RADIAL TURBINE WITH AIRFLOW RECTIFICATION SYSTEM FOR WAVE ENERGY CONVERSION

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ABSTRACT The objective of this study is to propose a new radial flow turbine for wave energy conversion and to clarify its performance by model testing. The proposed radial turbine has a rotor blade row for uni-directional airflow and two guide vane rows. The guide vane rows are named ‘floating nozzle’ in the study. The guide vane rows slide in an axial direction and work as nozzle in the turbine alternately for bi-directional airflow, so as to rectify bi-directional airflow and to make uni-directional airflow. The rotor with a diameter of 500mm has been manufactured and investigated experimentally under steady flow condition which is generated by a wind tunnel using a piston/cylinder system with a diameter of 1.4m. As a result, it has been found that the peak efficiency of the proposed turbine is approximately 57% and the rotational speed of this turbine is considerably lower than that of Wells turbine.

Keywords: Fluid Machinery, Natural Energy, Radial Turbine, Wave Energy Conversion

1. INTRODUCTION

Several of the wave energy devices being studied under any wave energy program make use of the principle of an oscillating water column (OWC). In such wave energy devices an oscillating water column due to wave motion is used to drive an oscillating air column which is converted into mechanical energy. The energy conversion from the oscillating air column can be achieved by using a self-rectifying air turbine such as Wells turbine [1-7] and other newly proposed turbines [5, 8-14]. However, in general, the self-rectifying turbine has inherent disadvantages: relatively low efficiency and poor starting characteristics because the self-rectifying turbine has symmetrical configuration with respect to the plane perpendicular to the rotor axis in order to operate in bi-directional reciprocating flow. For instance, the efficiency of these turbines under steady flow condition is approximately 60% at the best. Further, the noise will be a serious problem when a large-scaled Wells turbine is installed in a coastal bank or gully because it is operated essentially at a high rotational speed in the running conditions. And such a high speed operation may increase maintenance costs. In order to develop a self-rectifying air turbine operated at low rotational speed, some radial flow turbines for bi-directional airflow have been studied so far [15, 16]. According to previous studies, it was found that the efficiencies of the radial flow turbines were less than 50%.

On the other hand, researches and proposals on the wave energy devices using a system of non-return valves for rectifying the airflow, together with a conventional turbine such as the Francis turbine, have been reported so far [17-21]. This is because the peak efficiency of the conventional turbine is higher than that of the self-rectifying turbine, though such a system is complicated and difficult to maintain. The representative wave energy converter using the rectification valve system is the wave activated generator used as navigation buoy invented in Japan, and it has been used in some countries including Japan [17]. It is important to develop a turbine with the rectification system for wave energy conversion because the system with rectification valves seems to be a promising technique to utilize the wave energy with small wave height. Although axial flow turbines were used for the above devices so far, a radial flow turbine for wave energy conversion has not been developed for uni-directional air flow.

The objective of this study is to propose a new radial flow turbine with air flow rectification system for wave energy conversion and to clarify its performance by model testing under steady flow condition. Figure 1 is a photograph of the proposed radial turbine. This radial turbine has a rotor blade row for uni-directional airflow and two guide vane rows as shown in the photograph. The guide vane rows are named ‘floating nozzle’ in the study. The guide vane rows slide in an axial direction and work as nozzle in the turbine alternately for bi-directional airflow, so as to rectify bi-directional airflow and to make uni-directional airflow. The radial flow turbine with a diameter of 500mm has been manufactured and investigated experimentally under steady flow condition generated by a wind tunnel using a piston/cylinder system with a diameter of 1.4m.

2. RADIAL TURBINE USING FLOATING NOZZLE FOR WAVE ENERGY CONVERSION
lower nozzle rows. When an OWC in air chamber goes down together with wave motion as shown in Fig. 2(a) (this phenomenon is named ‘inhalation’ in the study), floating nozzle rows also come down and it set by lower stopper. Then, air comes into upper nozzle row from atmosphere, and it flows from upper nozzle row to air chamber via rotor blade row. Conversely, when the OWC goes up as shown in Fig. 2(b) (this phenomenon is named ‘exhalation’ in the study), floating nozzle rows also go up and they are placed at upper stopper. And next, air from air chamber passes through lower nozzle row and air comes into rotor blade. After passing rotor blade, air leaves for atmosphere. In both inhalation and exhalation, air always flows from outside of rotor to its inside. Therefore, this radial turbine rotates in the same direction and works efficiently in oscillating air flow.

