

ANALYSIS OF THE EFFECT OF PENSTOCK DIAMETER ON HYDROCOIL TURBINE PERFORMANCE IN SUKAJAYA VILLAGE, LEMBANG DISTRICT, WEST JAVA

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Abstract-- The turbine used in this study is a reaction turbine called hydrocoil turbine. In hydrocoil turbines require penstock pipe components to support turbine performance, the size of the penstock pipe has its own potential. Errors in determining the diameter of the penstock can affect the performance of hydrocoil turbines. The purpose of this study is to perform penstock comparison using ansys with a diameter of 6 inches, 8 inches and 10 inches and determine the diameter of the penstock to get the best hydrocoil turbine performance. This study was conducted using Computational fluid dynamics (CFD) method which includes torque, turbine power, and efficiency, the results of the analysis of the calculation of the highest torque value obtained by the 10-inch penstock at 150 rpm rotation of 398.51 Nm, and the torque value obtained by the 8-inch penstock at 150 rpm rotation of 282.47 Nm, the lowest torque value obtained by the 6-inch penstock at 950 rpm rotation of 51,061 Nm. Then the highest power value obtained by the 10-inch penstock at 950 rpm rotation of 27279.53 Watts and the power obtained by the 8-inch penstock at 950 rpm rotation of 21861.41 Watts, the lowest power obtained by the 6-inch penstock at 950 rpm rotation of 5077.16 Watts. So that the highest efficiency value obtained by 10-inch penstock at 950 rpm rotation of 90.58% and the efficiency value obtained by 8-inch penstock at 950 rpm rotation of 72.59 %, the lowest efficiency value obtained by 6-inch penstock at 950 rpm rotation of 16.85 %. It can be concluded from the values already obtained, penstock with a diameter of 10 inches has the highest value to get the best turbine performance, followed by penstock diameter of 8 inches has the highest value Number 2 and penstock with a size of 6 inches has the lowest value, proven by the speed varied according to the diameter of the penstock and constant discharge indicates that the larger the diameter of the penstock will produce the best turbine performance.

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1. INTRODUCTION

A water turbine is a device for converting the potential energy of water into mechanical energy. This mechanical energy is then converted into electrical energy by a generator. Water turbines were developed in the 19th century and were used extensively for electric power generation. the working principle of turbines in converting water potential energy into kinetic energy, water turbines are divided into two groups, namely impulse turbines and reaction turbines [8]

This research is a prototype design of a Pico hydropower plant. The Pico hydro laboratory scale is planned to be installed at the water outlet at the steam gas power plant (PLTGU) in Cilegon, whose water discharge has not been utilized. Pico hydro will produce green energy, which in turn can partially replace fossil energy needs. The effect of water discharge and the number of blades on the power generated by Pico hydro [1]

Water energy is the most widely used renewable energy source worldwide because it accounts for less than 20% of the world's electrical power from large and small power plants, among the potential

renewable energy resources, energy from water to meet electricity needs (hydropower) has the highest appeal because it is clean, cheap and environmentally friendly operation [2].

To overcome the problem of the condition of the region and the availability of supply of electrical resources for the community, it is necessary to search for alternative electrical energy supply to replace the services of the PLN, one of the alternative sources of electrical energy is to utilize mechanical power from water resources that are widely available in the area, To utilize the mechanical resources of the water is to build a small-scale power plant facilities in accordance with the conditions of topographic / geographical areas such as the construction of MicroHydro power plants [3]. The development of MicroHydro hydroelectric power plant is an alternative to help the community in the provision of electrical energy, MicroHydro is a small-scale water energy utilization plant that is below 5 kW, but the construction of PLTMH is not always run straight and can be utilized well by the local community. A very classic reason is the lack of water discharge so that it is not able to produce large power from the PLTMH so that it becomes one of the reasons for the cessation of PLTMH operations [4].

A turbine that is smaller than a MicroHydro turbine is a hydrocoil turbine. Hydrocoil turbine is also known as helical drive power generator because the turbine has a blade shaped helical coil, hydrocoil turbine is able to work at low head and flow rate. In hydrocoil turbines require components that are penstock pipes to support turbine performance, the size of the penstock pipe has its own potential level. Errors in the determination of penstock diameter can affect the performance of hydrocoil turbine [5].

