Experimental Analysis of Semi-Open Impeller Pump as Turbine

D.L Zariatin*, Risdianto, Amat Chaeroni, Ismail
Mechanical Engineering, Universitas Pancasila, Jakarta, Indonesia
*dedeliazariatin@univpancasila.ac.id

Abstract. Pump as turbine is one of the options for low-cost and simple electric power generation that suitable for rural area. Pump as turbine facing the same problem as any other hydropower plant which is low efficiency. Researchers focus on modification of the impeller, such as rounding, trimming, and surface smoothing. Most of the modified impeller was closed impeller type. The objective of this research was to investigate the possibility to generate more electric power of a PAT by using semi-open impeller. Simulation analysis was performed to analyze fluid flow in the pump housing. The simulation result shows the fluid velocity for open, semi-open and closed impeller is 646.87, 641.76, 639.89 m/s, respectively. The pressure of each open, semi-open and closed impeller is approximately 356, 361, and 388 kPa, respectively. The conclusion is that the open impeller had a higher velocity and lower pressure among two others. In the experimental testing, a semi-open impeller was selected because it had more strength and rigid body when it encountered the water impact. Three semi-open impellers with a blade thickness of 2, 4 and 6 mm made of brass were manufactured and tested. A close impeller which is the original impeller of the pump was also tested as a comparison. It is found that the open impeller with 2 mm blade thickness generated more electric power, approximately 36% than the original impeller.

Keyword: velocity contour, pressure contour, electric power generation.

1. Introduction
Pump as Turbine (PAT) is one of a renewable power plant that used a commercial pump to generate electrical power by reversing the flow [1] and modified the motor pump as a generator [2]. An impeller is one of the essential parts of PAT that affects the PAT performance because it transforms the water flows to rotate the generator shaft. Several studies have performed to improve the PAT performance by modifying[3][4], re-designing[5], and re-manufacturing the impeller. Impeller trimming and rounding were proven to be able to improve the PAT performance. [6][7][8].

There are three types of impeller which are open, semi-open, and closed impeller. Commercial centrifugal pump only provides a closed-impeller. Thus most of the impeller modification was implemented in a closed-impeller. The objective of this research is to analyze the feasibility to improve the efficiency of PAT by using semi-open impeller. Before the experiment, simulation analysis for three types of the impeller (open, semi-open, and closed) was executed.

2. Simulation Analysis
In this research, Grundfos NF 30-18 was used as a PAT. The model of the impeller was developed based on the dimension of pump housing as shown in Figure 1 (d). Figure 1 shows three types of impellers, which is an open impeller, semi-open impeller and closed impeller.
The model analysis used ANSYS Fluent 13.2 with the parameter of k-epsilon (2eqn) viscous turbulence and pressure based transient solver. Cast iron and steel set as the housing and impeller material, respectively. Coupled solution method with time step run calculation of 0.000001 set for 100 number of step in maximum 20 iterations was used in the simulation. Figure 2, 3, and 4 show the analysis result of each impeller type.

**Table 1. Pressure and Velocity of Open Impeller Simulation**

| Point | Pressure (Pa) | Velocity (m/s) |
|-------|---------------|----------------|
| A     | 205381        | 91.40          |
| B     | 207310        | 65.34          |
| C     | 187388        | 26.90          |
| D     | 173785        | 18.88          |
| E     | 161761        | 13.79          |
| F     | 137679        | 15.29          |
| G     | 356032        | 646.87         |
Figure 3. Simulation Analysis of Semi-Open Impeller (a) Pressure and (b) Velocity Contour

Table 2. Pressure and Velocity of the Semi-Open Impeller Simulation

| Point | Pressure (Pa) | Velocity (m/s) |
|-------|---------------|----------------|
| A     | 46182         | 77.08          |
| B     | 212555        | 112.84         |
| C     | 194894        | 48.15          |
| D     | 179183        | 27.25          |
| E     | 166737        | 21.97          |
| F     | 152827        | 14.24          |
| G     | 361216        | 641.76         |
| H     | 120603        | 605.98         |
| I     | 139353        | 84.95          |
| J     | 245303        | 181.37         |

