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Analysis of Pressure Drop in Axial Turbine: Case Study of Discharge Line

Marco Sachio[1], Abrar Riza[2]*, Didi Widya Utama[3]*
Department of Mechanical Engineering
Universitas Tarumanagara Jakarta, Indonesia

Abstract:- Axial turbine is a very unique turbine, that has been used by water plantation (PLTA) in Indonesia, which can be found as many as 162 units of the water plantation per 2021. Axial turbine usually uses natural energy from water flowing, especially waterfall. The energy that is extracted from the waterfall is the potential energy of the water flowing down. Those energy is the source of power for this turbine to rotate, and through the rotating shaft, mechanical energy will be formed. In this paper, the output of an axial turbine will be analyzed, and the main variable for analyzing will be pressure drop towards the mechanical energy created by axial turbine on a lab scale. Tests will be carried out on a laboratory at Universitas Tarumanagara (UNTAR) for data to analyze.

***Keywords**:- Natural Energy, Mechanical energy, Pressure Drop.*

I. INTRODUCTION

In this world, every human has a undeniable dependence on electricity, where it can be seen everything that human does, almost all has a reliance on electricity. Even the gradually advancing technology, requires a big demand of electricity. But looking at this high demand, we can assume as well it's a high cost project for the advancing of technology. As of now, electricity as well still mainly depended on fossil fuel as main energy source for plantations, which is going to be a scarce fuel soon and unrecyclable source of energy.

This dependence on electricity certainly will increase the demand for electricity, which arises to the next problem, which is the cost. If electricity costs too much, it will certainly become a huge economic deficit problem in the country, especially which country are very into advancing on technology. Therefore, a source of electrical energy with a cheap and adequate method is sought. Currently, the most dominant power plant in Indonesia in generating electricity are none other than a diesel power plant, which contributes as much as 60% of Indonesia demands on electricity [1]. To even further prove that, there are a total of 5,258 units per 2021 diesel power plant, compared to water plantation in Indonesia, which only recorded 162 units per 2021 [2]. These diesel power plants uses fuel from limited natural resources, which will one day run out, whilst water plantation uses natural resources, such as waterfalls, which flow from high to low altitude, and cultivates the potential energy as useful energy like mechanical energy through the help of axial turbines. The rotation of the turbine will be converted into energy that humans use daily [3].

The identification applied axial turbine problem is to understand how Pressure Drop (ΔP) causes a fluctuating results on the output mechanical energy by axial turbine. Approaches to these variables are done by first setting up which variable will be the dependent and independent variable. By doing this, we can find the *trend* and relation between these varied variables in order to understand how these variables at the end affects the output mechanical energy created by axial turbine.

The purpose of the research applied in these tests are to analyze the mechanical energy created from the axial turbine rotation against the Pressure Drop (ΔP) that has been created along the path of the water flow. These tests will be carried out starting from the water pump that is powered by a motor, and go along the path that has been set until it reaches the axial turbine. Tests will be done with variety of valve openings, which to understand as well the relation between Head Loss (H) against ΔP and mechanical energy. [4].

The benefits obtained from conducting research in the form of testing in this experiment are divided into two, which are theoretical benefits and practical benefits. The theoretical benefits with this experiment are encouraged more of open minded about the Axial turbine, where its application is often found in hydropower plantations. Then for the practical benefits, divided into 2, which first practical benefits are for author which obtained a deeper understanding of the subject as explorations of Axial turbine done, and second practical benefits are for Universitas Tarumanagara (UNTAR), in the form of researching done on Axial turbin in UNTAR, which can potentially increase electricity efficiency through analyzing and deeper understanding efficiency by Pressure Drop (ΔP).

II. RESEARCH METHODOLOGY

A. Axial Turbine

Axial turbine used to do the analysis is located inside a laboratory in Universitas Tarumanagara (UNTAR). This turbine system is circulated, which is most likely, that the obtained results of Head Loss (h_L) and pressure drop (ΔP) The picture are shown below.

Fig. 1: Axial Turbine

The specifications of the Axial turbine are shown at the table below, table 1.

Table 1: Axial Turbine Specifications

Parameter	**Description**
Diameter of turbine (De)	0,14 m
Radius of turbine (re)	0,07 m
Diameter of hub (Di)	0,07 m
Radius of hub (Ri)	0,035 m

B. Motor & Pump

Motor and pump that is used as source of energy water flow inside pipes and to contact with the turbine to rotate axial turbine. For motor, specifications are stated below, table 2.