Thus, in this study focused on the analysis of the rapid pipe (penstock), Penstock is a pipe that serves to drain water from the tranquilizer tank (forebay tank) to the powerhouse. Rapid pipeline planning includes material selection, penstock diameter, thickness and type of connection (coordination point). The Material for the penstock pipe uses PVC pipes, and the diameter of the penstock pipe is determined based on the flow rate that will flow on the penstock pipe where in determining the diameter of the penstock pipe, several things are considered, namely security, ease of manufacturing process, material availability, the minimum possible level of loss from the penstock pipe, where pipe that have a [6]

the test was simulated using a DC motor whose rotation was adjusted to the turbine which reached 245 rpm. With the calculation and simulation of microhydro power plant is able to produce a voltage of 45 V and the power obtained is based on the calculation of 66.4 W and the overall efficiency of 21.4% [7]

A water turbine is a device for converting the potential energy of water into mechanical energy. This mechanical energy is then converted into electrical energy by a generator. Water turbines were developed in the 19th century and were used extensively for electric power generation. the working principle of turbines in converting water potential energy into kinetic energy, water turbines are divided into two groups, namely impulse turbines and reaction turbines [8]

Hydrocoil turbines in experimental prototypes have been designed, built and tested. The turbine includes a 4-inch acrylic with a ribbon-like curved insert, which presents a gradual curve of about 70 degrees from the axial flow of water continuing to a tightly curved angle perpendicular to the flow of water at the exit point. It thus demonstrates the promising potential of Hydrocoil technology to extract power from incoming water flow in Low head sources [9]

Rapid pipe (penstock) is a pipe that serves to drain water from the tranquilizer tub (forebay tank) to the powerhouse (powerhouse). Rapid pipeline planning includes material selection, penstock diameter, thickness and type of connection (coordination point). Rapid pipe Diameter is selected with consideration of safety, ease of manufacturing process, material availability and the level of losses (friction losses) to a minimum. The thickness of the penstock is chosen to withstand the hydraulic pressure and surge pressure that can occur [10]

CFD simulation is currently widely used as one of the research methods in the development of alternative natural ventilation design this is because CFD simulation is relatively cheaper and the conditions of limitation of research objects are easily controlled, CFD media simulate fluid motion based on a condition by using the basics of calculation of moving fluid. CFD simulation can predict in detail the movement of wind (moving fluid) around the object of research, both inside and outside the building. stating that the Large Eddy Simulation (LES) is a CFD model that has the best accuracy compared to other CFD models for the case of building research objects. Moreover, CFD analysis results are easy to understand [11]

CFD is a technique of analyzing systems involving fluid flow, in general the calculation process for fluid flow is solved by using the equation of energy, momentum and continuity, in general the calculation process for fluid flow is solved by using the equation of energy, momentum and continuity. The equation used is the Navier-Stokes equation, this equation was discovered by G.G. Stokes in English and M. Navier in France around the early 1800s [12]

2. RESEARCH METHODS

In this study, Computational Fluid Dynamics (CFD) method using Solidwork 2018 and ANSYS 2019 R2 software using Asus Notebook a407u laptop with Intel Core i3-6006U CPU specifications, 2.0 GHz. In this simulation using CFX model, Geometry used hydrocoil turbine mounted penstock. This simulation uses water fluid with penstock diameter $1'$.

2.1 Tools Used

In the hydrocoil & penstock turbine simulation, be sure to need tools and materials to support the success of the following are the tools and materials used:

1. Computer

The computer acts as a medium to run Solidworks software so that it can be used in making designs and simulations. To run CFD software a computer has sufficient specifications, in this study using the following specifications:

- Asus *Notebook A407U* CPU Intel *Core i3-6006U*, 2.0GHz
- Random Access Memory (RAM) 4GB.
- System type 64-bit.

2. Software Solidworks 2018

In making the design of penstock variations using solidworks 2018 software which is a special application for designing and can be simulated to meet engineering needs. In making the design is made as well as possible, to reduce errors that can occur in hydrocoil turbines. In the manufacture of penstock design is made as well as possible in order to improve the performance of hydrocoil turbines. So at this stage the selection of design using reverse engineering methods with consideration of variations in the diameter of the best penstock .

Here is the penstock design:

