The Performance of Pump as Turbine with Machined Impellers

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Abstract. Pump as turbine (PAT) is a type of micro hydro power plant, which uses a commercial pump as a turbine in order to generate electricity. Most of PAT facilities used centrifugal pump. The main component of the pump is impeller, which commonly produced by using casting process. However, this paper describes a manufacturing process to produce PAT impeller by using machining process. Four impellers were produced from two variations of materials (brass and AA-7075), each with 5 and 6 blades. The impellers were tested in a laboratory scale PAT power-plant facility, and the performance of each impeller was compared to its original impeller. The experiment results show that the impeller with 6 blades made of brass material improves 48.9% of power generated.

1. Introduction

Pump as turbine (PAT) is a type of hydro power plant, which uses a commercial pump as a turbine in order to generate electricity. PAT has several advantages such as low-cost, simple design and easy to assemble, widely application and viability, longer life time, etc. [1]. Therefore, it is suitable for rural and remote area [2, 3]. Numerous research papers about PAT technology have published [4 - 7]. Generally, commercial pump impellers are made by casting process with surface roughness around 50**μ**m- 0.4 **μ**m [8]. However, machining process could be an alternative of manufacturing process to produce an impeller. The main reason of using machining processes to manufacture an impeller is because the surface could be determined.

Young and Chuang [9] developed an integrated 5-axis machining module for a centrifugal impeller. Cutter Location (CL) point was generated based on the geometric model of the blade and the hub by using CAD/CAM software. Lazoglu et al [10] also used CAD/CAM software to generate the tool path by a developed boundary representation that considered as an approach for prediction of cutting forces. Yau et al [11] performed the mathematical calculation in CAD/CAM software simulation of three and five axis milling machine in order to produce complex shape such as an impeller. Meanwhile Tuysuz [12] performed the simulation of the milling process for ball and end-mill cutting tools that includes the cutting forces. Fan and Xi [4] proposed an algorithm to optimize the tool-path generation for three-axis machining of a sculptured impeller blade surface. The algorithm calculated the four tool sub-paths on the sub-surface.

It is known that surface roughness is an important parameter in fluid flow. Taylor et al [13] stated that surface roughness was shown to have a very little effect in the laminar region. However, it played a major role in the turbulent region. The laminar and turbulent region are identified by the

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Reynolds number (Re). The Reynolds number is increased on rougher surfaces [14, 15]. Kaewnai [16] stated that losses in the impeller increase with increasing the surface roughness. Five impeller models with different surface roughness, which is 0 mm, 0.0001 mm, 0.001 mm, 0.01 mm and 0.1 mm, were investigated by using CFD. It is found that the surface roughness has a high effect on loss.

In this research, the machining process was performed to produce impellers for the pump as turbine facilities. The effect of impeller material (brass and AA-7075), numbers of the blade (5 and 6-blades) and impeller surface roughness were studied. The impeller's performances to generate power were tested and analyzed.

2. Manufacture of Impeller

Fig. 1 shows the manufacturing steps to produce the impeller. The impeller dimension was based on the original impeller that measured by using the Coordinate Measuring Machine (CMM). Due to the surface roughness value of the original impeller was exceeded the lower limit of the Mitutoyo Digital Surface Tester SJ-201 range of measurement, therefore the surface roughness of the original impeller was measured by comparing it to standard roughness tester. The original impeller is made of brass and has six blades. In this research two types of material and two variation number of blades were produced. The materials are brass and AA-7075. The number of blades is 5 and 6 blades. So, there is a total of four impellers produced by machining process.

After identifying the geometric properties of the original impeller, CAD software was used to make the impeller model. Because the machining process was performed in 3-axis milling machine, the impeller model was divided into two part section. The machining strategy was generated by using CAM software. The tool path simulation and NC/G code or CL File were generated in this step. The CL file, then transferred and executed on YCM MV66A 3-axis milling machine.

The dimension of machined impellers was inspected by CMM and the surface roughness was measured by Mitutoyo Digital Surface Tester SJ-201. The measurement parameters of Mitutoyo SJ-201 were: length of cut = 0.8x5 mm, drive speed = 0.2 mm/s and sample length = 2.5 mm.

Two section part of the impeller was joint by using pin injector joint and then by the welding process. The next step after the impellers were produced, was to install the impeller in the pump that used as a turbine. Then, install the pump to the PAT test facility.

