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Study of the radial Turbine for Wave Energy Conversion

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파력발전용 레이디얼터빈성능에 관한 연구

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Abstract

The objective of this study is to clarify the detailed performances of the impulse type radial turbine and to present an optimum configuration of the turbine. The impulse type radial turbine has been manufactured and investigated experimentally under steady and sinusoidally oscillating flow conditions by model testing. Then, the starting characteristics under sinusoidally flow conditions have been evaluated by a numerical simulation using a quasi-steady analysis. As a result, the running and starting characteristics of the impulse type radial turbine for wave energy conversion have been clarified. Furthermore, the recommended configuration is presented, especially for setting angles of inner and outer guide vanes.

1. INTRODUCTION

A Wells turbine is a self-rectifying air turbine which is expected to be widely used in wave energy devices with oscillating water column. However, 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.

In order to develop the self-rectifying air turbine operated at low rotational speed, a number of radial flow turbines for wave power conversion have been studied so far [1~5]. It was found that the efficiency of radial turbines using reaction typed rotor blades [1,2]. On the other hand, according to previous studies [4,5], they said that the efficiency of impulse typed rotor blades was rather high. However, detailed performance characteristics of impulse typed radial turbine have not been reported until now. To investigate the performance, experimental works were carried out on a radial turbine (508.8mm rotor diameter) with different guide vane geometries. Performance was also measured for flow radially inward and outward though the turbine, which is made possible by an oscillating flow rig. Two different configurations were also tried. The results of laboratory tests are present in this paper.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

The test rig consists of a large piston-cylinder, one end of which is followed by a setting chamber. The radial turbine's axial entry/exit is attached to the setting chamber as shown in Fig. 1. 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 the three screws are driven by a D.C. servo-motor through chain and sprockets. A computer controls the motor and hence the piston velocity to produce sinusoidal flow or steady flow (intermittently for short periods).

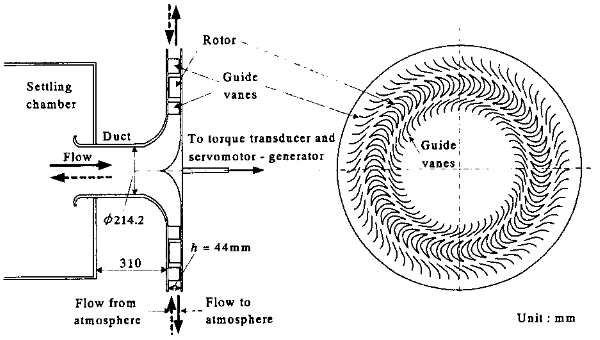

Fig. 1 Outline of radial turbine

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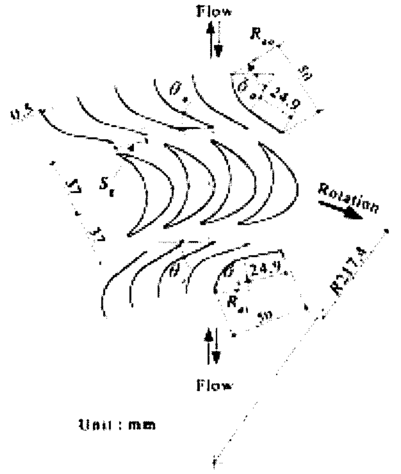
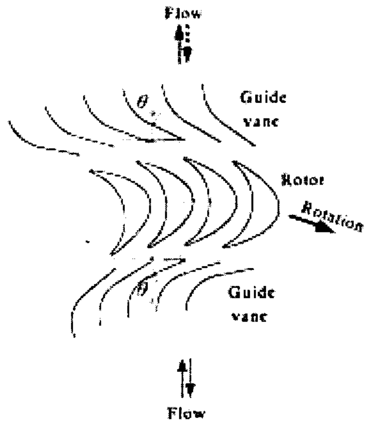
The flow rate through the turbine Q, whether it is inhalation (i.e., flow from atmosphere into the rig) or exhalation (i.e., flow from the rig to the atmosphere), is calculated by measuring the motion of piston. Tests were performed with turbine shaft angular velocities up to about 73 rad/s and flow rates up to about 0.32 m^3/s. The Reynolds number based on blade chord was approximately $6x10^4$ at conditions corresponding to peak efficiency of turbine. The measurement uncertainty in efficiency is about ±1%.