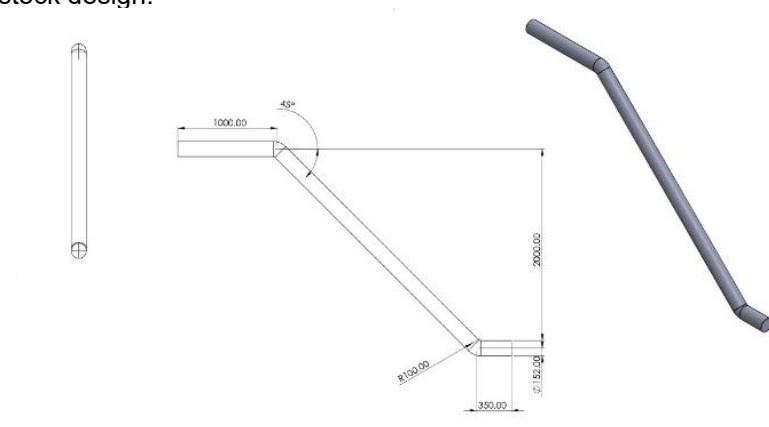


Figure 1. Penstock Design Software Solidworks 2018

3. Software CFD

In the simulation design variation of this study using Computational Fluid Dynamics (CFD) and the software used is ansys 2019 R2. At the design simulation stage at ansys, the solidworks file is changed to the IGES file type for the import geometry stage at ansys 2019 R2, the simulation process has five successive stages, namely the Geometry stage, the Meshing stage, the Setup stage, the Solution stage, and the Result stage. Here is the penstock in ansys simulation:

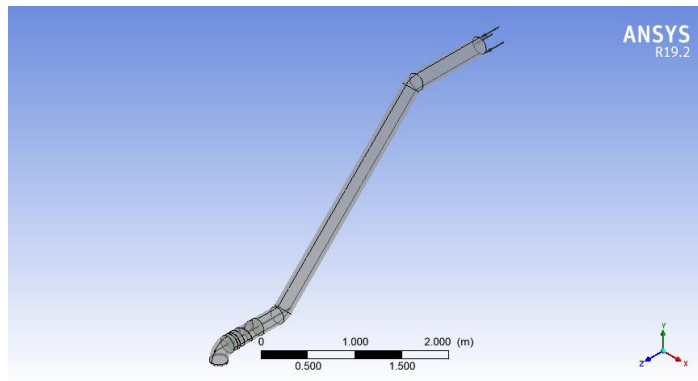


Figure 2. Penstock simulation using CFD

2.2 Simulation Stage

Simulation design using Computational Fluid Dynamics (CFD) and the software used is ansys 2019 R2. At the design simulation stage at ansys, the solidworks file is changed to the IGES file type for the import geometry stage at ansys 2019 R2, the simulation process has five successive stages, namely the Geometry stage, the Meshing stage, the Setup stage, the Solution stage, and the Result stage the simulation stage can be explained as follows:

1. Geometry Stage

When opening ansys CFX, the first stage is done by opening the geometry stage, the first stage is to import the design into geometry that has been created in Solidwork software in the form of IGES format to Ansys geometry 2019 R2 worksheet, after importing the design then need to define the stator and rotor parts. The Stator is the part of the turbine that is stationary while the rotor is the part of the turbine that rotates. The next step is to define the area that is completely filled with water with boolean menu and subtract. Boolean and subtract processes to reduce or eliminate water – filled areas such as turbine blades and turbine shafts.

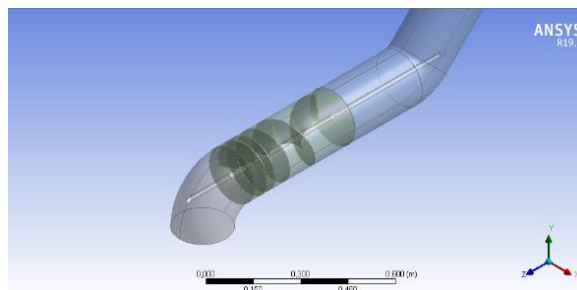


Figure 3. Geometry stage

2. Meshing Stage

Meshing is a stage for dividing an object into smaller parts. The smaller the meshing is made then the calculation results will be more precise but will require greater computing power. At this stage the selection and arrangement of meshing strategy or enumeration of objects. Meshing results obtained at this stage will be used as a reference calculation in the next stage. Steps that need to be done at this stage are setting the meshing size, meshing smoothness level, and meshing method, meshing results, methods used to check mesh quality and mesh success directly using mesh quality metrics available at ansys, the most commonly used metric is skewness, there is literature from ansys that provides useful guidelines and recommendations for mesh metrics including skewness, low quality mesh quality recommendations or high skewness values that are not recommended, generally try to keep the quality skewness value minimum >0.1 and maximum <0.95