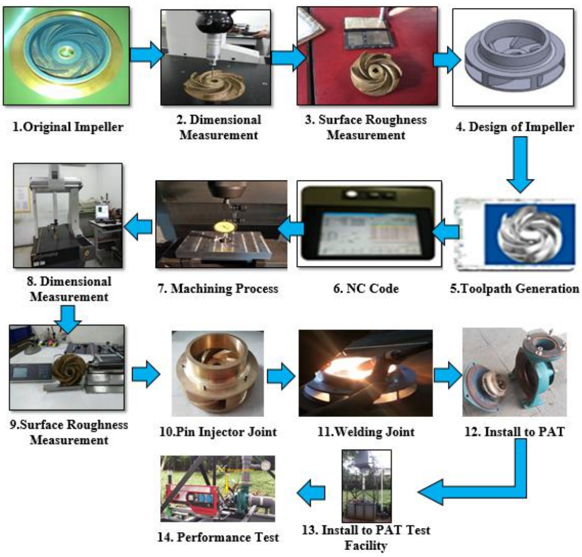


Fig.1. Manufacturing process of machined centrifugal impeller

The machining sequence (simplified) and the cutting parameters for both 5 and 6 blades are shown in Table 1 and Table 2. In order to monitor the cutting tools condition; before, during and after the machining process, the cutting tools were observed by using Dino Lite AM4815 digital microscope camera. The cutting tool monitoring process is performed because improper cutting tool condition such as tool wear, tool crack, etc. would degrade the impeller quality.

Table 1. Machining sequence and cutting parameter for 5 blades impeller

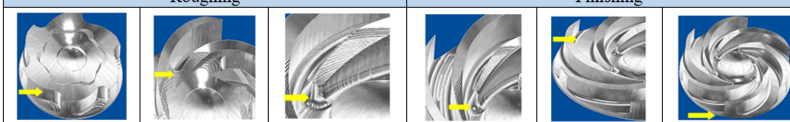
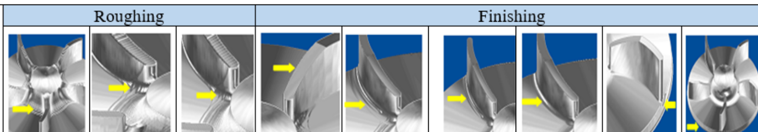
Operation		Roughing			Finishing		
							
		Rough 1	Rest 1	Rest 2	1	2	3
Allowance (mm)		0.3	0.3	0.35	0	0	0
Tolerance (mm)		0.05	0.05	0.05	0.005	0.005	0.005
Depth of Cut (mm)		0.5	0.5	0.3	0.1	0	1
Spindle Speed (Rpm)		2500	4500	4500	4500	4500	4500
Cutting Feed Rate (Rpm)		2000	1500	1500	1500	1500	1500
Step Over		16	6	2	0	0	0
Cutting Tool		ZCC 20	End-mill 10	Ball nose 6	Ball nose 6	Ball nose 6	End-mill 10
Machining time (min)	Dural	23	43	179	77	7	34
	Brass	92	24	31	179	78	7

Table 2. Machining sequence and cutting parameter for 6 blades impeller

Operation		Roughing			Finishing					
										
		Rest	1	2	1	2	3	4	5	6
Allowance (mm)		0.35	0.4	0.4	0	0	0	0.02	0.02	0
Tolerance (mm)		0.05	0.05	0.03	0.05	0.005	0.005	0.005	0.005	0.005
Depth of Cut (mm)		0.5	0.3	0.2	0	0.1	0	0	0	0
Spindle Speed (Rpm)		1500	1500	1500	1500	1500	1500	1500	1500	1500
Cutting Feed Rate (Rpm)		1000	1000	1000	1000	1500	1000	1000	1000	1000
Step Over		16	2	13	0.08	0.1	0.1	0	0	0
Cutting Tool		ZCC 20	Ball 6	Ball 4	Ball 4	Ball 6	Ball 6	Ball 4	Ball 2	Flat 10
Machining time (min)	Dural	98	14	7	21	66	67	10	20	6
	Brass	79	14	6	21	74	128	11	28	6

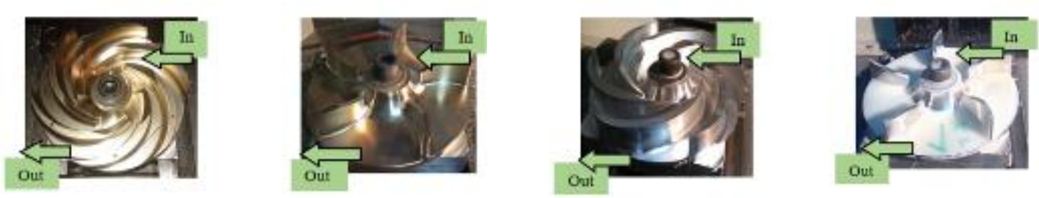


Fig.2. Cross-section view of the impellers; (a) Brass, 6-blades impeller, (b) Brass, 5-blades impeller, (c) AA-7075, 6-blades impellers, (d) AA-7075, 5-blades impellers.

Fig.2 shows the cross-section view of the impellers. This section part was assembled to the other section by using pin injector and welding. The result of the manufacturing process is shown in Table 3 pictures. Meanwhile the value of surface roughness (Ra) for each impeller is also listed in Table 3.

