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Increasing electric power in pump power plants as turbines through modifications in impeller housings

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Abstract
To improve the performance of a centrifugal pump as a turbine, one of the methods used is to modify the impeller housing. The impeller housing groove directs a certain speed fluid that enters the pump to convert mechanical energy from the pump into the rotating energy of a generator that produces electricity. The roughness on the inside of the pump housing will cause friction in the fluid flow, which will rotate the impeller so that it will reduce the flow velocity of the fluid, and the impact will decrease the impeller rotation, which results in the voltage and electric current generated by the generator being of small value. This study made modifications to increase the power (voltage and current) produced to be more optimal. There are three ways of modifications made to the impeller housing: modification of the impeller housing by using a lathe process, modification of the impeller housing by polishing using the sandblast method, and modification of the impeller housing by coating using the complicated chrome method. The three modifications carried out were tested on the pump device as a turbine (PsT), and the test data was taken for analysis and a conclusion was drawn that the modification of the impeller housing that has the most optimal impact on the power plant is the modification of the impeller housing with hard chrome with valve opening 100% at during testing because it produces a flow speed of 110 L/min, impeller rotation of 1050 rpm and electric power of 10.51 Watt.

Keywords: Modification, Impeller house, Impeller, Pump

1. Introduction

With the limitations of minerals derived from fossils as an energy source, there is a need for innovation to create renewable energy, which is related to power generation. There have been many applications of innovations related to renewable energy that can contribute to creating power plants, one of which is the study of power plants that use pumps as turbines (PsT) [1, 2].

The basic principle of PsT is to use a pump as a power plant by utilizing the flow of water with a specific height that falls with a large enough discharge to convert potential energy into mechanical energy in the pump. Water that falls freely will be directed through a pipe connected to a centrifugal pump to move the impeller blades on the pump. The result of the rotation of the impeller is the mechanical energy for the power plant [3].

Based on research that has been conducted at the Faculty of Engineering, Pancasila University, especially the Mechanical Engineering Study Program, it was found that several variables can improve the performance of the pump as PsT, one of which is seen from the impeller side, both from the surface roughness and from the fabrication process [4, 5].

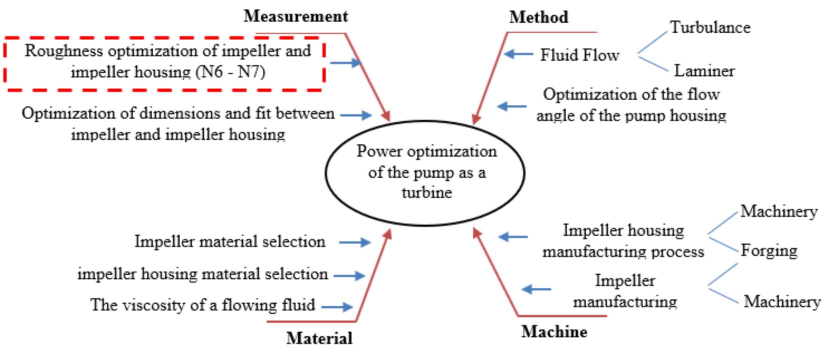


Fig 1: Power Optimization problem mapping

Based on the problem mapping above, the research appointed for power optimization in PsT was on the measurement variable with details of roughness optimization research on the impeller housing.

2. Literature Review

Based on the results of previous research on power optimization in PsT, it can be concluded that a smoother surface of the impeller can increase the efficiency of PsT (Moh. Sumardi's Research). The smoother the surface of the impeller will be passed by the water, causing the coefficient of friction to be smaller so that the flow of liquid through the device is laminar. Laminar current will have a higher flow velocity than the turbulent type [4, 6].

Previous studies carried out power optimization on PsT by fine-tuning the impeller utilizing the hand-grinding process. The grinding process is carried out to obtain the smoothness of the impeller product with mashed cast iron material with a performance ranging from N7 (Ra=1.6µm) [7].