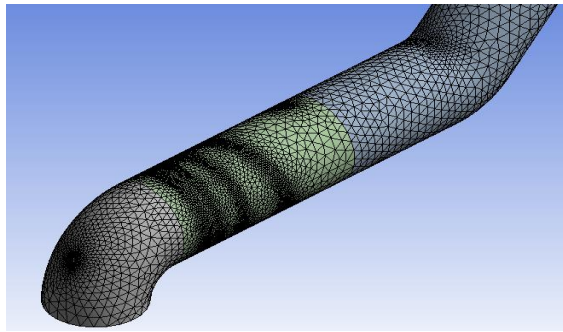


Figure 4. Meshing Stage

3. Setup Stage

Setup stage is a stage to set the analysis in the form of steady state, create the required domain, set the boundary condition, and create an interface. By continuing to set rotating and stationary which rotating is a rotating domain and stationary is a stationary domain, a stationary domain such as the penstock and drafttube domains while rotating domains such as rotating zones or rotating areas, then continue to set the rotation speed in the rotating area in the rotating domain. In this study the rotational speed is varied from 150-950 rpm, then the turbulence method used is Shear Stress Transport because it refers to the number of nodes and elements formed in the meshing process.

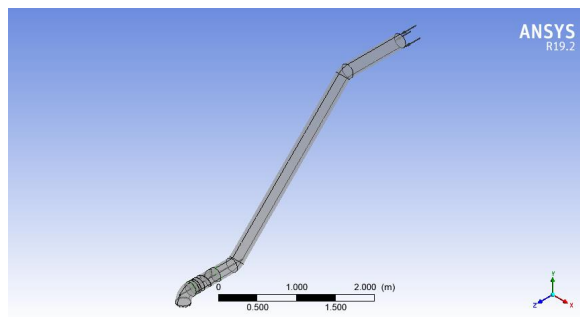
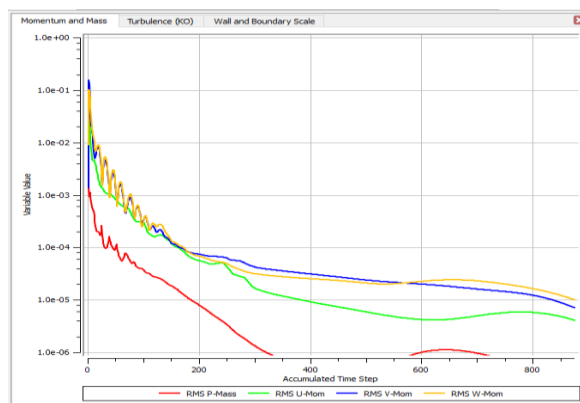


Figure 5. Setup Stage

4. Stage Solution

This solution stage is the stage of numerical calculation by computer. At the solution stage, the equations entered in the CFD simulation will be solved iteratively until they reach the convergent condition. The level of accuracy of the solution stage is determined by several factors such as the accuracy of the boundary conditions, meshing, and numerical error. At this stage the step taken is to start the running process by clicking run calculation or calculate. In this process requires sufficient time until the level of iteration that has been determined is 10000 iterations.



Gambar 6. Stage Solution

5. Stage Result

At the result stage we will obtain the results of the CFD simulation that has been carried out. To see the simulation results at this stage can be by displaying the results of the calculation of torque, contour water

pressure, contour water velocity, streamline, vector. The results of this stage we need to test the level of accuracy by comparing with other literature.

3. RESULTS AND DISCUSSION

Simulation results discussed about determining the diameter of the penstock to get the best hydrocoil turbine performance and Penstock comparison using ansys with a diameter of 6 inches, 8 inches and 10 inches.

3.1. CFD analysis

CFD is a technique of analyzing systems involving fluid flow, in general the calculation process for fluid flow, according to the purpose of this study is to compare the penstock pipe with a size of 6 inches, 8 inches and 10 inches, to get the most optimal turbine performance. Then the step is to do the calculation and find the total pressure value, the value of mass flow rate and potential power.

1. Calculation Of Total Pressure

The total pressure of a point in the pipe is related to the static pressure of that point and the velocity of the water flow passing through that point, the total pressure can be calculated using Equation (2.11), the total pressure value is the result of the sum of the static pressure value and also the dynamic pressure. These values will be used as input values at the inlet pipe during the Computational fluid dynamics (CFD) simulation process, here are the formulas and calculation results:

a. Penstock 6 inci

$$P_{Tot} = P_{Stat} + \frac{1}{2} \rho v^2$$

$$P_{Tot} = (998.2 \times 9.81 \times 0.2) + \left(\frac{1}{2} \times 998.2 \times 10.4^2\right)$$

$$P_{Tot} = 55941.12 \text{ Pa}$$

b. Penstock 8 inci

$$P_{Tot} = P_{Stat} + \frac{1}{2} \rho v^2$$

$$P_{Tot} = (998.2 \times 9.81 \times 0.2) + \left(\frac{1}{2} \times 998.2 \times 5.87^2\right)$$