3. EXPERIMENTAL APPARATUS AND PROCEDURE

The test rig consists of a large piston-cylinder, one end of which is followed by a settling chamber as shown in Fig. 3. The radial turbine’s axial entry/exit is attached to the settling chamber. The piston can be driven back and forth inside the cylinder by means of three ball screws through three nuts fixed to the piston. All three screws are driven by a d.c. servo-motor through chain and sprockets. A computer controls this motor and hence the piston velocity to produce any airflows (intermittently for short periods). The test turbine rotor shaft is coupled to the shaft of a servo-motor-generator through a torque transducer. The motor-generator is electronically controlled such that the turbine shaft angular velocity is held constant at any set value. The flow rate through the turbine $Q$, whether it is inhalation (flow from the atmosphere into the rig) or exhalation (flow from the rig to the atmosphere), is measured by Pitot tube survey. The radial flow velocity $v_R$ at mean radius $r_R$ in the turbine is calculated from $Q = A_R v_R$ where $A_R$ is the flow passage area at mean radius ($= 2\pi r_R h$). In a typical test, for a particular
In order to investigate the effect of nozzle setting angle \( \theta \) (see Fig. 4) on turbine characteristics, the range of \( \theta \) is from \( 103^\circ \) to \( 115^\circ \).

The geometry of rotor blade is shown in Fig. 5 and is the same as what was used in previous studies [15]. Detailed information about the blade profile is as follows: chord length of 55mm; mean radius of \( r_R = 225mm \); height \( h = 30mm \); number of blades of 23; solidity at \( r_R \) of 0.895; radius of leading edge of 3mm; radius of leading edge of 0.5mm.

In the experiments, only one nozzle row is used and fixed in the turbine in order to investigate the performance of the rotor blade as the first step of the study.
Fig. 7 Effect of nozzle setting angle on peak efficiency under steady flow conditions

4. EXPERIMENTAL RESULTS AND DISCUSSIONS

As the first step to an analysis of the new radial turbine, the turbine characteristics under steady flow conditions have been clarified in this section. Experimental results on the running characteristics of turbine are expressed in terms of the torque coefficients $C_T$, input coefficient $C_A$, and efficiency $\eta$, which are all plotted against the flow coefficient $\phi$. The various definitions are:

$$C_T = T / (\rho (w_r^2 + U_R^2) \Delta p R^2 / 2)$$  \hspace{1cm} (1)

$$C_A = \Delta p Q / \rho (w_r^2 + U_R^2) A_v w_R / 2$$

$$= \Delta p (\rho (w_r^2 + U_R^2) / 2)$$  \hspace{1cm} (2)

where $\rho$ and $U_R$ are the density of air and the rotational speed at $\rho_0$, respectively.

Efficiency, which is the ratio of shaft power output to pneumatic power input, can be expressed in terms of the coefficients mentioned above:

$$\eta = T_\omega / (\Delta p Q) = C_T (C_A \phi).$$  \hspace{1cm} (3)

The flow coefficient $\phi$ is defined as

$$\phi = w_R / U_R.$$  \hspace{1cm} (4)

Figures 6 and 7 show the effect of nozzle setting angle on the turbine characteristics under steady flow conditions. As shown in Fig. 6(a), the torque coefficient $C_T$ depends on $\theta$ and $C_T$ decreases with $\theta$ increasing. This is because the whirl velocity of inlet flow to rotor decreases with $\theta$ increasing. On the other hand, the input coefficient $C_A$ also decreases with $\theta$ increasing in Fig. 6(b). This is because the flow path area between the nozzles increases with $\theta$. Combining the above results and Eq. (3), it is evident from Figs. 6(c) and 7 that the peak efficiency $\eta_{\text{peak}}$ increases with $\theta$ and the highest efficiency occurs at $\theta = 107^\circ$. Its value is approximately 0.571. However, the efficiency increases with $\theta$ at higher flow coefficient as shown in Fig. 6(c). Regarding the flow coefficient showing the peak efficiency $\phi_{\text{peak}}$ increases with $\theta$.

Therefore, from a view point of the rotation speed, the higher setting angle is better for the turbine. Moreover, the rotational speed of this radial turbine is considerably lower than that of Wells turbine which is operated at approximately $\phi = 0.2$.

5. CONCLUSIONS

The objective of this study was to propose a new radial flow turbine with novel airflow rectification system for wave energy conversion and to clarify its performance by model testing under steady flow condition. As a result, it has been found in the study that the peak efficiency of the proposed radial turbine in the study is approximately 57% and the rotational speed of this turbine is considerably lower that that of Wells turbine. Further, the effect of nozzle setting angle on the turbine performance was investigated and it was concluded that the optimum nozzle setting angle seems to be $\theta = 107^\circ$ (see Fig. 4) in the study.

REFERENCES