In this study, the power optimization process on PsT was carried out by processing the smoothness of the impeller housing with cast iron material (Ra=6.3 m) to become N6 (Ra=0.8 m) with several process steps. The stages of the process carried out are as follows: Stages without modification process

A. This stage is without modification to the impeller housing, where the impeller housing is to be tested the original impeller housing.
B. Stages of modification of the impeller housing with a lathe
   This stage is where the impeller housing is tested and modified using a lathe process to get a better roughness value than the stage without modification.
C. Stages of modification of the impeller housing with the sandblasting process.
   At this stage, modifications are made to the impeller housing using scraping/polishing with the sandblast method. This aims to get a better smoothness than the modification of the impeller housing using the lathe process, especially in parts that are not reached by the lathe process.
D. Stages of modification of the impeller housing with the complicated chrome process.
   At this stage, modifications are made to the impeller housing by carrying out a coating process using the complicated chrome method. At this stage, the final goal is to get the best fineness value compared to the previous three stages [8].

3. Research Method

A. Research Flowchart

In the research on power plant optimization (PsT) through the modification of the impeller housing, it is described through the following flow diagram:

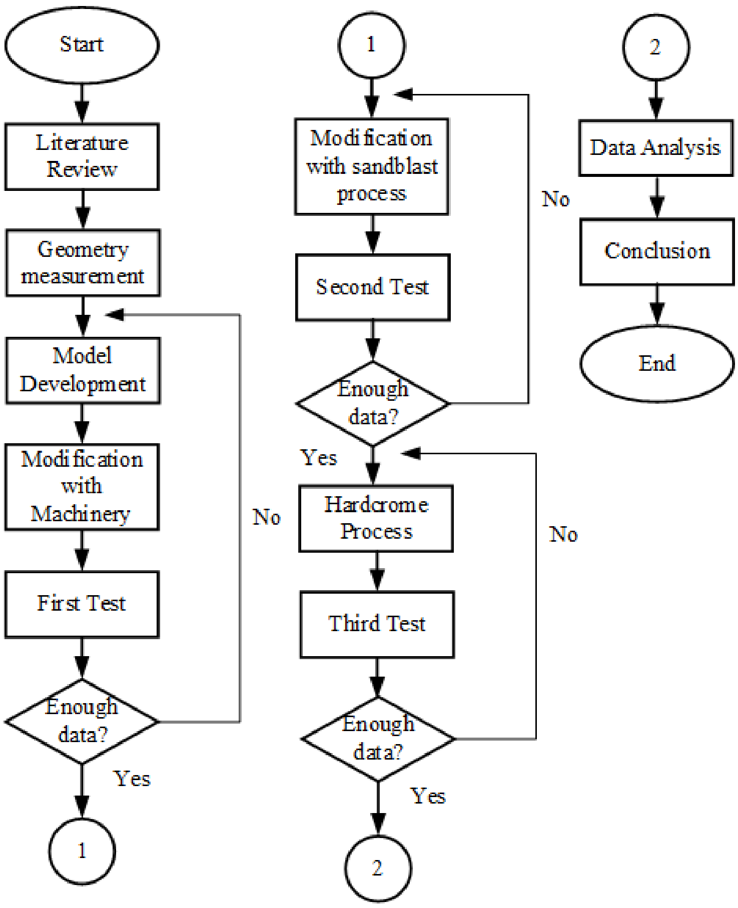


Fig 2: Research Flow

B. Impeller House Modification Planning

In this study, optimizing the power plant in the pump research as a turbine was carried out with three stages of modification to the impeller housing. The three stages of the impeller housing modification have the final goal of being a roughness variant to see the impact of power optimization as turbine output [9].

B.1. Impeller housing modification with lathe process
In planning the modification of the impeller housing at this stage, a modification process is carried out by turning the inside to get a smoothness that follows engine standards.

