Development of Testing Equipment of Gravitational Water Vortex Turbine to Support Implementation the Laboratory Work

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Abstract

Mechanical Engineering Department, University of Lampung has been established since 1998 and in the implementation of learning process at this departmen supported by ten laboratories, that is: Laboratory of CNC, Laboratory of Drafting, Laboratory of Materials, Laboratory of Manufactured, Laboratory of Computer, Laboratory of Industry Metrology, Laboratory of Structural Mechanics, Laboratory of Thermodynamics, Laboratory of Fluid Mechanics, and Laboratory of Combustion Engine. These laboratories are used as research means for the lecturers and the students and also for the implementation of the subject of available laboratory work in the curriculum of Mechanical Engineering Department, University of Lampung, One of the subjects of laboratory work is machine performance, where this laboratory work is carried out in three laboratories, that is Laboratory of Thermodynamics, Laboratory of Fluid mechanics, and Laboratory of Combustion Engine. The testing equipments are available until now, namely, vapour compression refrigeration system, Pelton turbine, and combustion engine, and these testing equipments need for the addition to support this laboratory work. However the funding from university is very limited. Therefore addition testing equipment must be developed. In this paper development of a testing equipment of gravitational water vortex turbine model is presented to be used for laboratory work in Mechanical Engineering Department, University of Lampung.

Keywords: Hydraulic Turbine, vortexTurbine, Low Head, Laboratory Work

1. Introduction

The Department of Mechanical Engineering is one of the departments located in the Faculty of Engineering, University of Lampung, and this department was established in 1988 with supporting fund from EEDP and HEDS-Project, especially in development of human resources, laboratories, physical buildings and learning process and office facilities. The goal of establishing of this Mechanical Engineering Department is:

1. To develop graduates who have a reasonable, logical and rational mindset with the basic knowledge of Mechanical Engineering to be able to analyze and synthesize machine characteristics.
2. To develop graduates who have the ability to create new solutions, adopt old solutions, and use the knowledge gained in the science of energy conversion, design and construction, materials and manufacturing.
3. To develop graduates who can model and predict the behavior of engineering equipment through the application of scientific and technological principles.

One of the missions to achieve this goal is to carry out an effective and efficient learning process by improving facilities and infrastructure to support the learning process including laboratory equipment.

The learning process carry out at the Mechanical Engineering Department of Faculty of Engineering, University of Lampung is currently supported by 10 laboratories, namely: Laboratory of CNC, Laboratory of Drafting, Laboratory of Materials, Laboratory of Manufactured, Laboratory of Computer, Laboratory of Industry Metrology, Laboratory of Structural Mechanics, Laboratory of Thermodynamics, Laboratory of Fluid Mechanics, and Laboratory of Combustion Engine. These laboratories are used as research facilities for lecturers and students and also for the implementation of laboratory work courses in the curriculum of the Department of Mechanical Engineering, Faculty of Engineering, University of Lampung. One of the laboratory work courses is the laboratory work of machine performance. This laboratory work is carried out so that students are able to determine and measure the performance parameters of energy conversion machines by applying theories that have been obtained in the courses of Fluid Mechanics, Thermodynamics, and Energy Conversion Machines. However, the testing equipment to carry out the laboratory work of machine performance is still lacking, where the testing equipments are available until now, combustion engine, Pelton turbine and Air Conditioning (AC). This is caused by the limited funds provided by the university to supply the testing equipment in the laboratory. So it is necessary to develop additional testing equipment to support implementation of this laboratory work. In this paper is presented the design and development of testing equipment of gravitational water vortex power turbine model to support implementation the laboratory work of machine performance in Mechanical Engineering Department, University of Lampung.

1.1. **Turbine**

Turbine is one of the most important components for vortex flow power generation. The turbine is positioned in the center, aligned with the central outlet of the basin. The turbine is forced by the water power that came from the water vortex. Most of the research has focused on turbine optimization to increase turbine efficiency. Dhakal, et al.[1] proposed that the optimal turbine blade position in a vortex flow power plant is 65% of the vortex peak, because this is the point at which the maximum speed is reached.