Table 3. Impeller surface roughness

Picture	Impeller	Outer Ra (µm)	Inner Ra (µm)	Average Ra (µm)
	Original Brass, 6-blades	12.5	12.5	12.5
	Brass, 6-blades	0.24	0.33	0.28
	Brass, 5-blades	0.38	0.34	0.36
	AA-7075, 6-blades	0.46	0.38	0.42
	AA-7075, 5-blades	0.31	0.46	0.31

3. Experimental Setup

The Experimental test was performed by using a Laboratory Scale PAT test facility as shown in Fig.3. In this facility, the top reservoir tank made of PVC, stores the water supply. It is placed 3.7 meters height above the ground. Clean water (assumed as H_2O Constant) flows from the tank into the PAT through PVC pipe. The water flows into the pump and rotates the impeller and its shaft. The shaft rotates the generator and produces electricity. The rotational speed of generator shaft was measured by using a digital tachometer. Meanwhile, the voltage and current produced by the generator was measured by using a Fluke 73 series II digital multi tester with accuracy ±0.4%+1.

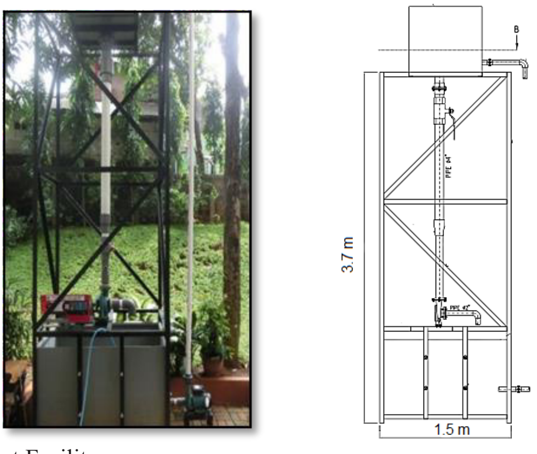


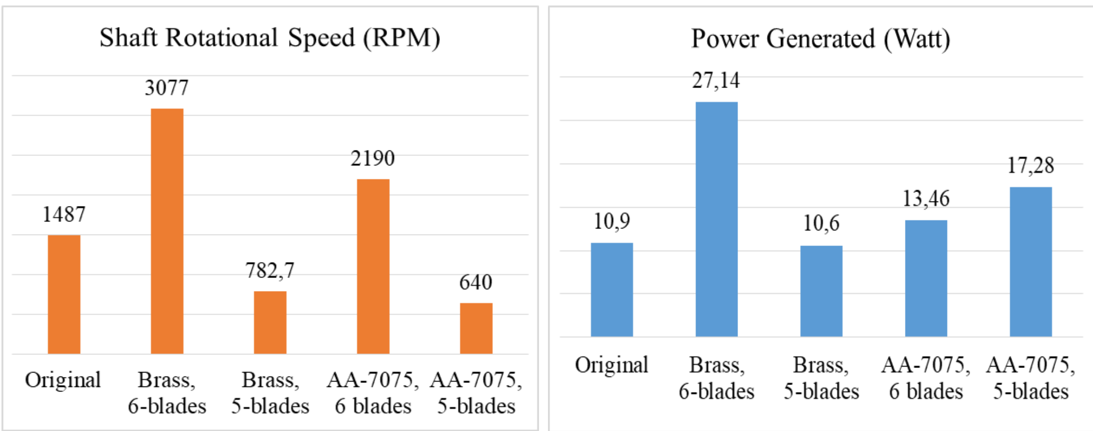
Fig.3. PAT Laboratory Scale Test Facility

4. Result and Discussion

Table 4 shows the experimental results of the shaft generator rotational speed and the power generated for each impeller. The table also listed the rotational speed and power improvement. Fig. 4 (a) shows the chart of the shaft generator rotational speed; meanwhile Fig. 4 (b) shows the electric power generated by the generator. It indicated that impeller made of brass with 6 numbers of blades generates the highest rotational speed and electric power. This impeller has the lower surface roughness among others. It could be concluded that the better quality of surface roughness of PAT impeller would produce more electric power.

Table 4. Experiment Result

No	Type of Impeller	Avg. Surface Roughness (µm)	Shaft Generator Rotational Speed (RPM)	Rotational Speed Improvement (%)	Power (Watt)	Power Improvement (%)
1	Original	12.5	1487	-	10.9	-
2	Brass, 6-blades	0.28	3077	106.9	27.14	148.99
3	Brass, 5-blades	0.36	782.7	-47.36	10.6	-2.75
4	AA-7075, 6- blades	0.42	2190	47.27	13.46	23.48
5	AA-7075, 5 -blades	0.31	640	-56.96	17.28	58.53



(a) (b)

Fig. 4. (a) The rotational speed of shaft generator, and (b) the power generated

5. Conclusion

In this research, centrifugal impellers manufactured by machining process were used as impellers in a laboratory scale PAT micro-hydro power plant. Four impellers made of brass and AA-7075 with 5 and 6 numbers of blades were manufactured and tested for its performance. The performance is compared to the original impeller performance. Based on the experimental results, it is found that, impeller with 6-blades generates more power than 5-blade impeller. However, the type of material did not have any influence to the power generated. Meanwhile, the smoother impeller surface will increase the impeller rotational speed, up to two times faster than the original impeller.

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