(a) Case (1)



(b) Case (2)

Fig. 2 Configuration of turbine

Table 1 Specifications of guide vane

θ_o°	R_{ao} mm	δ_o°	Remarks
15	24.9	66	Number of vanes : z_{go}=73, z_{gi}=52; Solidity : σ_{go} =2.28, σ_{gi} =2.29; Pitch : S_g=22mm ; Chord length: 50mm; Height : 43mm.
20	26.8	62	
25	28.7	55	
30	30.4	52.5	
θ_i°	R_{ai} mm	δ_i°	
20	22.1	83.1	
25	22.2	78	
30	23.8	71.7	

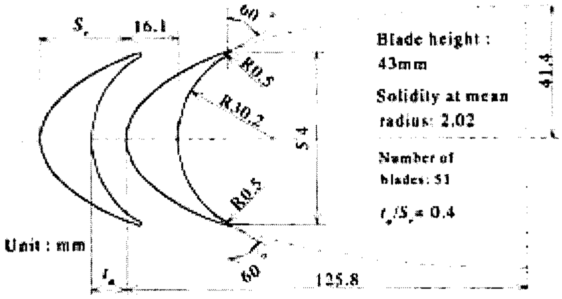


Fig. 3 Rotor geometry

The radial turbine shown in Fig. 1 was tested at a constant rotational speed under steady and sinusoidal oscillating flow (frequency f = 0.1). The sign and magnitude of the torque of the motor-generator is servo-controlled so as to hold the turbine speed constant even if flow velocity is varying with time. The part of turbine casing and the part of disk covering both the guide vanes are flat and parallel to the axial entry/exit has been shaped such that the flow area is constant along this passagae.

The guide vane geometries are shown in Fig. 2. Four outer guide vanes and three inner guide vanes were used in the tests. Details of the guide vanes are given in Table 1. Rotor blade geometry is shown in Fig. 3 and it is the same one that was used in previous studies [6,7]. Two orientations are possible while fixing a rotor to the disk as shown in Figs. 2(a) and (b). They are designated as case (1) and case(2) in this paper.

3. RESULTS AND DISCUSSIONS

3.1 Turbine Performance under Steady Flow Conditions

Experimental results on the running characteristics of turbine are expressed in terms of the torque coefficients C_T, input coefficient C_A and efficiency η, which are all plotted against the flow coefficient ϕ.

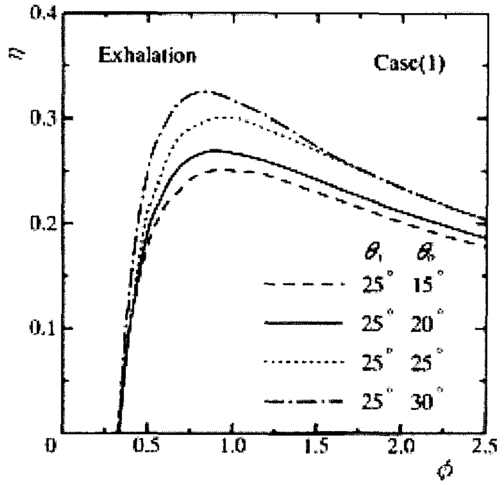
$$C_T = T_o/\{\rho\ (v_R^2+U_R^2)\ A_R r_R/2\} \tag{1}$$

$$C_A = \Delta pQ/\{\rho\ (v_R^2+U_R^2)\ A_R v_R/2\}=\Delta p/\{\rho\ (v_R^2+U_R^2)/2\} \tag{2}$$