Dhakal, et al.[2] also studied three different blades with straight (rectangular blade), angled blade and curved (curved blade) where the blade profile is rectangular and concluded that the curved blade profile is suitable for vortex flow power generation. The results also show that efficiency decrease with an increase in the number of blades because it causes greater distortion in the vortex. Efficiency also decreases with an increase in the blade radius because the water velocity at the radius away from the core is lower [3]). Sritram and Suntivarakorn [4] conducted a study on the effect of the number of blades and baffle plates of a turbine on the efficiency of a free vortex flow turbine. Experiments in the laboratory were carried out to determine the efficiency of free vortex water flow power generation. The number of turbine blades 2 to 7 water was tested to find the most suitable number of blades, and the results showed a turbine with 5 blades was the most suitable because it produced maximum torque when receiving jets of water. Insulation plates are also designed and installed at the top and bottom of the turbine blades. The results showed that the proportion of 50% of the curvature of the area was the most suitable, and the blades installed with the upper and lower insulating plates had the highest efficiency of 43.83%, which was 6.59% higher than without the insulating plates.

Acharya, et al.[5] conducted a simulation to optimize the shape of the motion of a free vortex power plant using a conical basin. In this study, two parameters of the inlet jet angle and the radius of curvature of the turbine blades on torque, power and turbine efficiency were studied. Both parameters were analyzed analytically and verified using 3-d simulation. Their results show that the maximum torque is produced at the angle of the blade inlet of 18^{o}, with a curvature radius of 285 mm, where the torque generated is 0.413 Nm.

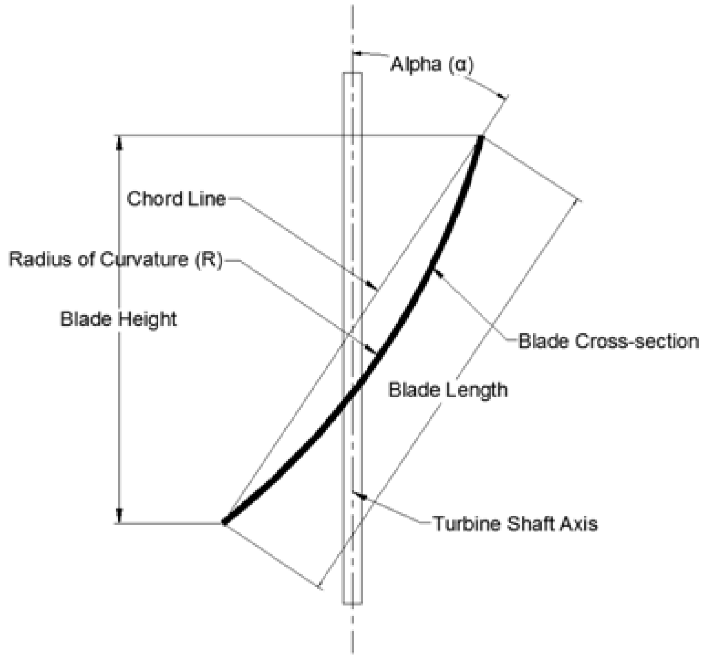


Figure 1. Nomenclature of turbine

2.2 Inlet and Outlet Configurations

For GWVPP, the inlet flow rates are the water that is released into a channel connected to the basin. The channel is responsible to direct the water flow into the basin tangentially. It can be horizontal or slanted at desired angle. The channel width between two ends could be different or the same. One of the study that will be mentioned below also shows that the inlet of GWVPP could be in the form of pipe instead of channel [9]. The inlet height has two meaning, first one deals with the height of water while another one indicate the height of channel from the bottom of the basin. The inlet and outlet parameters are shown in Figure 1.

