Test of Shrouded 2-dimensional Microimpeller Made of SU-8

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Abstract

This paper first reports the measured performance of 2-dimensional micro impellers made of ultrathick photoresist SU-8 3000. A 16 mm diameter impeller was tested using a compact electromagnetic motor with a rated rotation speed of 100,000 rpm. The achieved pressure rise is only 0.16 kPa at 80,000 rpm, but agrees well with a computational fluid dynamics (CFD) simulation result. Also, two kinds of 10 mm diameter impeller were tested at higher rotation speed from 200,000 rpm to 400,000 rpm using an air turbine. The achieved pressure rise is 5 kPa at 200,000 rpm and 12.5 kPa at 30,0000 rpm. However, they are approximately a half of the values predicted by CFD simulation.

Keywords: *Microturbomachinery, Impeller, Turbo pump, SU-8, Computational fluid dynamics (CFD), Fuel cell*

1 INTRODUCTION

Recently, polymer electrolyte fuel cells (PEFCs), which are fueled with methanol or hydrogen, are expected as power sources of portable devices. For hydrogen-fueled PEFCs, the reaction at a cathode ($2H^+ + 2e^- + 1/2O_2 \rightarrow H_2O$) often restricts electrical output. This is because generated water covers the cathode to restrict air to enter the cathode. Therefore, it is necessary to flush the cathode with flowing air to improve efficiency. For direct methanol fuel cells (DMFCs), methanol crossover is another dominant factor to restrict the electrical output and efficiency. By crossed-over methanol, the cathode is blocked, and a part of the catalysis is wasted for the useless oxidation of methanol.

To solve these problems, we developed a miniature turbo pump to blow cathodes using a 2-dimensinal microimpeller made of ultrathick photoresist SU-8. For the application to 20 W class portable fuel cells, a flow rate of about 10 kPa and a pressure rise of 3–5 kPa are required. However, such a performance does not suit existing displacement type air pumps such as diaphragm, piston and scroll pumps, because these types of pump can produce high pressure but not large flow rate. Therefore, we have selected centrifugal turbo pump combining a 2-dimensional impeller and a high speed electromagnetic motor.

Recently, several research groups are studying microturbomachinery [1, 2]. Our group first measured the performance of a 10 mm diameter 3-dimensional impeller at high rotation speed [3]. An adiabatic efficiency of about 70 % was obtained at 83 % of the designed rotation speed (870,000 rpm). However, no experimental result for a 2-dimensional microimpeller has been reported.

In this study, the SU-8 microimpellers were tested at high rotation speed using two setups. One setup used a high-speed magnetic motor, whose rated rotation speed is 100,000 rpm. The other one used an air turbine for tests at higher rotation speed. In addition, the experimental results were compared with simulation results.

2 FABRICATION OF MICROIMPELLERS

Figure 1 show the fabrication process of SU-8 microimpellers. At first, 7 μm thick PMGI SFG15 (Kayaku MicroChem) is spin-deposited on a silicon wafer, and cured at 180 °C for 20 min (a). PMGI, which is imide-copolymer, is used as a sacrificial layer for SU-8, as it is not dissolved by SU-8 developer or thinner, but easily stripped by weak alkali water solutions such as 2–3 % TMAH. On the PMGI layer, SU-8 3000 (Kayaku MicroChem) is spin-deposited twice at 1,000 rpm for 20 s, pre-baked at 95 °C for 4 h (b), exposed

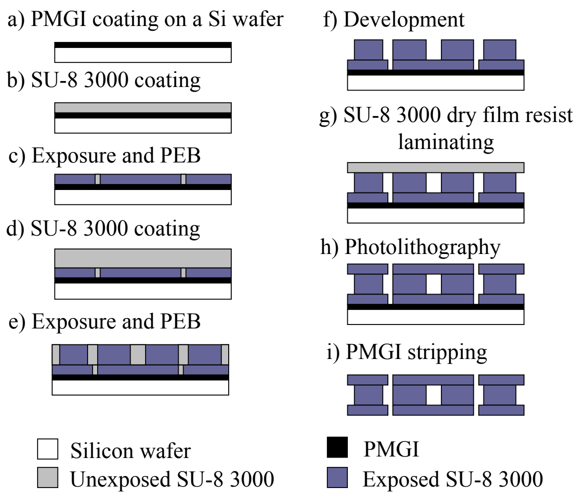

Figure 1 Fabrication process of SU-8 impellers.