$$P_{Tot} = 19155.9 \text{ Pa}$$

c. Penstock 10 inci

$$P_{Tot} = P_{Stat} + \frac{1}{2} \rho v^2$$

$$P_{Tot} = (998.2 \times 9.81 \times 0.2) + \left(\frac{1}{2} \times 998.2 \times 3.76^2\right)$$

$$P_{Tot} = 9014.54 \text{ Pa}$$

2. Calculation Of Future Flow Rate

After obtaining the total pressure value which will be used at the input value at the inlet then proceed to find the input value at the outlet (mass flow rate), the calculation of the mass flow rate can be calculated by equation (2.13) the value of the mass flow rate will be used as the input value at the penstock outlet during the:

a. 6 inch Penstock mass flow rate

$$\dot{m}_1 = \rho \cdot V \cdot A$$

$$\dot{m}_1 = (998.2 \times 10.4 \times 0.018)$$

$$\dot{m}_1 = 186.86 \text{ kg/s}$$

- b. 8 inch Penstock mass flow rate

$$\dot{m}_2 = \rho \cdot V \cdot A$$

$$\dot{m}_2 = (998.2 \times 5.87 \times 0.032)$$

$$\dot{m}_2 = 187.5 \text{ kg/s}$$

- c. 10 inch Penstock mass flow rate

$$\dot{m}_3 = \rho \cdot V \cdot A$$

$$\dot{m}_3 = (998.2 \times 3.76 \times 0.050)$$

$$\dot{m}_3 = 210.1 \text{ kg/s}$$

3. Potential Power

Calculation of potential power can be calculated using Equation (2.9) calculation of potential power required to calculate the value of the efficiency of the turbine as shown in equation (2.9) this calculation will be divided by the resulting turbine power to obtain the value of turbine efficiency.

$$P_h = \rho \cdot g \cdot Q \cdot H_{eff}$$

$$P_h = (998.2 \times 9.8 \times 1.184 \times 2.6)$$

$$P_h = 30114.01 \text{ watt}$$

3.2. Cfd Thought 6 inci, 8 inci, 10 inci

1. 6 inch Penstock simulation

In Figure 7 (a) is the result of contour velocity, in Figure 7(b) is the result of pressure, and in Figure 7(c) is the result of streamline.

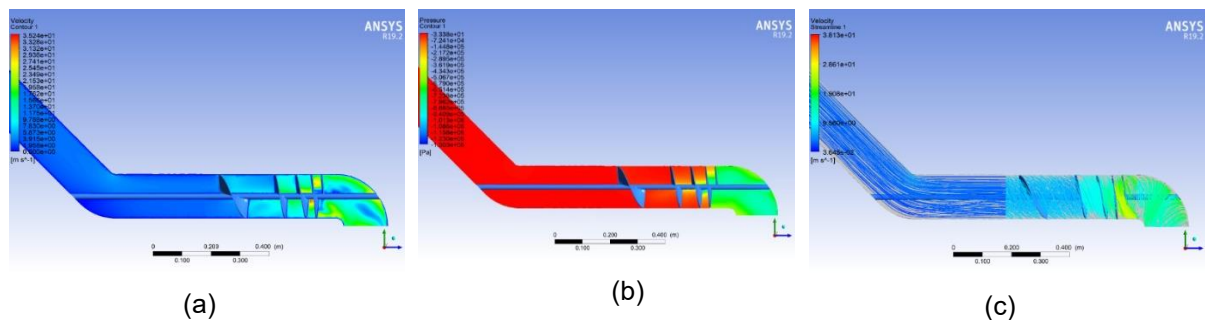


Figure 7. Figure (a) contour Speed, (b) pressure, (c) streamline.

2. 8 inch Penstock simulation

In Figure 8 (a) is the result of contour velocity, in Figure 8(b) is the result of pressure, and in Figure 8(c) is the result of streamline.