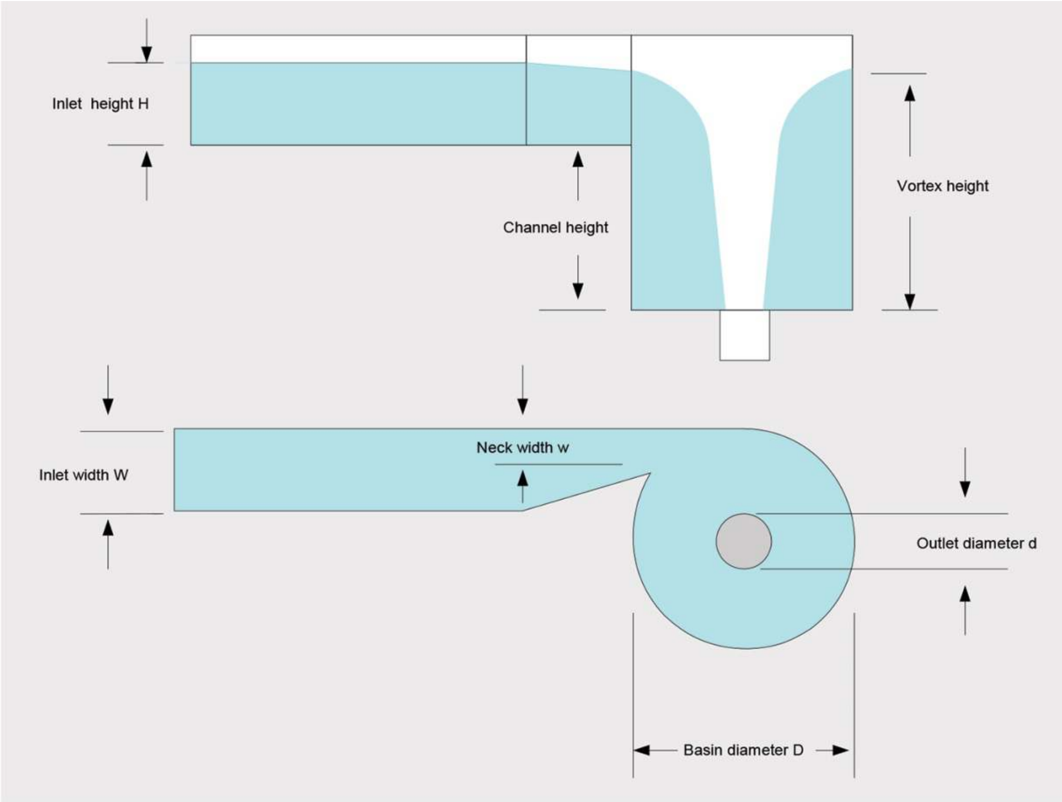


Figure 1. Scheme of gravitational water vortex power plant

Figure 1 shows that the outlet was usually at the centre of the basin and its diameter has significant affect on vortex strength as well as efficiency of vortex turbine [6] [7] [8].

Wanchat et. Al. [6] studied the effects of outlet diameter varied from 0.10m to 0.40m on them efficiency of vortex turbine. The inlet velocity was set at 0.1m/s and the inlet channel was converged at the end which was connected to the basin. A five blades vertical axis turbine was used for electricity generation. It is found that the outlet diameter within the range from 0.20m to 0.35m has significant effect on power generation. The overall efficiency was reported as 30%. Shabara et. al. [7][8] conducted simulation and experimental studies. The GWVPP's $Hchannel$ was zero. The simulation results showed that the outlet speed was inversely proportional to the outlet diameter. For the highest $Hinlet$, the outlet velocity was also maximum, which matched with the experimental results [7][8]. The inlet flow rate has significant effects on efficiency. The efficiency of the vortex turbine is directly proportional to the inlet flow rate and the optimal $Hchannel$ was one-third of the basin's height [9].