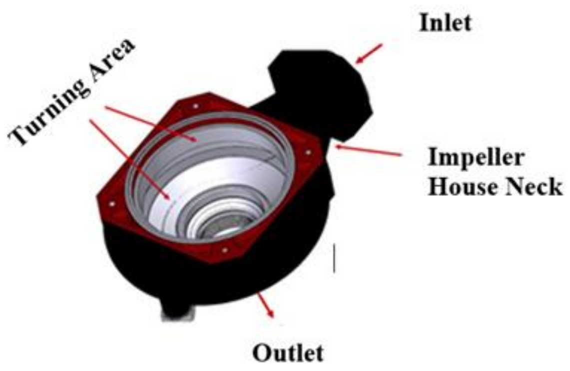


Fig 2: Lathe modification area on the impeller housing

B.2. Modification of the impeller housing with the sandblast process.
In the sandblast process, using a polishing particle spraying system, even the most minor parts, profiles, or angles can be exposed to polishing sand to get better smoothness than the initial conditions. Based on this condition, all parts of the impeller housing that are traversed by water can impact friction, which will affect the flow rate from the neck side of the impeller housing (inlet) and rotate the impeller before being ejected through the water outlet (outlet) [10].
B.3. Impeller housing modification with hard chrome process
The last modification method to the impeller housing is the hard chrome method. This is done after going through the polishing step using a sandblast system so that all parts of the impeller housing already have a certain smoothness that will facilitate the chrome process.
In this modification step, because the complicated chrome process is carried out with a dipping system, the entire surface of the impeller housing becomes shiny. The function of hard chrome in this impeller housing modification is to smooth further the grooves through which water passes in the impeller housing to have a higher level of smoothness than the sandblast polishing method [11].

C. Modeling
After measuring the physical sample of the impeller housing, the next step is to do the modeling by redrawing. The drawing carried out is a 3D drawing using "Solidwork" to obtain a 3D simulation (Figure 3) and to see the fluid flow in the impeller housing in a simulation.

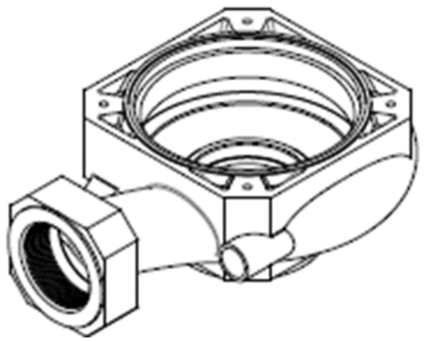


Fig 3: 3D isometric design of impeller housing

The next stage is a 2-dimensional (2D) drawing process to create a working drawing by doing a drafting process from a 3D image.

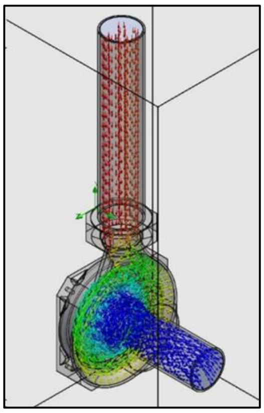


Fig 4: Simulative drawing of impeller homework

When modeling using a 3-dimensional program for the design of the impeller housing, by entering the parameters of the type of cast alloy steel material, the material properties for the impeller housing are obtained. The impeller housing material properties data can be seen in table 1, and for a 3D design simulation, it can be seen in Figure 5.