Table 2: Motor Specifications

Parameter	**Description**
Torque at 50 Hz	2,4 kg.m
Rotation	120-1200 rpm
Speed Generator 60 Hz	1500 rpm

As for the pump, it is an End Suction Head Pump, and it has only the information of Head, which is 150m.

C. Variables

First variable is the flowrate of water, where can be found at venturimeter, the first apparatus for measuring. Venturimeter has two different cross-sectional area and are connected to a manometer, with the mercury placed inside a U-tube, as a measuring medium. Specifications are stated in below, table iii.

Table 3: Venturimeter Specifications

Parameter	Description
Diameter of venturimeter (D1)	0,1217 m
Diameter of throat (D2)	0,075 m
Coefficient of discharge (Cd)	0,95-0,98
The cross-sectional area of venturimeter (A1)	0,0116324 m2
The cross-sectional area of the throat (A2)	0,00442 m2

Next variable is the torque, which is measured by a torquemeter, that is mechanically connected to the shaft of the axial turbine. Torque will be used to find out how much output of the mechanical power that have been created.

The setup of the Axial turbine from the discharge or starting from pump, towards the turbine (shown in red circle) is as such shown in Figure 2.

Fig. 2: Valves and Turbine Location

Head Loss Total (h_{LT}) in this analysis are divided into two, which is Head Loss Major (h_L) and Head Loss Minor (h_{LM}).

For Head Loss Major (h_l), value comes from friction with inner surface of pipe, which material of the pipe is PVC. As for the value of Head Loss Major, it is fluctuating due to equation for this variable directly connected to flowrate of water (Q). Equation of Head Loss Major as shown below: [6]

$$h_{L\,major} = f\frac{l}{D}\frac{v^2}{2g} \quad \text{...... (1)}$$

For Head Loss Minor (h_{LM}), it is divided into three parts, which is turns, valve (shown in green circle on Figure 2), and from venturimeter itself. Equation of h_{LM} is shown below:[6]

$$h_{L\,minor} = K\frac{v^2}{2g} \quad \text{...... (2)}$$

For turns, there are total of 6 turns, which on every turn, the Loss Coefficient (K_L) value is 0.3 [6].

For venturimeter, h_{LM} is found by the manometer with mercury as measurement, which directly shows the value of Δh, and $\Delta h = h_{LM}$.

Final part are valves. Butterfly valves are used on this setup. Value of K for butterfly varies between

The valves are the most important variable. Every data and graphs that are obtained, will be done with different varieties of valve openings. There are one valve variety, and two valve variety at most.

On one variety opening of valves, there will be two different opening, which is ¾ valve opened and ½ valve opened. Whilst on two variety opening of valves, there will be two different variables of opening as well, which ¾ & ¾ opened, and ½ & ¾ opened.

Tests will be done on five different n (rpm), which varies such as 700 rpm, 800 rpm, 900 rpm, 1000 rpm, and 1100 rpm. Measurement of these varibles are going to be done with tachometer. [7]

III. RESULTS AND DISCUSSION

Before finding results, we must first understand the relation of different variables theoretically, and also act as a proof of correction to our graphic trend. Relation shown by first equations to see how the relations between variables are. From there on, connections are understood and we can take a conclusion by using theory and graphic trend as a base data.

Before obtaining the final equation for flowrate of water (Q), we need to start deriving from the Bernoulli Principle. Bernoulli Principle states that the higher the velocity is, the lower pressure is. Bernoulli Principle starts with pressure from start or intake, with the addition of pressure from kinetic energy and potential energy and equals to pressure from output, with the same addition but from output. Equations of Bernoulli Principle can be stated as below:[6]

$$p_1 + \frac{1}{2}\rho {v_1}^2 + \rho g h_1 = p_2 + \frac{1}{2}\rho {v_2}^2 + \rho g h_2 \quad \text{...... (3)}$$

From this Bernoulli Equation, using the continuity equation, which is the product of cross-sectional area with velocity of water, an equation for finding flowrate of water (Q) from venturimeter is obtained.

