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Simulator Performance of a Pelton Type Micro Hydro Power Plant Using Half-Spherical Profile Bucket

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ABSTRACT

Simulator of Pelton type micro hydro power plant is a laboratory facility owned by Department of Mechanical Engineering of Mayasari Bakti University. This facility is used for development research in energy conversion. The research focuses on performance simulator that using half-spherical profile bucket attached in propeller. There are 8 buckets installed in a propeller. The aim of this research is to study the performance of the simulator system. The main indicator of performance is indicated by system efficiency (η system %). The research methodology used in this study is experimental with quantitative data produced by testing and measuring the variables. This study is implemented according to Bernoulli's Law, mechanical system used in Kinematic and Dynamic and Ohm's Law. During testing results debit, mass flow rate, thrust force due to water pressure, shaft revolution, electric current, electric voltage and power. These parameters are used to analyze performance of simulator. The performance of simulator using half-spherical profile bucket shows 7.28 % increase. The average of efficiency of simulator of Pelton type micro hydro is 74.28 %.

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1. Introduction

In the energy conversion machine laboratory of the Department of Mechanical Engineering, Mayasari Bakti University, there is a Pelton type micro hydro hydroelectric power plant simulator. This simulator is designed on a small scale but strives to resemble actual conditions in the field. This simulator is used for practical work for Mechanical Engineering students and for further research on energy conversion for Mechanical Engineering lecturers.

This research is developmental research which focuses on the performance of the simulator where the impeller uses a half-spherical profile bucket. The bucket used is designed to resemble a Pelton turbine impeller but on a reduced scale. The bucket material is made of composites with resin, catalyst and fiber raw materials using a reinforcement manufacturing method, so that it can increase the rigidity of the bucket without increasing its dimensions.

Previously, the propeller profile installed in the simulator was in the form of a double radius with a divider in the middle. This profile produces a fluid flow pattern that is distributed laterally. The following is the profile of a double radius propeller totaling 8 buckets.

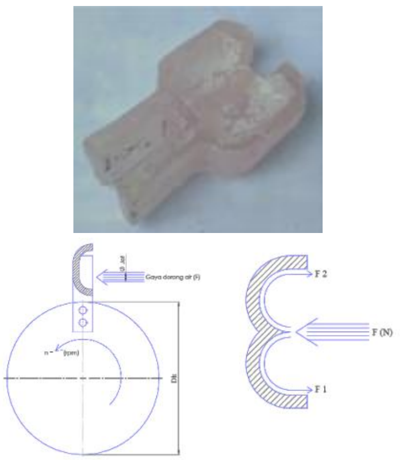

Figure 1. Double half radius bucket profile

The maximum turbine efficiency that can be achieved is 78.87% with an average efficiency is 67%. The following is the complete Pelton turbine simulator construction.

Figure 2. Construction of pelton turbine simulator

The working principle of this simulator is to convert the potential energy of water into electrical energy. Water potential energy is created from a 125 Watt capacity water pump connected to a pipe installation equipped with a pressure gage. Next, the pipe is connected to the nozzle, wheel runner, shaft and 30 Volt DC electric generator. The theoretical basis used is Bernoulli, Kinematics and Engineering Dynamics and Ohm's Law. The aim of this research is to determine the performance of the Pelton type micro hydro power plant simulator system with the main indicator being turbine efficiency with a bucket propeller with a half-spherical profile (ηT).

2. Methodology of Research

A water turbine is a device that works with water as a working fluid. The height of the water as the working fluid is positioned in such a way as to form a height difference or head. Different heights of water positions will result in potential differences. So that in the fluid there will be flow and cause a flow velocity. The flow speed of the fluid will produce kinetic energy. Meanwhile, the difference in water potential will produce potential energy.

This energy will be used to rotate the turbine blades and ultimately will be used to rotate the electric generator. So in this case there will be an energy conversion from water potential energy into mechanical energy of the turbine shaft and finally into electrical energy.

In general, in Indonesia, the use of potential water energy into electricity continues to be developed in order to meet electricity needs, both for households and industry. The potential for hydroelectric power generation in Indonesia is very large, reaching 75,000 MW. So if used optimally, dependence on fossil energy can be reduced significantly. As is known, fossil energy will produce exhaust emissions which can damage the environment and endanger health.