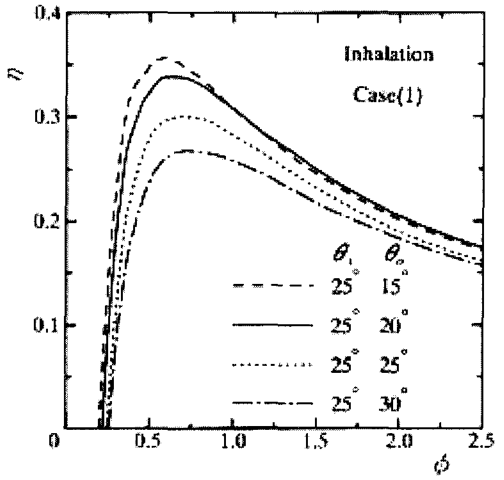
$$\eta = T_o\omega\ /(\Delta pQ)= C_T/(C_A\phi) \tag{3}$$

$$\phi = v_R\ /U_R \tag{4}$$

Fig. 4 shows the effect of setting angle of outer guide vane on the turbine characteristics during the exhalation and inhalation flow processes under steady flow conditions. In experiments the inner guide vane was fixed in the setting

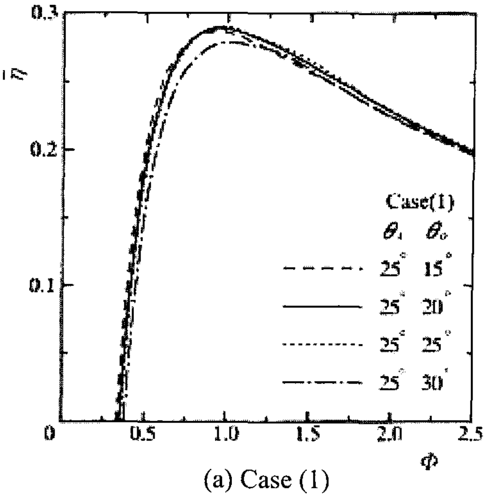


(a) Exhalation flow process

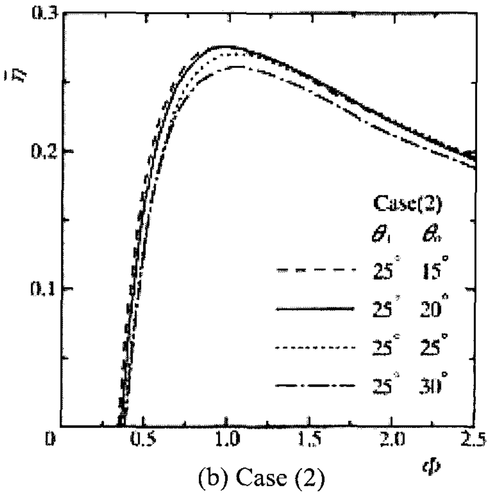


(b) Inhalation flow process

Fig. 4 Effect of setting angle of outer guide vane on turbine efficiency under steady flow conditions



(a) Case (1)



(b) Case (2)

Fig. 5 Effect of configuration on mean efficiency under sinusoidally oscillating flow conditions

angle of 25°. As shown in Fig. 4(a), the turbine efficiency increases with increasing the setting angle of outer guide vane. This is because the outer guide vane works as a diffuser during the exhalation flow process. In Fig. 4(b), the turbine efficiency decreases with increasing the setting angle of outer guide vane because the outer guide vane works as nozzle. From Figs. 4(a) and (b), it can be seen that the maximum efficiency in the inhalation flow process is slightly higher than that in the exhalation flow process.