Table 1: Material properties of the impeller housinger

Specification	Value
Density	$0{,}01\ {}^{gr}/_{mm^3}$
Mass	5789,47 gr
Volume	793078,3 mm^3
Surface Area	245622,52 mm^2

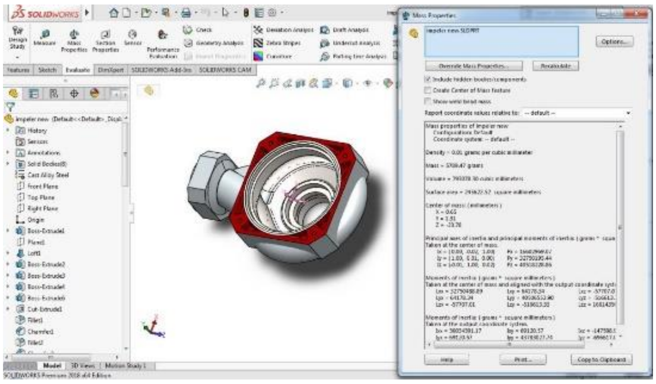


Fig 5: 3D design of impeller housing with material properties

D. Testing and Processing of Test Data

D.1. Testing

The testing was carried out at Pancasila University by using a pump installation device as a turbine as stated in the test steps as follows:

1. When the test starts, the centrifugal pump will fill the upper water tank to the brim with water from the lower water tank.
2. Perform valve opening variations with the conditions as stated in the test table provided.
3. When the valve opening is opened according to a predetermined degree.
4. After the water drops and starts to move the turbine, all the measurement values contained in the test table have been prepared with verified measuring instruments.
5. Make notes in the test table that has been prepared
6. Perform the test with the same method for the 1st test to the 3rd test.

Fig 6: Pump testing device as a turbine

D.2. Data Processing

Based on the experimental data obtained in the first to third tests, the next step is to create a mathematical model and a comparison graph (figure 7) as a data analysis method and a reference to conclude this experimental study.

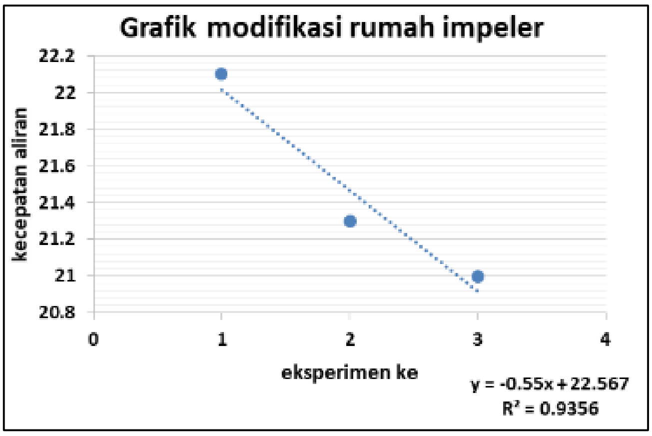


Fig 7: Example of a comparison graph of experimental data

4. Results and Discussion

A. Impeller House Modification Process

Table 2: Hasil modifikasi rumah impeller

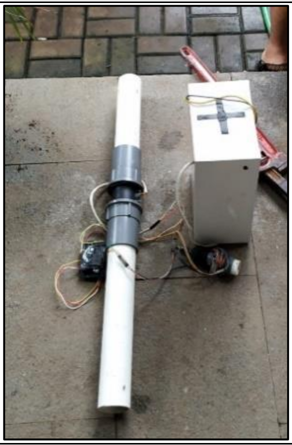
Modification	Figure
No modification	
Modification by turning process	
Modification of the impeller housing with the sandblast process	

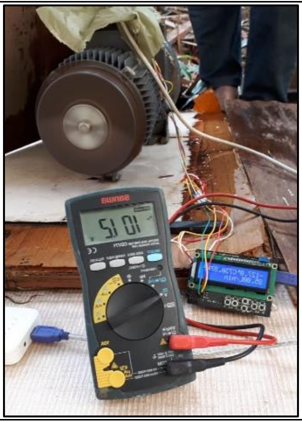
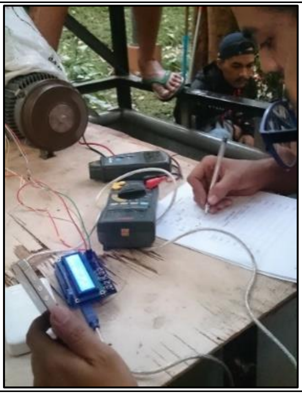
Impeller housing modification with hard chrome process	

4.1 Testing Process

In general, the testing steps for these four types of impeller housing variants are the same, starting from test preparation to the activity of the testing process itself and the collection of test data. The actualization of the tests carried out is described in the test activity table below.