Figure 4. Simulation Analysis of Closed Impeller (a) Pressure and (b) Velocity Contour

Table 3. Pressure and Velocity of the Closed Impeller Simulation

| Point | Pressure (Pa) | Velocity (m/s) |
|-------|---------------|----------------|
| A     | 297295        | 168.39         |
| B     | 235051        | 85.07          |
| C     | 208031        | 64.82          |
| D     | 189393        | 34.20          |
Table 3. Pressure and Velocity of the Closed Impeller Simulation (cont)

| Point | Pressure (Pa) | Velocity (m/s) |
|-------|---------------|----------------|
| E     | 176062        | 32.45          |
| F     | 146753        | 36.93          |
| G     | 388180        | 639.89         |
| H     | 13243         | 359.33         |
| I     | 8574          | 574.02         |
| J     | 268233        | 184.92         |

Figure 5 shows the maximum value of (a) pressure and (b) velocity of each impeller. It can be seen that the highest value of velocity occurs in open impeller, which compromises that it will generate more power. On the contrary, the closed impeller that mostly used in commercial pump has the lowest velocity and highest pressure.

3. Experimental Setup

According to the simulation result, the conclusion is that open impeller will produce more power. However, when concerning the blade strength and rigidity when encountered water impact, semi-open impellers is a better choice. The open impeller is easily deformed when receiving water pressure load. Three semi-open impellers made of brass with thickness of 2, 4, and 6 mm were manufactured, as shown in Figure 6. The original impeller of the pump, which is a closed-impeller was also tested in the experiment as the comparison.

![Figure 6. Semi-open impeller (a) model; (b) machining process; (c) Quality Check](image)

The experiments were carried out on a PAT laboratory-scale test facility [9] as shown in Figure 7(a). Figure 7(b) shows the semi-open impeller installed in the pump before testing.
Meanwhile Figure 7(c) shows the instruments used in measuring the parameter. Two digital multi-testers (Fluke II with accuracy ±0.4%+1) measured the voltage and current generated. A digital tachometer with accuracy 0.05%+1 and sampling ratio of 0.8 over 60 rpm measured the rotational speed of the flywheel. A Sea DN50 flow-rate sensor measured the flow-rate before entering the PAT.

![Measurement instruments](image1)

Figure 7. Experiment (a) testing facility; (b) semi-open impeller; (c) measurement instrument

4. Experimental Result

Figure 8 shows the electric power generated by each impeller. It shows that more power is generated as the increase of water flow-rate that control by the valve opening. At the maximum valve opening (90º), the closed impeller produced 49.65 Watt. Meanwhile, the semi-open impeller with blade thickness of 2, 4, and 6 mm produced 67.65 Watt, 63.43 Watt, and 61.37 Watt, respectively. It is found that the semi-open impeller with 2 mm blade thickness generated more electric power, approximately 36% than the close impeller (the original impeller of the pump). Meanwhile the 4 and 6 mm blade thickness generate more power than the closed impeller, approximately 28%, and 24%, respectively.

![Power generated graph](image2)

Figure 8. Power Generated
5. Conclusion
The simulation of three types of the impeller which is open, semi-open and closed shows that the velocity of the open and semi-open impeller is 1.09% and 0.29% higher than the closed-impeller, respectively.

It can be concluded that the open impeller will produce more power. However, when concerning the strength and rigidity of the blade, an open impeller is considered to be more fragile. Therefore, the semi-open impeller was chosen to be manufactured and tested.

Three semi-open impellers with thickness of 2 mm, 4 mm, and 6 mm were tested. The experimental result shows that the semi-open impeller generated more power than the closed-impeller. Blade thickness of 2 mm produces more electric power (approximately 36%) than the closed impeller. Meanwhile, 4 mm, and 6 mm generate approximately 28% and 24% than close impeller. It can be concluded that the thinner the blade, the more power generated. However, the blade deformation must be considered for long term of usage.

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