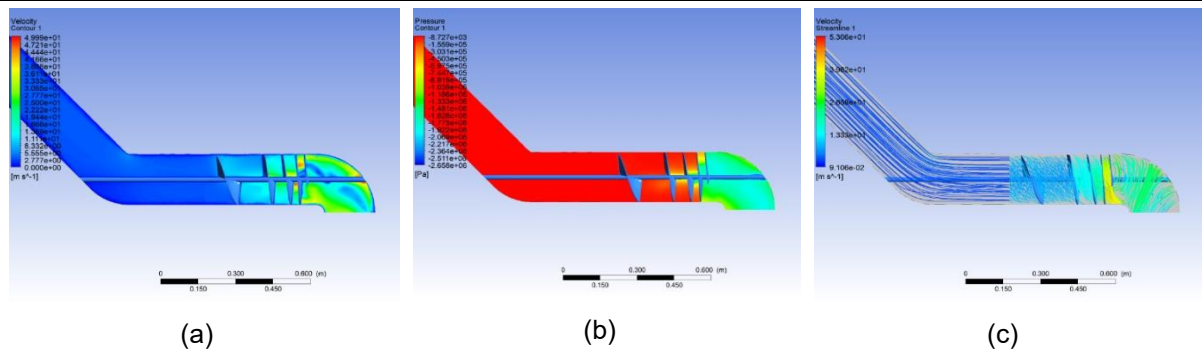
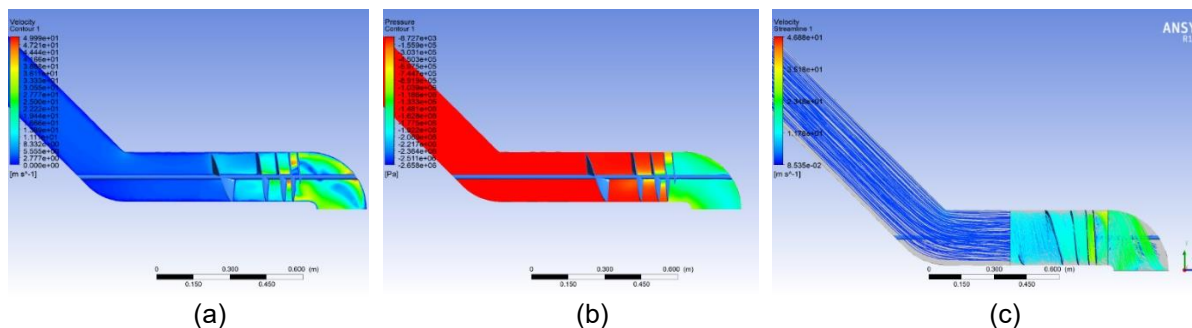


Figure 8. Figure (a) contour Speed, (b) pressure, (c) streamline.

3. 10 inch Penstock simulation

In Figure 9 (a) is the result of contour velocity, in Figure 9(b) is the result of pressure, and in Figure 9(c) is the result of streamline.



Picture 9. Figure (a) contour Speed, (b) pressure, (c) streamline.

3.3. Results Of Performance Analysis On Turbine

Turbine performance analysis to be able to see the results of the turbine efficiency of the PLTMH, but in finding the turbine efficiency is needed to find the torque that can be found in Ansys CFX at the result stage by means of a calculator menu that can be used to calculate the torque value at each variation in the specified rotational speed. Then after getting the results of the torque to find the turbine power using the results of torque multiplied by the angular velocity (7) using Equation (2.11). After obtaining the results of the turbine power to obtain the efficiency of the turbine power value divided by the hydraulic power of the turbine and multiplied by 100% as in equation (2.12). The performance of the turbine on a 6-inch penstock can be seen in the following:

In the calculation of turbine performance on 6inch penstock, the largest torque is obtained at a rotational speed of 150 rpm with a result of 74.394 Nm, then the largest turbine power is obtained at a rotational speed of 950 rpm with a turbine power value of 5077.16 Watts and the largest turbine efficiency is obtained at a rotational speed of 950 rpm with an efficiency value of 16.85%.

In the calculation of turbine performance on 8inch penstock, the largest torque is obtained at a rotational speed of 150 rpm with a result of 282.47 Nm, then the largest turbine power is obtained at a rotational speed of 950 rpm with a turbine power value of 21861.41 Watts and the largest turbine efficiency is obtained at a rotational speed of 950 rpm with an efficiency value of 72.59 %.

In the calculation of turbine performance on 10inch penstock, the largest torque is obtained at a rotational speed of 150 rpm with a result of 398.51 Nm, then the largest turbine power is obtained at a rotational speed of 950 rpm with a turbine power value of 27279.53 Watts and the largest turbine efficiency is obtained at a rotational speed of 950 rpm with an efficiency value of 90.58 %.

1. Torque

At the result stage there is a function calculator menu that can be used to calculate the torque value at each variation in the specified rotational speed. Torque values in each variation can be seen below:

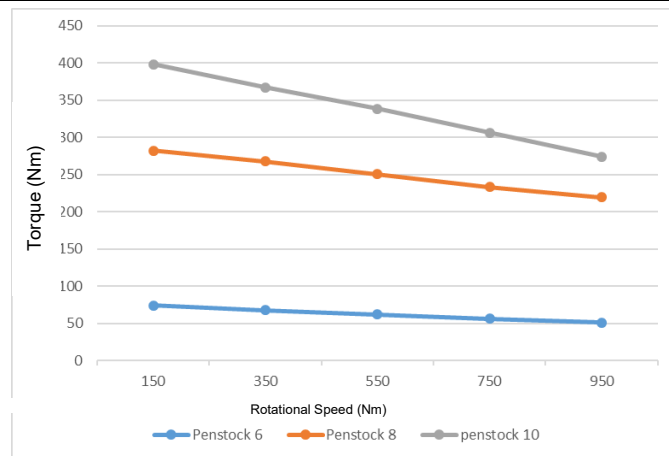


Figure 10. Graph of Rotational Speed To Torque On Each Penstock

Picture 10. the highest torque value is obtained by a 10-inch penstock at 150 rpm. And the lowest torque value is obtained by a 6-inch penstock at 950 rpm. In this case shows that the smaller the rotational speed, the greater the torque generated.

2. Turbine Power

The value of power in each variation is calculated using Equation (2.11) by multiplying the torque value obtained by the angular velocity (ω) at each rotational speed. The complete turbine power value can be seen in the following figure:

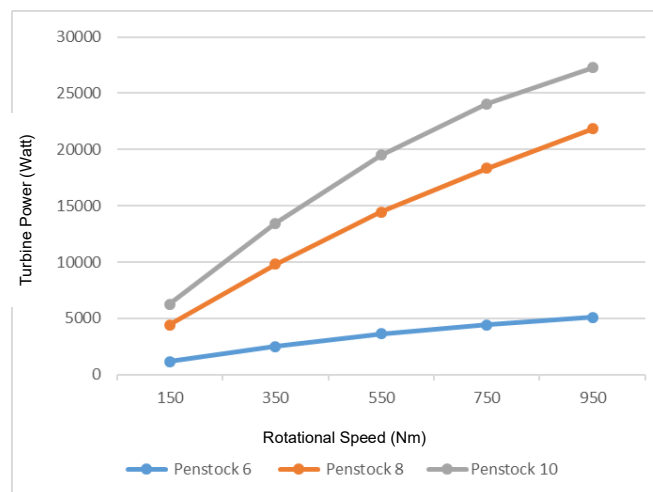
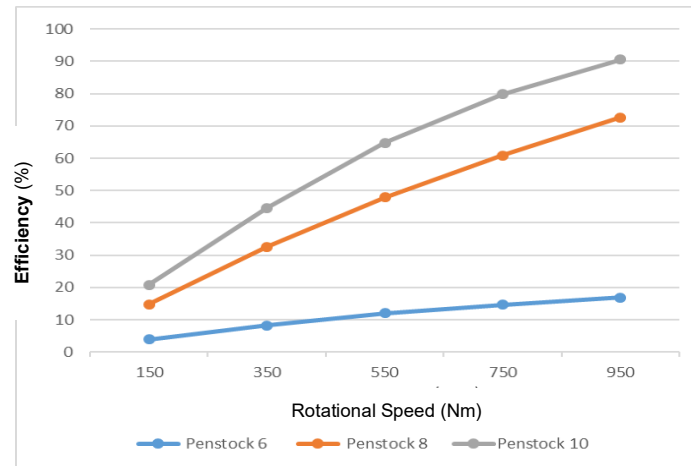


Figure 11. Graph Of Rotational Speed Against Turbine Power At Each Penstock

From Figure 11. the highest power value is obtained by a 10-inch penstock at 950 rpm. and the lowest power is obtained by a 6-inch penstock at 150 rpm. In this case shows the greater the rotational speed, the greater the power generated.

3. Turbine Efficiency

The value of efficiency in each variation is calculated using the equation (2.19) is by dividing the turbine power that has been calculated with the hydraulic power of water and then multiplied by the value of 100%.



Picture 12. Graph Of Spin Speed To Efficiency On Each Penstock

From Figure 12. the highest efficiency value is obtained by a 10-inch penstock at 950 rpm. and the lowest power is obtained by a 6-inch penstock at 150 rpm. In this case shows the greater the rotational speed, the greater the efficiency produced.