Table 3. Testing process

Activity	Figure
Installation of standard impeller housings and modifications to the test pump.	 
Measurement device installation ▪ Flowmeter ▪ Pressuremeter ▪ etc	
Impeller rotation measurement in each valve opening variant (15%, 25%, 35%, 50%, 75% and 100%)	

Measurement of voltage, current and velocity for each valve opening variant (15%, 25%, 35%, 50%, 75% and 100%)	
Recording of test results in each variant of the impeller housing as well as in each variant of the valve opening	

B. Results and Data Processing

Based on the test data table for the modification of the impeller housing, it is possible to calculate the electrical power (Pe) on each test result with the formulation for calculating the electrical power generated, namely P_e=V.i .cosΦ and the value of cosΦ=0.8.

Table 2: Result of processing test data with standard impeller housing

Valve Open	*Velocity* (L/mn)	Pressure (Pa)	Volt (V)	Amp (A)	Rpm	Electrical power (W)
15%	64	1298	-	-	-	0
25%	65	1261	-	-	-	0
35%	65,7	1258	2,5	0,27	843	0,54
50%	65,7	1278	2,4	0,27	845,3	0,52
75%	70,65	1225	2,6	0,27	855,2	0,56
100%	65,7	1193	2,7	0,29	876,2	0,6

Table 3: The results of processing test data using a lathe-modified impeller housing

Valve Open	*Velocity* (L/mn)	Pressure (Pa)	Volt (V)	Amp (A)	Rpm	Electrical power (W)
15%	33	1235	-	-	-	0
25%	40,745	1211	-	-	-	0
35%	63	1211	1,8	0,13	556,7	0,19
50%	72	1198	2,0	0,22	590	0,46
75%	80	1180	2,5	0,29	878,1	0,58
100%	85	1183	2,8	0,79	879,8	1,77

Table 4: The results of processing test data using a sand blast modified impeller housing

Valve Open	*Velocity* (L/mn)	Pressure (Pa)	Volt (V)	Amp (A)	Rpm	Electrical power (W)
15%	64	1349	-	-	-	0
25%	64,7	1349	-	-	-	0
35%	65	1252	1,086	1,15	31,7	0,99
50%	70	1211	1,180	1,85	288	1,75
75%	95	1191,5	3,500	2,71	937	7,59
100%	100	1179	4,490	2,71	1028	9,73

Table 5: The results of processing test data using a hard chrome modified impeller housing

Valve Open	*Velocity* (L/mn)	Pressure (Pa)	Volt (V)	Amp (A)	Rpm	Electrical power (W)
15%	25	1349,33	-	-	-	0
25%	55	1349	-	-	-	0
35%	100	1230	2,700	2,43	788	5,25
50%	100	1169	3,510	2,51	952	7,05
75%	105	1132	3,700	2,67	990	7,9
100%	110	1108	4,711	2,79	1050	10,51

C. Data Comparison Chart

Based on the calculations and the test data processing table above, it can be concluded that the relationship between valve opening (%) and power (W) in the form of a comparative graph shown in Figure 8 below.