1. *Water turbine classification*

Water turbines can be classified into the several types, such as based on working fluid momentum, based on head and fluid capacity, and based on specific velocity.

Water turbines in terms of the influence of their working momentum are divided into two, which are reaction turbine and impulse turbine. Reaction turbines are distinguished by variations in the direction of flow through their blades. The types of reaction turbines are as follows :

a. Francis turbine radial flow.

b. Francis turbine mixed flow.

c. Kaplan turbine axial flow.

In radial flow and mixed flow turbines, the outflow radius at the exit section is different from the inflow radius at the inlet section. If the flow enters the blade only in the radial direction, in contrast to a mixed flow turbine, the flow enters the blade from both the radial and axial directions.

Axial flow blades are divided into propeller types or fixed blades and Kaplan blades or changeable blades. The propeller turbine is a classic type of flow turbine. Meanwhile, the Kaplan turbine has a directional blade and the angle of motion can be changed. By adjusting the angle of motion of the blades, the Kaplan turbine can operate at varying loads with high efficiency. The reaction turbine has a guide blade equipped with a cochlea and suction pipe. The flow entering the cochlea in the horizontal direction and entering the guide vane radially will flow in the axial direction and then be released into the pipe in the vertical direction.

Impulse turbine is a popular type of modern impulse turbine is the Pelton turbine. Pelton turbines are suitable for use at high heads with one or more jet nozzles striking bowl-shaped blades from the inlet to the outlet. Pelton turbines can work at low specific flow speeds. Another advantage of the Pelton turbine is that it can operate with relatively constant efficiency at varying loads. This is because the control needle valve can produce varying discharge at a fixed jet speed, so that the relative speed at the inlet and outlet sections does not change.

Turbine head and flow capacity are the factors that influence the size of the turbine wheel, turbine blade and its curvature. The lower the height of the falling water, the less blade curvature it requires [1].

The specific fluid velocity is used as a limit to differentiate turbine wheel types and is used as an important quantity in turbine design planning. Turbine wheels that work at different water fall heights and different water capacities, and work at predetermined rotations, then the turbines have similar geometries. The basic dimensions, turbine wheel diameter and width are different. But the blade shape, blade angle and wheel diameter ratio are the same [1].

Hydroelectric Power Plants or PLTA have several types of driving turbines. The following are several types of water turbines that are popularly used as electricity generators. The Francis turbine is a type of turbine that has three main parts, namely the turbine housing (casing), the moving blade (runner) and the directional blade (nozzle) which surrounds the runner. All these parts are immersed in water. Francis turbines are used to harness potential energy at medium heights from several tens of meters to 100 meters. Apart from that, the Francis turbine can produce high shaft rotational speeds which will later be used to drive the generator [1].

While The Kaplan turbine is a type of propeller type water turbine that has adjustable blades. The Kaplan turbine was developed by Professor Viktor Kaplan from Austria which combines automatic regulation of the propeller. The Kaplan turbine is a development of the Francis turbine and can use a lower head ranging from 10 to 70 meters. The resulting output power can reach 5 to 200 MW. This amount of power cannot be achieved by a Francis turbine [1].

The Kaplan turbine is a deep flow reaction turbine. This means that in this turbine changes in fluid pressure work when the moving fluid hits the turbine wall, thereby producing energy.

2. *Simulator of pelton type microhydro power plant*

The Pelton type Microhydro Power Plant Simulator in the energy conversion laboratory at Mayasari Bakti University is a facility for practicum, research and development of energy conversion machines, especially micro-scale power plants. The simulator was designed and created by students from the Department of Mechanical Engineering, Mayasari Bakti University under the guidance of lecturers. The basic design of this simulator is made in such a way as to be close to a real Pelton turbine, especially the design of the bucket and wheel runner.

In general, this simulator consists of a mechanical system and a piping system. The main components of the mechanical system consist of bucket, wheel runner, shaft, bearings, pulleys, belt and 30 Volt DC electric generator. Meanwhile, the piping system consists of a 125 Watt capacity water pump as a water booster, 1 inch diameter PVC pipe, pressure gage, nozzles, valves and water storage tank [7][8].

The working principle of the Pelton type micro-hydro power plant simulator located in the energy conversion laboratory at Mayasari Bakti University can operate based on the water flow rate. The flow rate of water as a working fluid is produced by the pressure of the water pump. The water pump has model specifications PS-128 BIT, debit of 10 – 18 liters/minute, maximum head of 9 meters and exit hole diameter of 1 inch.