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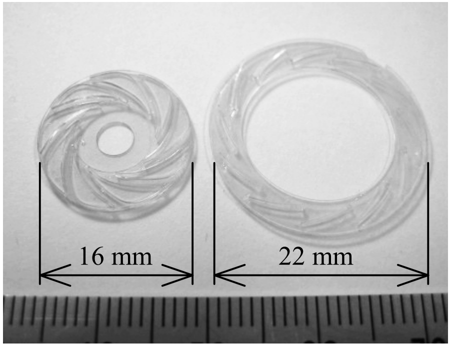


Figure 2 Fabricated impeller and diffuser.

to i-line light at 400 mJ/cm^2, and then post-exposure-baked (PEBed) at 95 °C for 10 min (c). Before the development of the first layer, the second SU-8 3000 layer is formed by 4 times spin-coating and similar subsequent processes (pre-baking at 95 °C for 12 h, exposure at 1,200 mJ/cm^2, and PEB for at 95 °C 20 min) (d, e). The first and second layer are then simultaneously developed by SU-8 developer at 54 °C (f) for 60 min, and the hub and blades are fabricated by this step.

On the second layer, 30 μm thick SU-8 3000 dry films are laminated (g) to make the shroud. The dry films are exposed at 400 mJ/cm^2, PEBed for 10 min at 95 °C, and then developed (h). Finally, the SU-8 3000 impeller and diffuser are released from the support silicon wafer by dissolving the PMGI sacrificial layer in 2.38 % TMAH solution (i). Figure 2 shows a fabricated impeller and diffuser.

3 ROTATION TEST OF MICROIMPELLERS

3.1 Test Using Electromagnetic Motor

An impeller with a 16 mm diameter was designed using the velocity triangle method and continuity equation to achieve a pressure rise of 2 kPa and a flow rate of 10 l/min at 100,000 rpm. The designed blade shape and design details are shown in Figure 3 and Table 1, respectively.

The designed impeller was fabricated by the abovementioned process, and glued onto the compact high-speed electromagnetic motor with a herring-bone hydrodynamic bearing. The outer size of the motor is ϕ40.0 mm × 12.6 mm, and the rated rotation speed is 100,000 rpm. The rotation speed, flow rate and pressure rise were measured using a setup shown in Figure. 4. Figure 5 shows the test result. The impeller generated 6.5 l/min air flow and 0.16 kPa pressure rise at 80,000 rpm.

Computational fluid dynamics (CFD) simulation was carried out to compare with the experimental result. Grid was generated in one passage of the impeller using GAMBIT, and exported to FLUENT. The grid has approximately 170,000 nodes in one passage. Computation was done using a coupled implicit solver and a k-ε turbulence model. The enhanced wall treatment was used to solve the flow near walls. The simulation result is compared with the experimental result in Figure 5. Both results agree well, and show that the pressure rise is much lower than expected. This suggests that the design of the blades is unsuitable for low tip Mach number (0.24 at 100,000 rpm).

Table 1- Blade design details for rotation test with the motor.