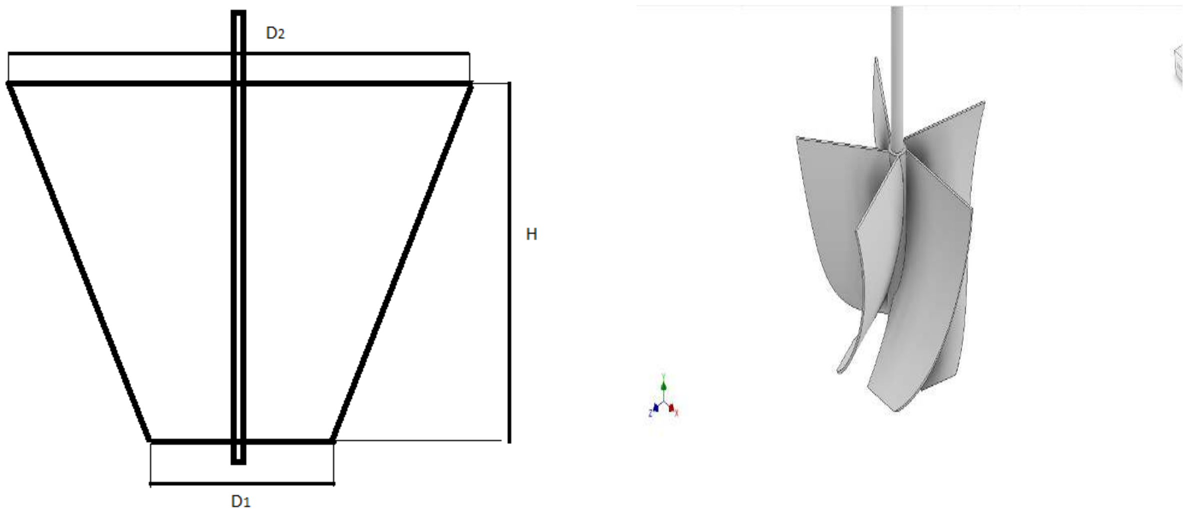
1.3 **Basin Configurations**

Depending on the design of the basin of GWVPP, the vortex profiles created will be different. Wanchat and Suntivarakorn conducted research through simulations with three proposed designs which were 1) cylindrical basin with central outlet, 2) rectangular basin with pre-rotation and 3) cylindrical basin with inlet guide. It was observed that cylindrical basin with inlet guide was the most suitable basin since it provides better and more uniform velocity compared to others [8]. Dhakal et. al. conducted studies with conical basin instead of conventional cylindrical basin. Vortex velocity was measured for different basin diameter, notch angle, notch inlet width (Win), cone angle and canal height ($Hchannel$) and it is found that Win, cone angle and $Hchannel$ have the most significant effects on the vortex velocity. The value of Win was suggested to be as small as possible on the other hand the cone angle and the $Hchannel$ were suggested to be as high as possible to maximize the performance. Notch length (length of inlet channel) is also recommended to be kept as long as possible to prevent unwanted loses [10].

2. Materials and Methods

2.1 Determining Turbine Parameters

The model of designed turbine to be used in the testing equipment is shown in Figure 2. The parameters of turbine to be determined: height of turbine L, diameter of turbine D_1 and D_2, shape of blade, number of blades n, and angle of blade inclination α.



(b)

(a)

Figure 2. (a) Turbine parameters. (b). 3 d drawing of turbine model.

Determining dimensions of the testing equipment system and the parameters of the turbine should consider the Fluid Mechanics Laboratory conditions and the available measurement instruments. The measurement instruments used to execute this laboratory experiment are torque meter to measure the torque of turbine shaft, tacho meter to measure the speed of turbine rotation (rpm) and propeller flow meter to measure the velocity of flow (m/s).

(a) (b) (c)

Figure 3. Photograph of measurement instruments: a. tacho meter, b. torque meter, and c. propeller flow meter

2.2. Construction of Testing Equipment

Scheme of the testing equipment design can be seen in Figure 4. This device transforms kinetic energy derived from low head, to turn a turbine to produces mechanical energy of rotation and whose primary function is to drive a electric generator.

