A pump system with wave powered impulse turbine

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Abstract. Japan is surrounded on all sides by the sea. Thus, ocean development has been carried out in the midst of environmental protection. In this consequence, a numerous researches have been conducted on various apparatus that can utilize the wave energy. In this study, a pump system based on the wave energy was developed for pumping the seawater, the facility uses (e.g. aquarium, swimming pool with seawater, etc...), the preservation of farming conditions of marine products, and the replacement of seawater by pumping of the deep water. A radial pump that can be operated by an impulse turbine used for wave energy conversion was developed. The performance of this pump system was investigated experimentally. From the experimental results, the pump system could be started approximately in 20 seconds.

1. Introduction

Nowadays, the necessity of using the natural energy has increased all over the world with attention to the environmental issues. Many natural energies can be used as a renewable energy, such as solar energy, wind energy, ocean energy and so on. In ocean energy as the renewable energy, many types are focused on, such as ocean thermal energy, ocean current, wave energy, tidal energy and so on.

In wave energy conversion, several of the wave energy devices make use of the principle of oscillating water columns (OWC) for converting wave energy to pneumatic energy, which in turn can be converted into the mechanical energy. In this case, a bi-directional air turbine is necessary to convert the pneumatic energy into the mechanical energy. Setoguchi et al. [1, 2] have been developing a bi-directional impulse turbine with a fixed guide vane, and it has reported that this impulse turbine has a suitable running and starting characteristics. Finally, a generator is used to convert the mechanical power into the electricity. Previously, in order to lift the sea water, several wave-energy pumps were developed [3,4], in which the water is lifted by the reciprocating motion of the piston as shown in Figure 1. However, the maintenance for the reciprocating motion is remained as a big problem. While a turbo-type pump is easier for the maintenance. Therefore, a pump system, in which a centrifugal pump is connected directly to the shaft of the impulse turbine as shown in Figure 2, was developed in this study.
2. Experimental apparatus and procedure

Figure 3 shows the experimental setup used in this study. A piston is placed in a circular cylinder with a diameter of 1.4m and a length of 1.7m. The piston is operated by a computer controlled ball screw to generate a reciprocating airflow in the test chamber. A tested impulse turbine is connected at the test section in the wind tunnel, and a tested centrifugal pump is then installed to the same axis of the impulse turbine. In the experiment, the turbine was driven by the reciprocating airflow, and the turbine propelled the water pump. The turbine rotation speed $N$, the output torque $T_o$, the pressure difference before and after the pump $\Delta p$, the pump flow rate $Q$ were measured in order to evaluate the turbine / pump performance.

The tested turbine has two rows of guide vanes before and after the rotor, as shown in Figure 4. The turbine has an impulse type rotor with a two-dimensional shape, and the detail of the rotor is as follows:
chord length of 54mm, blade thickness ratio of 0.3, number of blades of 30, blade inlet / outlet angle of 60°. The guide vane has also a two-dimensional shape with a radius of curvature of 32.7mm followed by a straight line, a chord length of 70mm, a thickness of 2.0mm, and a setting angle of 22.5°.

As the tested pump, a single-suction and single-stage volute pump manufactured by Torishima Pump Mfg. Co., Ltd. with an inlet diameter of 50mm and an outlet diameter of 32mm was used.

In this study, a reciprocating airflow with a sinusoidal wave and a periodic time of 8.0s was used. The maximum axial airflow velocity $V$ used are 8.9 m/s, 11.0m/s, and 13.0m/s in order to investigate the influence of $V$ on the turbine-pump performance.

3. Results and discussion

For the practical purpose, a starting characteristics of the impulse air turbine and the volute pump is important. Therefore, it is investigated that the unsteady performance of the turbine and the pump from the rest to quasi-steady state.

Figure 5 shows the starting characteristics of the turbine and pump. As shown obviously in the figure, under all the experimental conditions, the turbine as well as the pump shifts from the rest to a periodic rotational state (i.e. quasi-steady condition) at approximately 20s. It can be considered from this fact that a seawater acquisition system using an impulse turbine for bi-directional air flow and a centrifugal pump could take water from the sea.

![Figure 4. Geometric details of bi-directional impulse turbine with fixed guide vanes.](image-url)
Figure 5. Time history of shaft rotation speed.

Figure 6 shows the torque-rotational speed $T_o-N$ characteristics, where $Q_{bep}$ means the flow rate at best efficiency point in the performance test of the pump itself. As seen from the figure, in the quasi-steady state, the torque of the turbine under all the experimental conditions changes periodically before and after the maximum rated flow rate of the pump. From this result, it is considered that when the torque of the turbine is higher than the torque of the pump at maximum flow rate, the rotation of the turbine is accelerated, and when the torque is low, the rotation speed of the turbine decelerates, that means a periodical change in the rotational speed occurs.

Figure 6. The relation between torque and rotation speed.
Figure 7. Unsteady characteristic curve of the pump.

Figure 7 shows the $H$-$Q$ characteristics. From the figure, under all experimental conditions, the pump flow rate or the total head in the quasi-steady state is less than half of the pump flow rate or the total head at each rotation speed calculated from the rated specification of the pump. From this result, since the flow rate is very low, the radial inflow velocity at the entrance to the pump impeller becomes extremely small with respect to the circumferential inflow velocity; the water can not sufficiently flow along the impeller. Thus, it leads to the reduction in the total head.

Figure 8 shows the pump efficiency. From the figure, under all the experimental conditions, the average pump efficiency in the quasi-steady condition is approximately 9%, which is about 1/7 of the pump efficiency at the rated maximum flow rate. This result seems to be because the flow rate or the total head is lower, and the water power becomes smaller than the torque generated in the turbine.
4. Conclusions
A seawater acquisition system, which consists of an impulse turbine for bi-directional airflow and a centrifugal pump, was investigated experimentally under a reciprocating airflow, and the following conclusions are obtained from the results of the turbine and pump performance.

(1) It was confirmed that the proposed system could pump the water for a seawater acquisition pump system combining with an impulse turbine for bi-directional airflow and a centrifugal pump.

(2) The time required to shift the system from the rest to a quasi-steady condition was almost constant irrespective of the change in the maximum axial flow velocity of the turbine.

(3) It was found that the torque increases with the maximum axial flow velocity of the turbine, and therefore, it results in the increase in the flow rate and total head.

5. References
[1] Setoguchi T, Takao M, Kinoue Y, Kaneko K, Santhakumar S and Inoue M 2000 *Int. J. Offshore and Polar Eng.* **10** 145
[2] Setoguchi T, Santhakumar S, Maeda H, Takao M and Kaneko K 2001 *Renewable Energy* **23** 261
[3] Ishibashi M, Harada H and Siki A 1987 *Proc. 2nd Symp. on Wave Energy Utilization in Japan (Tokyo)* p 35
[4] Kawaguty K and Ueki H 1991 *Proc. 3rd Symp. on Wave Energy Utilization in Japan (Tokyo)* p 37