The water pump is connected to a 1 inch diameter pipe which is designed in such a way that it forms a bend at an angle of 90 0. A pressure gage is attached to the pipe to measure the working pressure of the water fluid. Apart from that, a valve is also installed to regulate the amount of working fluid flow. At the end of the pipe, a nozzle with an output diameter of 12 mm is attached. Thus, the fluid flow at the tip of the nozzle will experience an increase in flow speed and pressure.

The pressure difference creates momentum and is used to rotate the bucket and wheel runner. The rotation of the wheel runner will be transmitted to the turbine shaft and electric generator. So the electric generator will produce DC electric voltage.

The main component of simulator consists of:

1. Water Pump. The water pump used has model specifications PS-128BIT equivalent to 125 Watts with a Q discharge of 10-18 liters per minute, with a suction and push pipe diameter of 1 inch. This water pump functions to produce a fluid flow of water with a certain discharge and pressure.
2. Piping system. This piping system uses PVC pipe with a nominal diameter of 1 inch.
3. Pressure Gauge. This pressure gauge functions to measure the pressure of the water fluid in the pipe. The working pressure is generated by the pump.
4. Valves. Valves are installed in the piping system with the function of regulating the flow of water fluid.
5. Nozzle. The nozzle used is made of Teflon with an inner diameter of 12 mm.
6. Water storage tank. The water storage tank functions to accommodate water that is created by circulation.
7. Turbine blade. This turbine blade is in the shape of a bucket with a total of 8 pieces. This bucket is designed in such a way that it can hold water for a certain period of time and produce energy.
8. Wheel runners. The wheel runner functions as a position for the bucket. The wheel runner diameter is 125 mm.
9. Shaft and pulley. The shaft and pulley components function to continue rotation. Both of these components are made of aluminum.
10. DC electric generator. This electric generator functions to generate DC electric current.

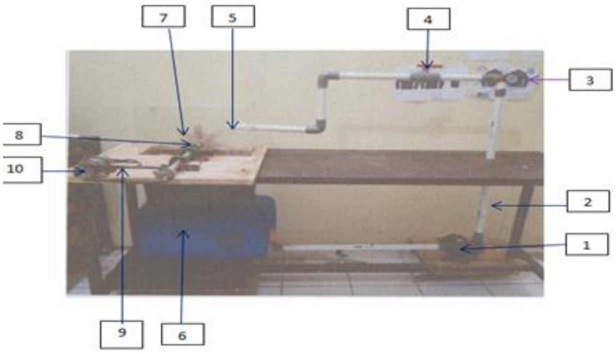

Figure 3. Pelton type micro hydro power plant simulator [2]

3. Formula

The research method used in this analysis combines three scientific disciplines, namely:

1. Fluid dynamics by applying Bernoulli's Law to the control volume.
2. Mechanical systems with emphasis on the relationship between power, torque and force [9].
3. Electricity by applying Ohm's Law with variable voltage, current and electrical power.
4. Analysis of turbine performance expressed by turbine efficiency.

The explanation can be explained as follows:

1. Control volume in Bernoulli's Law [10] :
   The flow of working fluid produced by the pump in the pipe will produce a debit and fluid flow velocity. From this variable the following relationship will be obtained:

$$Q = v \cdot A \quad \ldots (1)$$

Explanation :

Q = fluid flow debit (m^3/s)
v = fluid flow velocity (m/s)
A = pipe cross sectional area (m^2)

A flowing fluid will produce a mass flow flux with the relationship between variables as follows:

$$\dot{m} = \frac{m}{t} \quad \ldots (2)$$

or

$$\dot{m} = \rho \cdot v \cdot A \quad \ldots (3)$$

Explanation :

$\dot{m}$ = mass flow rate (kg/s)
m = fluid mass (kg)
t = time (s)
ρ = fluid specific mass (kg/m^3)

Fluid flow in the pipe will produce a thrust force F as follows:

$$F = \dot{m} \cdot v \quad ...(4)$$

Explanation :

F = fluid thrust force (N)
$\dot{m}$ = mass flow rate (kg/s)
v = fluid flow velocity (m/s)