	Impeller	Diffuser
Blade count	9	Vaneless
Inlet diameter [mm]	8.5	16.4
Exit diameter [mm]	16.0	23.0
Blade inlet angle [degree]	17.1	-
Blade exit angle [degree]	40.8	-
Blade height [μm]	400	-
Rotation speed [rpm]	100,000	

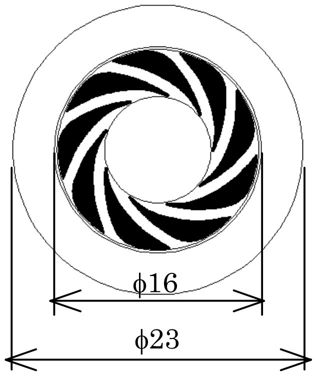


Figure 3 Designed blade shape for rotation test using the electromagnetic motor.

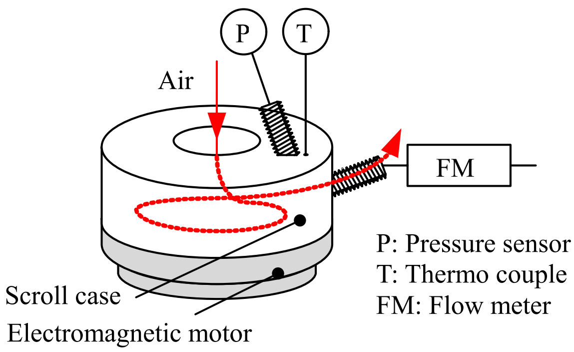


Figure 4 Test setup using the electromagnetic motor.

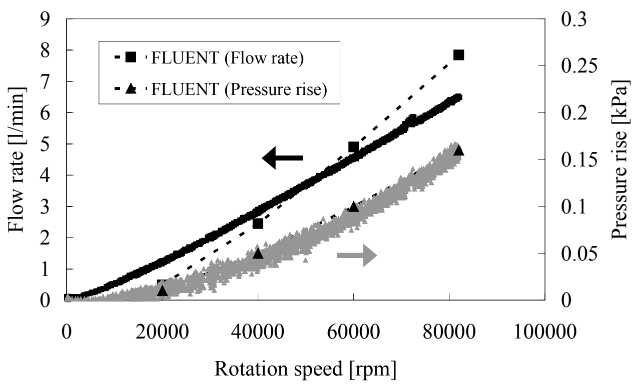


Figure 5 Measured and simulated performance of the 16 mm diameter impeller.

3.2 Test Using Air Turbine

Impeller design

Microimpellers with a 10 mm diameter were designed using the velocity triangle method and FLUENT at 500,000 rpm. Two baseline designs with thick and thin blades were determined, and the parametric study for screening was performed by changing the number, length and inlet angle of the blades. As a result, we selected two designs (Type 1 and 2) to be tested. Figure 6 and Table 2 show the designed blade shapes and design details, respectively. The diffuser for Type 1 is vane type, and set with a 200 μm clearance from the impeller. The diffuser for Type 2 is vaneless type, and set with a 150 μm clearance from the impeller. The performance of the selected two impellers was predicted in detail using FLUENT.

Experimental setup

The two designed impellers were tested using the air turbine, because high rotation speed is needed for small impellers. The configuration of the experimental setup is shown in Figure 7. The air turbine unit which drives the impeller to be tested was developed for the test of a 10 mm diameter 3-dimensional impeller [3]. In this study, the compressor unit and rotor were newly prepared. Figure 8 shows the rotor with the SU-8 microimpeller glued. The shaft and turbine impeller are made of titanium alloy, and have 4 mm and 10 mm diameter, respectively. The rotor was balanced approximately to 3.6 g·μm after assembled.

The journal and thrust bearings are hydroinertia air bearings [4] made of zirconia ceramics with a clearance of *ca.* 30 μm. The journal bearings are half-splitting type, which allows us to insert the balanced rotor into the bearings. A diffuser is also made of SU-8 3000, and glued onto a stator block with a scroll. PEEK (polyetheretherketone), which is a popular engineering plastic, is selected as the material of the stator block, because low thermal conduction of plastics is suitable to measure the efficiency of impellers. The rotation speed is measured using an optical fiber displacement sensor (D-20, Philtec) at the nut.