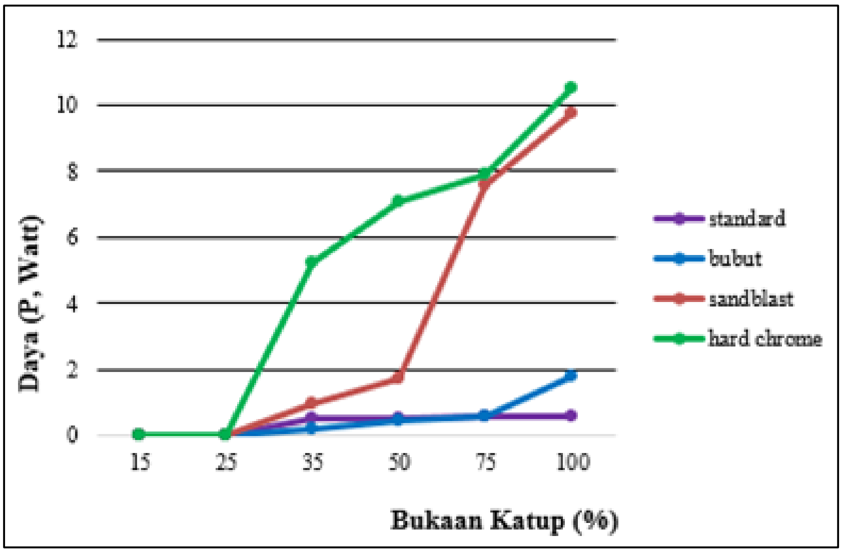


Fig 8: Graph of the relationship between valve opening (%) and electric power (P_e)

Based on Figure 8 above, it can be seen that the most significant power is generated by testing the pump as a turbine (PsT) with a modified impeller housing using hard chrome at 100% valve opening with a discharge (Q) of 110 L⁄min and producing an electric power (P_e) of 10.51 W

Meanwhile, based on the calculations and the test data processing table above, it can also be concluded that the relationship between the discharge (velocity) and the rotational speed (rpm) in the form of a comparative graph shown in Figure 9 below.

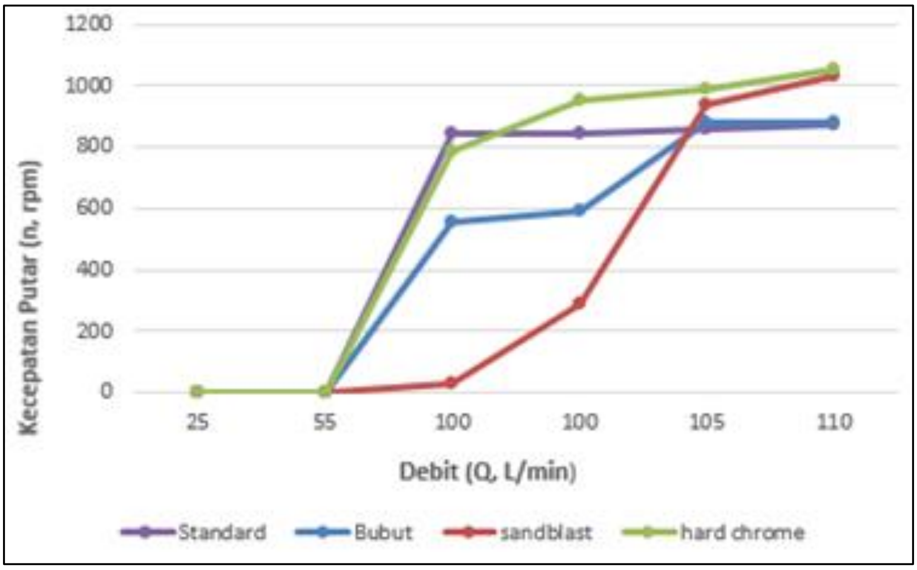


Fig 9: Graph of the relationship between discharge (Q) and rotational speed (n)

Based on Figure 9 above, it can be seen that the largest impeller rotation speed is produced by testing the pump as a turbine (PsT) with a modification of the impeller housing using hard chrome at 100% valve opening with a discharge (Q) of 110 L⁄min and producing a rotational speed (n).) at 1050 rpm

D. Flow Simulation with 3D Programs

Simulatively, fluid flow movement during testing can also be simulated when drawing the impeller housing with a 3D SolidWorks design program. In this case, the flow simulation function (figure 10) shows the flow direction when the centrifugal pump functions as a turbine. What distinguishes it from a pump as a turbine is the direction of the pump flow is vertical upwards, whereas if the pump is a turbine, the vertical flow direction of the fluid is downward.