2. Mechanical System [4]:
The mechanical system includes the bucket, wheel runner and shaft. The mechanical power of the turbine can be calculated using the following equation:

$$P = T \cdot \omega \quad .. (5)$$

Explanation:

P = mechanical power (Watt)
T = turbine shaft torque (Nm)
ω = angular velocity (radian/s)

3. Power generator system [5]:
The power generator system in this simulator uses a DC electric generator with a maximum capacity of 30 Watts. The variables that can be calculated are as follows:

$$E = V \cdot I \quad ... (6)$$

Explanation:

E = electric power generated by electric generator (Watt)
V = DC electric voltage (Volt)
I = electric current (Ampere)

4. Turbine Efficiency [6]:
Turbine efficiency (η) is the main indicator of the performance of the Pelton simulator. In a system, not all energy can be fully utilized 100%. There are some that come out of the system or are called losses. The system efficiency can be calculated with the following equation:

$$\eta_{system} = \frac{Power-output}{Power-input} \times 100\% \quad ... (7)$$

Explanation:

Output power is the power produced by the electric generator in Watts. Meanwhile input power is the power produced by the mechanical system in Watt.

3. Result and Discussion

Testing is carried out based on a predetermined formula in stages. Testing starts from the mechanical system input that produces turbine power. Test results are as follows:

Table 1. The result on mechanical system as input data

No	$\dot{m}$	v	F	n shaft	P turbine
	(kg/s)	(m/s)	(N)	(rpm)	(Watt)
1	0.394	3.485	1.373	240.2	3.83
2	0.343	3.043	1.044	180	2.55
3	0.315	2.792	0.879	148.5	1,55
4	0.289	2.561	0.740	135.3	1.04
5	0.265	2.354	0.625	98.3	0.65
6	0.224	1.991	0.447	55.6	0.25

The next test was carried out on the output of the DC power generator system from a DC 30 Watts. The test results are as follows:

Table 2. Test result on DC generator 30 watt as output data

No	I	Voltage	P generator DC
	(Ampere)	(Volt)	(Watt)
1	0.88	3.40	2.99
2	0.75	2.50	1.86
3	0.52	2.20	1.14
4	0.51	1.70	0.87
5	0.31	1.30	0.40
6	0.19	1.00	0.19

The next stage is to analyze the efficiency of the turbine system in the simulator. System efficiency can be calculated by comparing the generator output power results with the turbine shaft input power results. The results of the system efficiency analysis can be seen in the following Table 3:

Table 3. Efficiency of System

No	P turbine (Watt)	P generator DC(Watt)	η_{system} (%)
1	3.83	2.99	78.06
2	2.55	1.86	72.94
3	1.55	1.14	73.54
4	1.04	0.87	**83.65**
5	0.65	0.40	61.53
6	0.25	0.19	76.00
		Average	**74.28**

It can be seen that the maximum system efficiency is 83.65% and the average system efficiency is 74.28%.

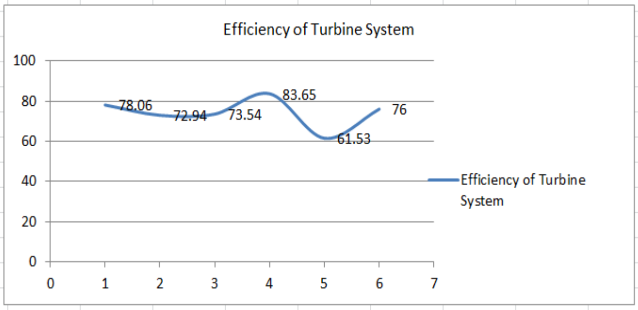

Figure 4. Graphic of turbine system efficiency

When compared with the previous bucket model, namely double radius, there is an increase in turbine system efficiency, from an average efficiency of 67% to 74.28%. The half-spherical profile bucket model was able to increase the performance of the turbine system by 7.28%. The half-spherical bucket profile attached to the impeller turned out to be more effective in absorbing the thrust force of water through the nozzle.

4. Conclusion

Based on the discussion, it can be concluded that the half-spherical bucket profile installed in the Pelton type micro hydro power plant simulator is capable of producing an average system efficiency of 74.28%. The half-spherical bucket profile is more effective than the double radius profile in absorbing the thrust force of water passing through the nozzle.

5. Acknowledgement

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