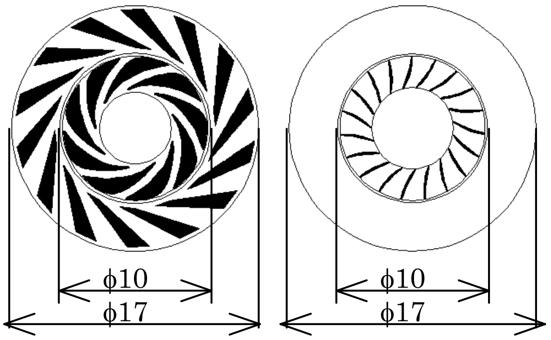


Figure 6 Designed blade shapes for rotation test using the air turbine.

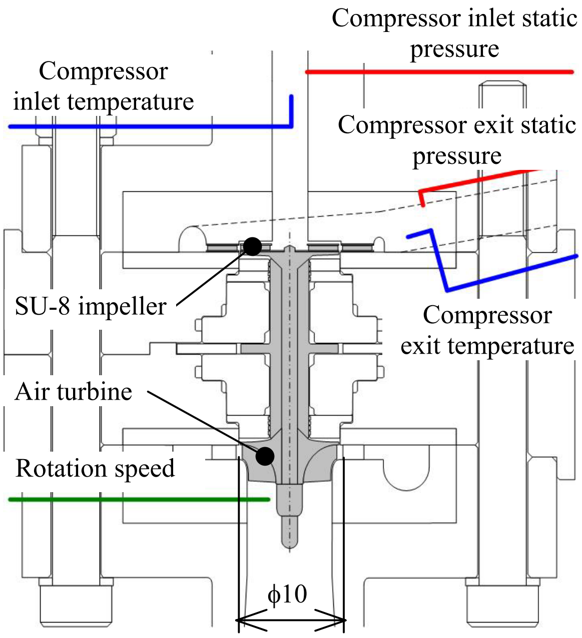


Figure 7 Configuration of the experimental setup using the electromagnetic motor.

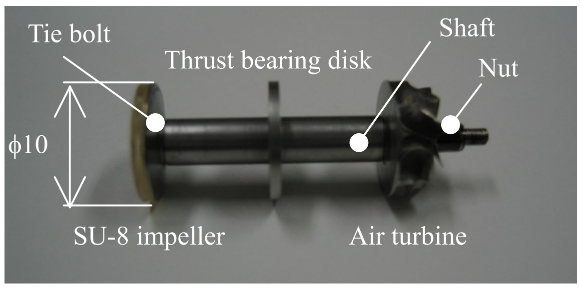
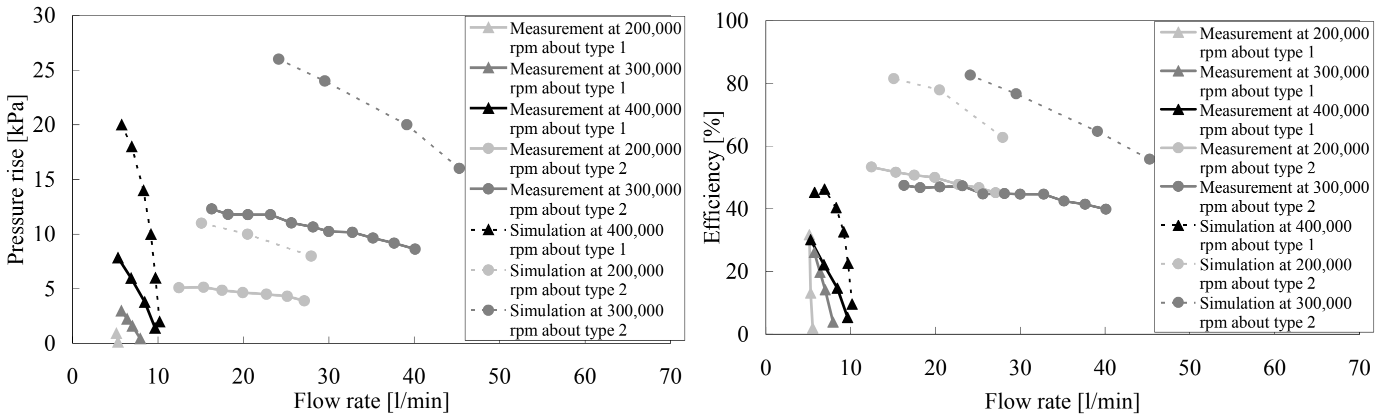


