the cursor over the desired material, then select the "Apply" button.
5) There are several indicators that must be

used, the first is determining the geometric position. Design analysis begins with determining the geometry or footing when the analysis is carried out. This footing functions as a reference point for static loading where at this point it is a fixed point or not affected by force. You do this by selecting the "Fixtures Advisor" view then selecting the "Fixed Geometry" menu.

6) After selecting the "Fixed Geometry" view, a menu will appear as seen below. Here, we can select the point on the workpiece that will be set as a geometry or reference point by selecting the "External Load Advisor" option, then selecting the type of load that will be applied and analyzed using SolidWorks. This loading is applied by selecting an area in the workpiece design.
7) Before starting the simulation testing process, it is necessary to determine the size of the "Mesh" or elements to be used. The way to adjust the size of the elements is to select the "Run This Study" view, then a new submenu will appear, particularly "Create Mesh". As you go to the right, the element size will become smaller, resulting in a more detailed analysis even though the computational process will take longer. After the mesh or element size is determined, a display will appear on the workpiece showing the shape of the element and its size.
8) Once the mesh size has been determined, the simulation object is ready to undergo design analysis. The cursor is directed back to the "Run This Study" display, then two new submenus appear, select "Run This Study". Automatically, the program will start the computing process.
9) After the computing process is complete, the analysis results will be displayed on the display. There are three display options available in this analysis process, stress, displacement or deformation, and strain. To produce the desired display, select one of the three displays, then right click and set the display via the "Chart Options" menu, then order it to display the results by clicking the "Show" menu.

3.6 Simulation Result

The static loading simulation that is carried out applies input in the form of strength or load force. The results of the simulation produce output in the form of the magnitude and distribution of stress and strain on the screw.

3.6.1 Stress Test Analysis on Blade Screw

Stress distribution functions to predict the extent to which a material can withstand the load imposed by that material. Materials are said to begin to experience permanent deformation when the impact stress reaches a known limit value, specifically yield strength.

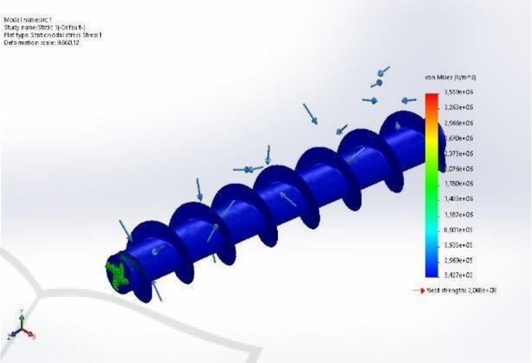


Figure 3: Stress Distribution.

In the 3D simulation with Solidworks 2022, the maximum stress that occurs is obtained, the points can be seen from the simulation results, there is a color change from solid blue to green to yellow, which indicates that the maximum stress occurs in the Archimedes Screw Turbine runner as in Figure 4.23, which is 3.59 x 106 N/m2, with a yield strength of 2.06 x 106 N/m2, shows that the AISI 304 Stainless Steel material is safe for use in the blue area with 73379 nodes examined.

3.6.2 Strain Test Analysis on Blade Screw

Strain is the increase in the length of an object relative to its initial length caused by an external force affecting the object. Strain can also be interpreted as a measure of dimensional changes that occur due to stress. Strain is part of the change in shape which describes the relative change of particles in an object that does not have conservation properties in its shape. In Figure 4.24, the strain distribution can be seen which indicates that there are large strains, especially in the screw area adjacent to the generator.

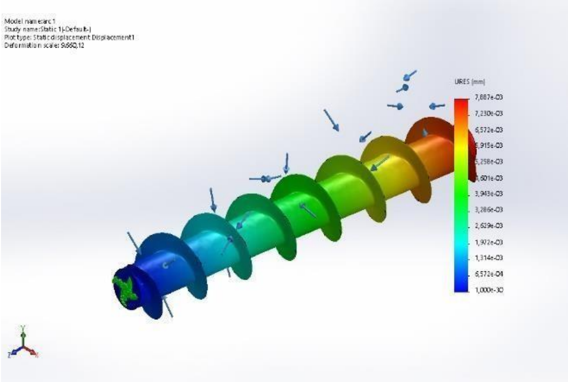


Figure 4: Strain Distribution.

From the simulation above, it is found that there is a maximum stretch at the water entry point area of the screw above with a maximum deflection of 7.88x10-3 mm at the 38871 node points of the elements examined.

4 CONCLUSIONS

After trying a simulation of the test analysis and design of an Archimedes screw turbine, it can be concluded that:

1) Based on the measurement results, the cross-sectional area of the Cilember River is

   1.09 m2 and the measured discharge is Q=0.46 m^3/s

2) The electricity potential of the river is P_t=8,624 kW.

3) Based on static simulation results, stress analysis, the maximum stress that occurs on the blade screw is 3.59 x 106 N/m2, with a yield strength of 2.06 x 106 N/m2, and AISI 304 Stainless Steel is safe to use.

4) Based on the static simulation results, the maximum deflection analysis that occurs in the runner is 7.88x10-3 mm at the 38871 node points of the elements examined.

This research can be further developed by employing more advanced research methods. The author suggests that in future studies, more simulations should be conducted on different materials to optimize the screw turbine material.

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