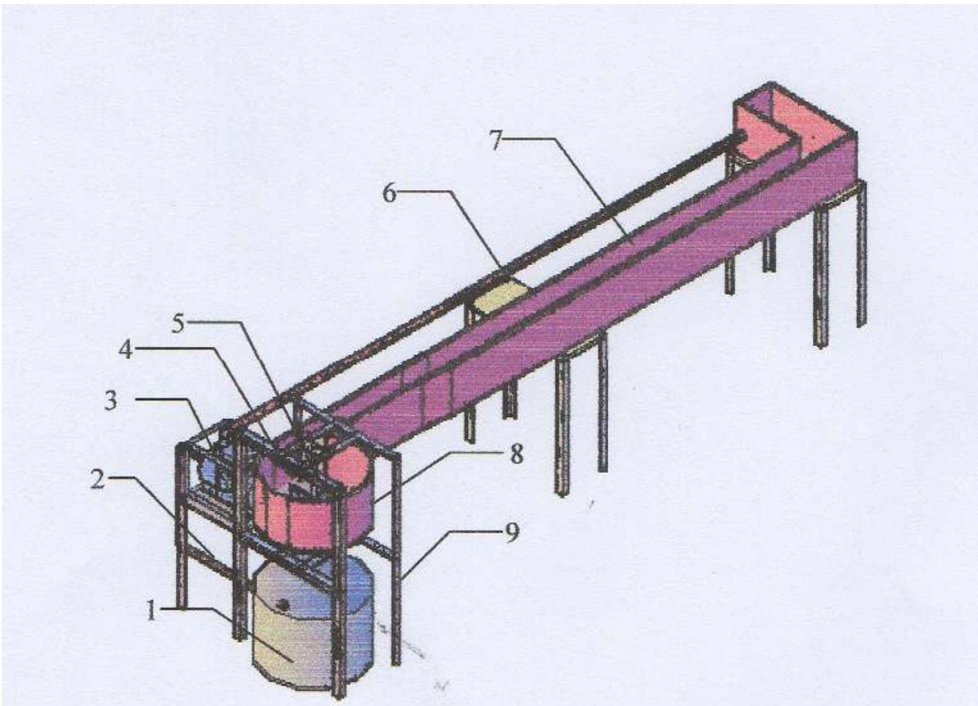


Figure 4. Schematic of testing equipment

Caption:

1. Vortex turbine	2.Torque meter
3. Channel	4. Pump
5. Pipe	6. Tank
7. Reservoir	8. Testing equipment supporting

The efficiency η_t of turbine model can be calculated using the equation:

$$\eta_{sys} = \frac{P_t}{0{,}5 \cdot \rho . A_t . V^3} \qquad (1)$$

Where P_t is power generated by turbine shaft (W), it can be calculated using the Equation 7, ρ is water density (kg/m^3), V is velocity of water flow (m/s), and A_t is cross sectional area of vortex turbine (m^2).

Power of turbine shaft (W), it can be calculated using the Equation:

$$P_t = T\omega \qquad (2)$$

3. Results and discussion.

3.1. Model of Testing Equipment System

According to the conditions of space of the Fluid Mechanics Laboratory, dimensions of thank and cross-sectional area of channel were determined 1 m x 1 m x 1 m and 25 cm x 25 cm respectively. The available head of flow is 1 m to run the experiment. The velocity of flow in channel was measured by propeller flow meter and it can be varied to 1.37 m/s, 1.56 m/s and 2.1 m/s.

Figure 5. System of testing equipment

3.2. Turbine Model

The turbine used uses a rectangular blade profile and it is concluded that the curved blade rofile is suitable for vortex flow power plants [5]. The turbine is positioned in the center, parallel to the outflow at the center of the circulation tank. The optimal turbine blade position in a vortex flow power plant is 65–75% of the overall height of the tank measured from the top of the channel. In this test the position of turbine is 320 mm from the bottom of the tank. The shape and dimensions of the turbine size follow the shape of the cylindrical basin [3] . The turbine heigth of 288 mm, top turbine diameter of 280 mm, and bottom turbine diameter of 100 mm. The inclination of the turbine blades when mounted on the turbine shaft is 18^{o}. Tests were carried out to determine the performance by varying the number of blades from 4 to 6.

Figure 6. Turbine model

3.2 Basin Design

The cylindrical basin with inlet guide was used according to the recommendation of Wanchat and Suntivarakorn and Dhakal et.al. The basin inlet diameter for the conical basin is 600 mm. This is the required diameter of the orifice was calculated to be 100 mm. Optimum vortex strength occurs within the range of orifice diameter to tank diameter ratios (d/D) of 14% - 18% for low and high head sites respectively [3]. For d=100 mm, the ratio is 16 %, which is reasonably close to the value for which the optimum vortex strength occurs.