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$$Q = A.v \quad (4)$$

$$Q = CA_T\sqrt{\frac{2(p_1 - p_2)}{\rho_{raksa}(1-\beta^4)}} \quad (5)$$

Pressure drop (ΔP) has a correlation as well towards Head Loss (H).

$$\Delta P = \gamma.H \quad (6)$$

As shown on Equation 6, we can conclude that when ΔP has a higher value, H will also increase, which can be said that the two variable has a directly proportional relation. [8]

After the theoretical understanding part, plotting in graphs will be the next step. Data that are obtained through the measuring devices on the Axial turbine setup has been obtained, and there will be a total of 3 graphs with 4 different variables. First graph will be Q-ΔP, which we will directly understands the correlation of proportional between the two variables. Second will be P_m-ΔP, which P_m is the mechanical energy obtained through rotating shaft of Axial Turbine, which graph will be studied for its trend. Then it will be followed directly with ΔP_m-ΔP, where in this particular graph, it will be seen directly how a variety of valve openings may affect the loss in P_m by using the difference between normal full opened valve data against variety of choosing.

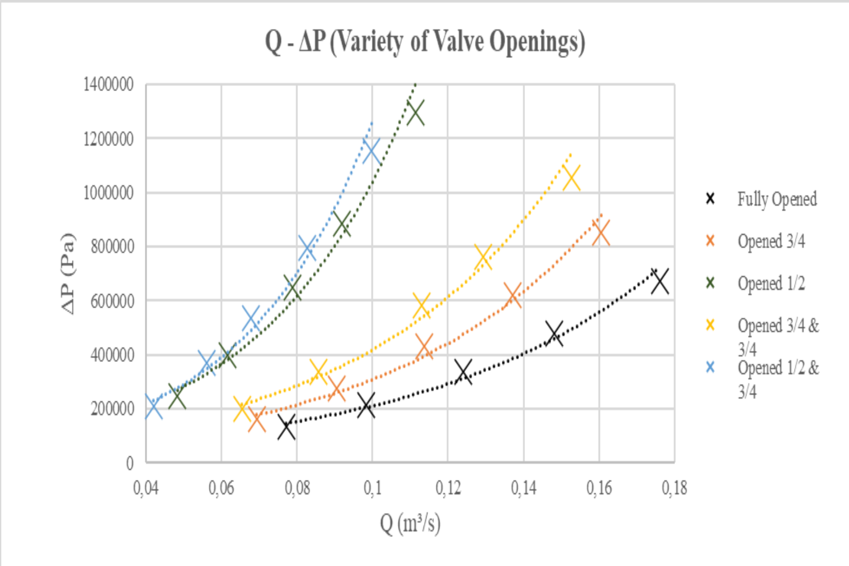

Fig. 3: Q-ΔP Graph

As seen in Figure 3, that the overall trend shown by Q-ΔP is inversely proportional if seen by highest point of each valve openings. This has also been proven theoretically from the derivation of the equations that have been done. As the valve opening gets smaller, it can be seen that the ΔP value on the graph gets higher for a smaller range of Q values, which proves next point correct, which is ΔP being directly proportional towards h_L.

In comparison, it can be seen first from the fully opened value, where the highest value of Q, around 0.176 m³/s has a ΔP value of 671 KPa. For this highest ΔP value increases as the valve opening is smaller, where it can be seen that the valve opening ¾ has a ΔP value of 850 KPa, and this value increases by 26.7% from the fully opened state of ΔP. As for the ½ valve opening, it has the highest ΔP value of 1296 KPa, where the value increases by 87.18% despite having the highest value of Q which is lower than the highest value of Q fully opened valve.

Next is the comparison with the two valve opening variation, where it can be seen from the highest value of ΔP for opening variations ¾ and ¾, that the highest value of ΔP is 1055 KPa, where it can be said that the highest ΔP value increased by 57.23% from the initial data, and it can be said that the increase in ΔP is lower than the one valve opening variation of ½. Next is the variation of opening two valves ½ and ¾, where the highest ΔP value is 1155 KPa. This value increased from the full opening result by 72.13%.

After the relationship of Q and ΔP have been concluded, another trend comparison will be made to find the power efficiency against the pressure drop that occurs.

The performance of the turbine system will be obtained through the application of valve opening variations in the form of mechanical power (P_m). From the application of this valve opening variation, the relationship between ΔP will be obtained as the value increases and shows the results of changes that occur to the P_m generated due to turbine rotation which produces torque.