4. CONCLUSION

Based on the purpose of research in sub chapter 1.3 perform Penstock comparison using ansys with a diameter of 6 inches, 8 inches and 10 inches and determine the size of the penstock diameter for hydrocoil turbine to get the best performance it can be concluded as follows:

1. After the hydrocoil turbine performance analysis with variations in the size of the penstock pipe using computational fluid dynamics method which includes torque, turbine power, and efficiency, the results of the analysis of the calculation of the highest torque value obtained by the 10-inch penstock at 150 rpm rotation of 398.51 Nm, and the torque value obtained by the 8-inch penstock at 150 rpm rotation of 282.47 Nm, the lowest torque value obtained by the 6-inch penstock at 950 rpm rotation of 51,061 Nm. Then the highest power value obtained by the 10-inch penstock at 950 rpm rotation of 27279.53 Watts and the power obtained by the 8-inch penstock at 950 rpm rotation of 21861.41 Watts, the lowest power obtained by the 6-inch penstock at 950 rpm rotation of 5077.16 Watts. So that the highest efficiency value obtained by the 10-inch penstock at 950 rpm rotation of 90.58% and the efficiency value obtained by the 8-inch penstock at 950 rpm rotation of 72.59 %, the lowest efficiency value obtained by the 6-inch penstock at 950 rpm rotation of 16.85 %.
2. So from the values that have been obtained and analyzed in determining the diameter of the penstock on hydrocoil turbine using computational fluid dynamics method to get the best turbine performance from the diameter of the penstock 6 inches, penstock 8 inches and penstock 10 inches which includes the value of torque, turbine power and efficiency, it can be concluded from the values already obtained, penstock with a diameter of 10 inches has the highest value to get the best turbine performance, continued penstock diameter size 8 inches has the highest value Number 2 and penstock with a size of 6 inches has the lowest value, proven by the speed varied in accordance with the diameter of the penstock and the constant discharge indicates that the larger the diameter of the penstock it will produce the best turbine performance.

REFERENCES

- [1] A. W. Biantoro, Iskendar, Subekti, and N. H. bin M. Noor, "The Effects of Water Debit and Number of Blades on the Power Generated of Prototype Turbines Propeller as Renewable Electricity," *J. Rekayasa Mesin*, vol. 12, no. 1, pp. 203–215, 2021.
- [2] B. Novianto, "Rancang Bangun Low Head Turbin Piko Hidro," *J. Saints dan Teknol.*, vol. 10, no. 01, 2020, [Online]. Available: <https://unsada.e-journal.id/jst/article/view/79>.
- [3] I. Hanggara and H. Irvani, "Potensi PLTMH (Pembangkit Listrik Tenaga Mikro Hidro) Di Kecamatan Ngantang Kabupaten Malang Jawa Timur," *J. Reka Buana*, vol. 2, no. (2), pp. 149–155, 2017.

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- [4] A. Akbar, Taupan, "Analisa Pengaruh Ketinggian Dan Debit Air Terhadap Output Energi Listrik `Yang Dihasilkan Pada Pembangkit Mikrohidro (PLTMH) Desa Girikerto," *Tek. Elektri Univ. Islam Indones.*, 2018.
 - [5] A. A. Luthfie, "Analisis Pengaruh Perubahan Pipa Siphon Terhadap Performasi Turbin Hydro coil Dengan Menggunakan Metode (CFD)," *J. Tek. Mesin*, vol. Vol. 06, no. No. 1, p. 41, 2017, [Online]. Available: <https://publikasi.mercubuana.ac.id/index.php/jtm/article/view/1336>.
 - [6] A. D. Pratama, E. W. Hidayah, and U. A. Retno, "Desain Determinasi Optimum Penstock Untuk Pembangkit Listrik MikroHidro Di Sungai Poreng, Jember," *J. Tek. Pengair.*, vol. Vol 12, no. (1), pp. 71–80, 2021.
 - [7] M. Syukri, "Pembangkit Listrik Tenaga Piko Hydro Dengan Menggunakan Turbin Ulir," *J. Komputer,Informasi Teknol. dan Elektro*, vol. Vol 2, no. No 1, 2017, [Online]. Available: <http://www.jurnal.unsyiah.ac.id/kitektro/article/view/6757>.
 - [8] D. Marsudi, "Pembangkit Energi Listrik," vol. vol 7, no. no1, pp. 4–31, 2016.
 - [9] A. Aprilliyanto, Indarto, and Prajitno, "Design Of A Prototype Hydro Coil Turbine Applied As Micro Hydro Solution," *ASEAN J. Syst. Eng.*, vol. 1, no. 2, pp. 72–76, 2013, [Online]. Available: <https://core.ac.uk/download/pdf/291675957.pdf>.
 - [10] N. Ma, ali, "Perencanaan Pembangkit Listrik Tenaga Mikro Hidro (PLTMH) Kepung Kabupaten Kediri," 2017.
 - [11] S. Maulana, "Pemanfaatan Computational Fluid Dynamics (CFD) Dalam Strategi Penelitian Simulasi MOD," *J. Educ. Build.*, vol. 2, no. 2, pp. 10–13, 2016.
 - [12] J. Cengel, Yunus A Cimbala, *Fluid Mechanics: Fundamental And Application*. 2006.