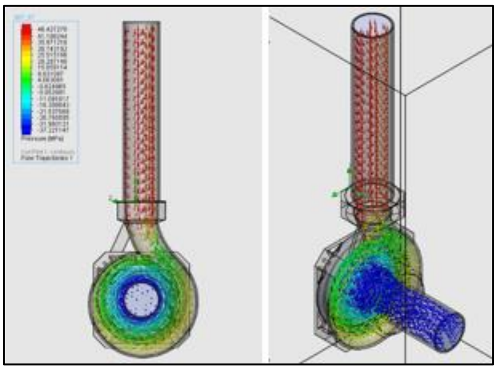


Fig 10: Simulation of the pump flow direction as a turbine

Based on the flow movement simulation using a 3D SolidWorks design program, the flow data obtained are as follows:

pressure (P)	:	1108 Pa = $0{,}00011\ {}^{N}/_{mm^2}$
Inlet and outlet diameter (d)	:	50 mm = 0,5 dm
Flow speed (v)	:	$0{,}86375\ {}^{m}/_{s} = 518{,}25\ {}^{dm}/_{mnt}$

Based on the data above, it can be determined the theoretical discharge that occurs with the following calculations:

Calculation of inlet/outlet cross-sectional area

$$A = \frac{\pi}{4} . d^2 = \frac{\pi}{4} . 0{,}5^2 = 0{,}1964\ dm^2$$

Calculation of theoretical flow rate (Qt)

$$Q_t = A.v$$
$$= 0{,}1964\ dm^2 . 518{,}25\ {}^{dm}/_{mnt}$$
$$Q_t = 101{,}7843\ {}^{dm^3}/_{mnt}$$
$$= 101{,}7843\ {}^{L}/_{mnt}$$

Based on the theoretical discharge (Qt) calculation above by entering the pressure parameter of $0{,}00011\ {}^{N}/_{mm^2}$ the theoretical discharge value is $101{,}7843\ {}^{L}/_{mnt}$. The parameter used is the pressure data in the test with the most considerable power value, namely the impeller housing test with modifications with hard chrome with 100% valve opening conditions.

5. Conclusion

5.1 Kesimpulan

Based on a series of studies on power plant optimization (PAT) through the modification of the impeller housing that has been carried out, the following conclusions can be drawn:
In the power plant optimization research (PAT), through the modification of the impeller housing, three variants of the impeller housing have been carried out and one standard impeller housing as a reference.
The variant of the impeller housing modification used is the modification of the impeller housing by machining with a lathe by turning 0.2 mm deep, then modifying the impeller housing by polishing using a sandblast with an erosion depth of 0.05 mm, and the last modification made is to perform plating process with 0.25mm thick hard chrome
Based on the test of the three variants of the impeller housing modification, it can be concluded that the modification of the impeller housing using the hard chrome process is the best at 100% valve opening, with the following results:
The discharge/velocity that occurs is 110 L⁄min
The impeller rotation that occurs at 1050 rpm is the highest compared to the other two tests
The electrical power generated by PsT is the largest at 10.51 Watt.
Comparison of the theoretical and experimental discharge was carried out on the test parameters that produced the greatest power, namely the test of the impeller housing modification using hard chrome with a valve opening of 100%. The results of the comparison of the debits are as follows:

Q_eks=110 L⁄min

Q_t=101.7843 L⁄mnt

From this value, it can be concluded that the difference between the theoretical discharge and the experimental discharge is 8.2157 L⁄mnt or about 7.47%.
Based on a sound engineering factor with a range of 90-110%, the amount of Qeks compared to Qt is within the range of a good engineering factor.

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