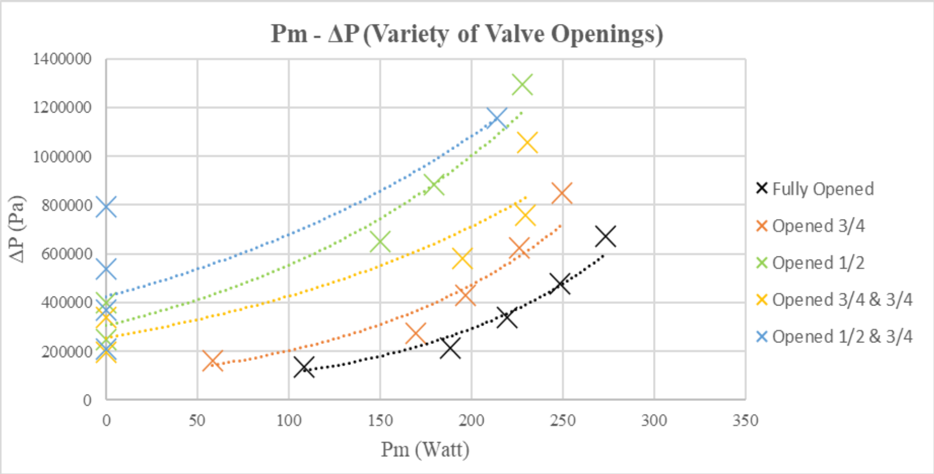

Fig. 4: P_m-ΔP Graph

It is shown in Figure 4, that the comparison of the variable P_m against ΔP. In the graph, a curve is formed which shows that the higher the ΔP value obtained, the lower the P_m value obtained by looking at the highest point per valve openings. It can be said that the relationship between ΔP and P_m is inversely proportional, and also, it can be concluded that the higher RPM is, the higher P_m obtained, as well as higher ΔP created. It can be concluded as well that h_L is inversely proportional towards P_m, as shown on graph that power are gradually dropping in output as openings are getting smaller.

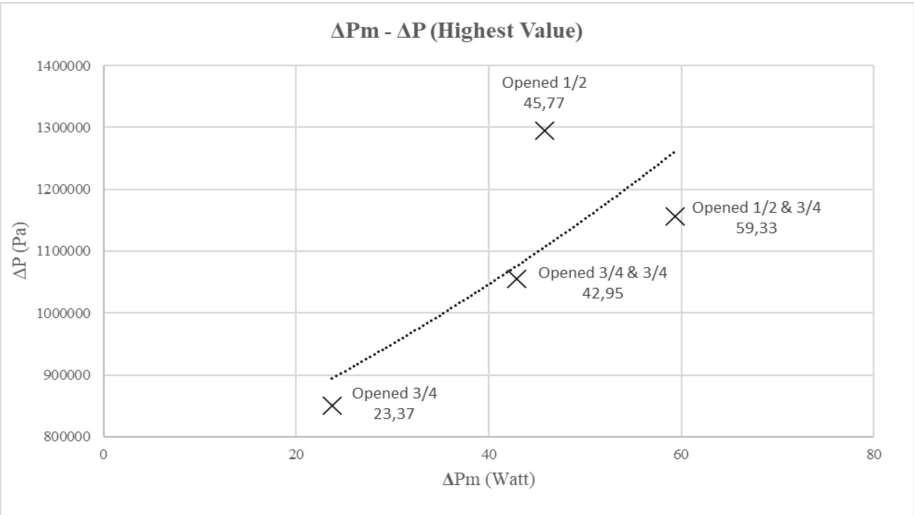

Fig. 5: ΔP_m-ΔP Graph

Comparison done between the highest value of P_m at fully opened valve against the variation of one valve opening shows a decrease in value, whereas the greater the head loss due to the inhibited valve opening, there is a decrease in the value of P_m obtained for each equalized ΔP value. It can be seen that the highest P_m obtained is as high as 273.5W, whilst valve opening ¾ it is only 249.8W, which decreases by 23.37W or 8.67%. For valve opening ½, highest P_m value stands at 227.7W and this decreases by 45.77W or 16.75% from the initial data.