Figure 7. Cylindrical basin

3.4. Testing Results and Discussion

Figure 9, 10, and 11 are given the testing results of the testing equipment of vortex turbine. From the testing results in Figure 9, the turbine using 5 number of blades give the highest efficiency and shaft power, where this value of efficiency was found 28.03 %. It was better as compare with the using 5 number of blades of turbine. This is due to the operation of turbine using 5 blades produced greater lift forces compared with the 2 number of blades.

Figure 8. Testing of the developed testing equipment

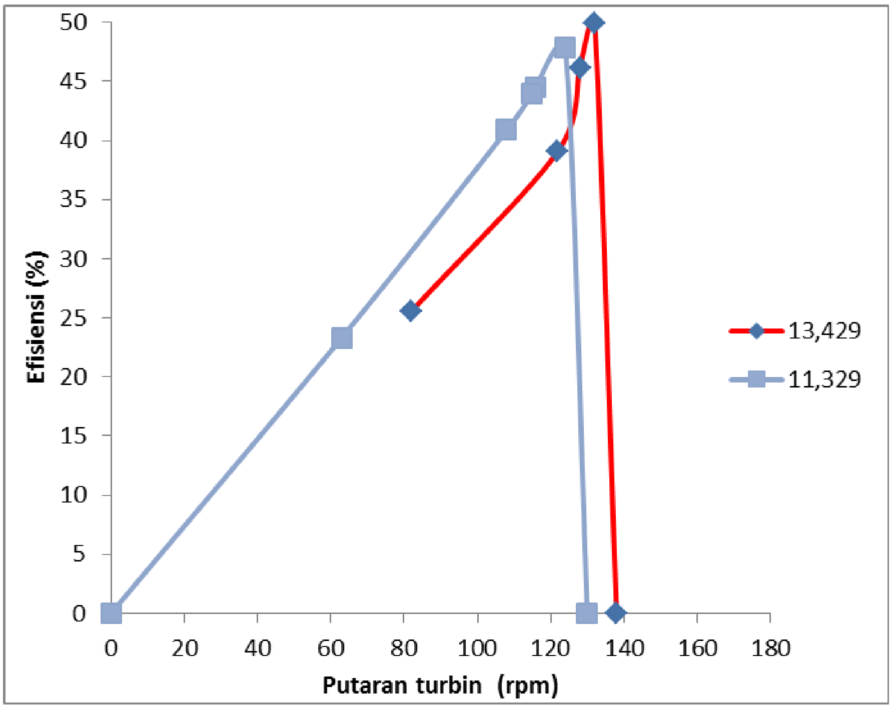


Figure 9. The testing results of vortex turbine using 4 blades

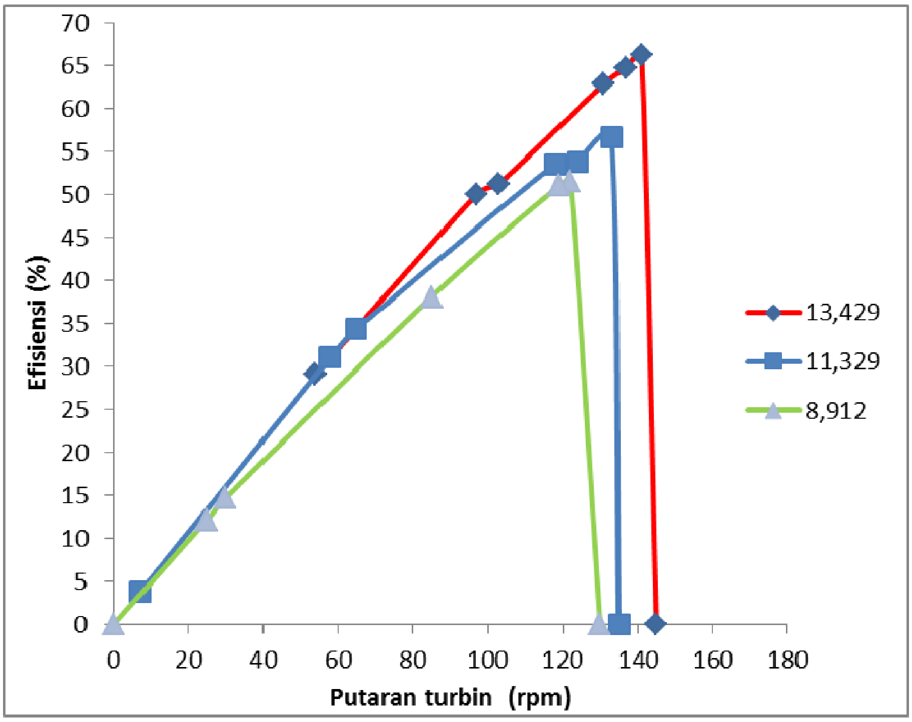


Figure 10. The testing results of vortex turbine using 5 blades

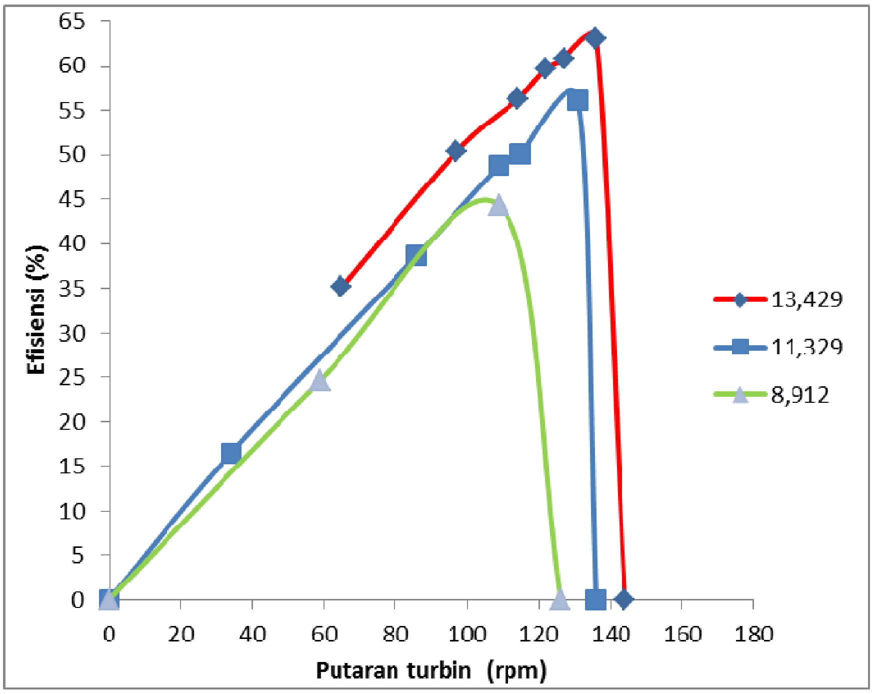


Figure 11. The testing results of vortex turbine using 6 blades

The developed testing equipment of vortex turbine model can perform the performance characteristics of vortex turbine. Using this testing equipment will help the students to understand how the working principle of vortex turbine to convert vortex energy of water flow into mechanical energy. The testing results also show how the number of blades and velocity of flow influence the performance characteristics of vortex turbine. Therefore this testing equipment of vortex turbine model can be used to support implementation the laboratory work at Mechanical Engineering Department. This testing equipment will also help the students who interested in studying the performance of this turbine when it is applied in the system of hydro electric power generation to utilize a low head or stream of water.

4. Conclusions

Based on the results that have been obtained and described earlier, it can be taken some conclusions:

1. In this research is given design method of the testing equipment of vortex turbine model to support implementation the laboratory work of machine performance in Mechanical Engineering Department.
2. The developed testing equipment of low head hydraulic turbine model can perform the performance characteristics of vortex turbine to utilize the stream flow energy which has very low head or only kinetic energy.

3. The test results show the number of blades and velocity of flow influence the performance characteristics of vortex turbine where using 5 number of blades gives the maximum of turbine efficiency of 28.03 %.
4. The course of this laboratory work will provide an opportunity for students to develop their competency in design and execution of laboratory experiments, analysis and interpretation of data use information from the engineering literature including basic concepts from the courses have introduced by the lecturer especially fluid mechanics, energy conversation and fluid machinery subject.

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