3.2 Turbine Performance under Sinusoidally Oscillating Flow Conditions

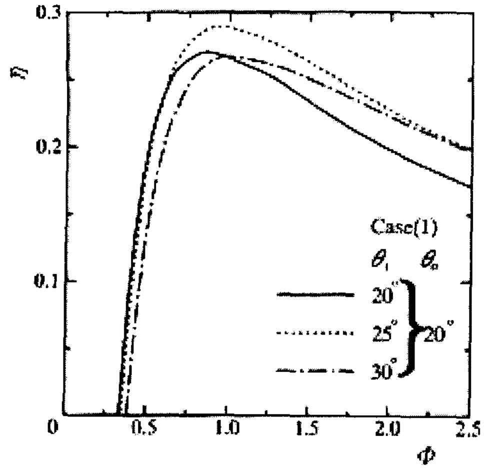
Experiments were carried out on the sinusoidally oscillating air flow with a period of T (= 10s). Mean efficiency $\bar{\eta}$ and flow coefficient Φ are defined as:

$$\bar{\eta} = \left\{\frac{1}{T}\int_0^T T_o\omega \,dt\right\} \Big/ \left\{\frac{1}{T}\int_0^T \Delta p Q \,dt\right\} \tag{5}$$

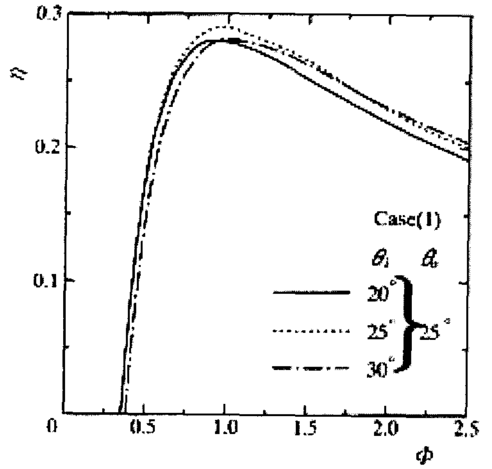
$$\Phi = V_R / U_R \tag{6}$$

Fig. 5 shows the effect of configuration on the mean efficiency under sinusoidally oscillating conditions. As is evident from the figures, the efficiency for case (1) is higher than that for case (2). Furthermore, the maximum efficiency is obtained for θ_o = 20° and 25° as shown in Fig. 5(a). Although the peak efficiency occurs for setting angle of 30° during the exhalation and for 15° during theinhalation in the steady flow as shown in Fig. 4, the best performance under the unsteady flow is obtained for medium values of setting angle (i.e., 20° and 25°).

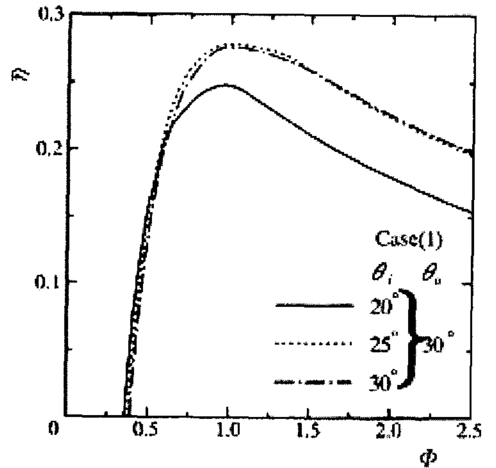
The effect of setting angle of inner guide vane on the mean efficiency in the sinusoidal air flow is presented in Fig. 6. It is found that θ_i = 25° gives the best efficiency for all values of θ_o as shown in the figures.



(a) $\theta_o = 20°$



(b) $\theta_o = 25°$



(c) $\theta_o = 30°$

Fig. 6 Effect of setting angle of inner guide vane on mean efficiency under sinusoidally oscillating flow conditions

4. CONCLUSION

The performance of radial turbine with impulse typed rotor blades has been investigated experimentally for running characteristics. Steady flow tests show that efficiency is higher in the inhalation flow process than in the exhalation flow process.

Parametric studies were made by varying the inner and outer guide vane angles and the rotor blade configuration. The recommended configuration consists of the 25° guide vane angle for both inner and outer guide vanes and case (1) rotor blade configuration in a sinusoidally oscillating air flow.

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