Next is the comparison of the initial data with the variation of two valve openings with the highest value of P_m. It can be seen that the value of the valve opening variation ¾ and ¾ that the highest P_m value of 230.6W, where this decreases by 42.95W or 15.69%, and this decrease is still a lower compared to the decrease in value from the variation of one valve opening ½. Meanwhile, for valve openings ½ & ¾, the P_m value obtained is 214.2W, where it decreases by 59.33W or 21.69%.

IV. CONCLUSION

Overall, based on the highest value for the variation of one valve opening for the comparison of Q-ΔP with the highest value of ΔP, it can be seen that the increase in the value of ΔP increased by 26.7% when changing the opening to ¾, and ΔP increased by around 60% when changing the valve opening ½ of the opening ¾, where the value of ΔP increased by 87.12% from the initial condition. As for the comparison between the highest value of P_m in the ΔP-P_m graph, it can be seen that the decrease in value from the variation of one valve opening ¾ is 8.67%, and decreases by another 8% when changing the valve opening to ½, which decreases by 16.75% from the initial data.

In terms of two valve variations for the comparison of Q-ΔP with the highest value, it can be seen that the drastic increase in the variation of valve openings ¾ and ¾, where it has increased by 57.23%, and not a very high rise when changing to opening variation of ½ and ¾, which is around 15% of the variation of valve openings ¾ and ¾, and 72.13% from the initial data. As for the comparison between the highest value of P_m in the ΔP-P_m graph, it was found that the decrease in value from the variation of the two valve openings ¾ & ¾, that the highest value of P_m decreases by 15.69%, which results on another decrease of 6% when the valve opening was changed to ½ & ¾, which decreased by 21.69% from the initial data.

Despite opening valve ½ sounded like a smaller loss compared to opening valve ¾ & ¾, the variation of valve with opening ¾ and ¾ has a lower ΔP than the variation of one valve with opening ½ when tested on Q-ΔP graph, which can also be concluded that the variation of one valve opening ½ has a higher head loss.

It can be concluded that based on the trends that have been seen, Q has an inversely proportional relationship with ΔP. Not only towards Q, ΔP also has a inversely proportional relationship with the results of P_m. There is also an important note, which as motor rpm (n) increases, all the other data increases as well, which can be said in a sense that the higher the rpm of motor, the higher the P_m obtained, despite having a higher losses due to higher Q value. However, every time there is a change in the valve opening, especially in the obstructed valve opening, the values of ΔP gradually increases, while as for Q and P_m gradually decreases. This means that it can be said that the h_L due to valve opening has an inversely proportional result to Q, and P_m, while being directly proportional to ΔP.

REFERENCES

[1.] H. Ardiansyah and H. Ardiansyah, "Hydropower Technology: Potential, Challenges, and the Future," 2022, doi: 10.55981/brin.562.c6.

[2.] "Ini Jenis Pembangkit Listrik PLN Paling Banyak pada 2021." https://databoks.katadata.co.id/datapublish/2022/03/31/ini-jenis-pembangkit-listrik-pln-paling-banyak-pada-2021

[3.] R. Saputra and T. Liichan, "Perancangan Ulang Turbin Kaplan Poros Vertikal Di Pltm Plumbungan," Bina Teknika, vol. 14, no. 2, p. 153, 2018, doi: 10.54378/bt.v14i2.354.

[4.] S. Anwar Syahputra, A. Panjaitan, S. Raja Kel Sei Raj Kec Sei Tualang Raso -Tanjungbalai, and P. Studi Teknik Mesin Politeknik Tanjungbalai Sei Raja Kel Sei Raj Kec Sei Tualang Raso -Tanjungbalai, "PENGARUH DEBIT ALIRAN TERHADAP HEAD LOSSES PADA VARIASI JENIS BELOKAN PIPA."

[5.] Buana Surabaya, "Major and Minor Head Losses Analysis on The Piping System in Pondok Pesantren Tahfizhul Qur'an Ibnu Abbas Tarakan".

[6.] R. Pere, "Fundamentals of Fluid Mechanics 7th Edition - Munson.". Available: https://www.academia.edu/50575798/Fundamentals_of_Fluid_Mechanics_7th_Edition_Munson

[7.] "Jual Tachometer - Jenis, Cara Kerja dan Contoh Tachometer Terbaik - LFC." https://www.lfc.co.id/blog/detail/tachometer.

[8.] "Understanding The Relationship Between Flow And Pressure | Atlas Scientific." https://atlas-scientific.com/blog/relationship-between-flow-and-pressure/ .