Figure 8 Rotor with the SU-8 microimpeller.

Table 2 - Blade design details for rotation test with the air turbine.

Blade type	1		2	
	Impeller	Diffuser	Impeller	Diffuser
Blade count	9	14	19	Vaneless
Inlet diameter [mm]	5	10.4	5.6	10.3
Exit diameter [mm]	10	17	10	17
Blade inlet angle [degree]	25.6	17.3	45	-
Blade exit angle [degree]	47.4	20.8	90	-
Blade height [μm]	280	280	600	-
Clearance [μm]	200		150	



(a) Pressure rise (b) Efficiency

Figure 9 Measured and simulated compressor performance.

Experimental result

Type 1 and 2 impeller were tested up to 400,000 rpm and 300,000 rpm, respectively. The maximum rotation speeds were limited by the destruction of the impellers. This limit came at lower rotation speed for Type 2 impeller, because it has thinner blades. Figure 9 shows the test results compared with the simulation results. The efficiency is defined as

$$\eta = \frac{\left(\dfrac{P_{exit}}{P_{inlet}}\right)^{(\gamma-1)/\gamma} - 1}{\dfrac{T_{exit}}{T_{inlet}} - 1}, \qquad (1)$$

where γ is specific heat ratio, $P_{\mathrm{exit}}/P_{\mathrm{inlet}}$ is a ratio of exit/inlet static pressure (pressure ratio) and $T_{\mathrm{exit}}/T_{\mathrm{inlet}}$ is a ratio of exit/inlet static temperature.

Type 2, which has thinner blades, shows higher performance than Type 1. The achieved pressure rise is 5 kPa at 200,000 rpm and 12.5 kPa at 300,000 rpm, which satisfy the requirement. However, measured pressure rise are approximately a half of the predicted one for both impellers at each rotation speed. Because the measured pressure ratio is much smaller than the predicted one, measured and predicted efficiency also show large discrepancy. We estimated pressure loss from the diffuser to a pressure sensor, but it is only a few kPa at the maximum. At present, the reason of this disagreement is not clear.

Normally, appropriate CFD simulation predicts pressure ratio within an error of ± 10 %. We need to verify the reasonableness of the CFD simulation process by solving reported problems, although the simulation result agrees well with the experimental result of the test using the electromagnetic motor.

CONCLUSION

For application to micro turbo pumps used in portable fuel cell systems, the performance of 2-dimensional microimpellers made of SU-8 3000 was measured. To the best of our knowledge, this is the first report of the measured performance of 2-dimensional microimpellers.

To test a 16 mm diameter impeller, a compact electromagnetic motor with a rated rotation speed of 100,000 rpm was used. The achieved pressure rise is only 0.16 kPa at 80,000 rpm, which is much lower than a required value of 3–5 kPa. However, simulation using FLUENT predicted a similar value to the experimental result, suggesting that the design of the blades was inappropriate.

10 mm diameter impellers were tested at higher rotation speeds from 200,000 rpm to 400,000 rpm using an air turbine. The achieved pressure rise is 5 kPa at 200,000 rpm and 12.5 kPa at 300,000 rpm, which satisfy the requirement. However, measured pressure rise are approximately a half of the predicted ones. At the present, the reason of this disagreement is not clear, and will be investigated.

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