International Journal of Offshore and Polar Engineering
Vol. 1, No. 2, June 1991 (ISSN 1053-5381)

Biplane Axial Turbine for Wave Power Generator

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ABSTRACT

Experimental investigations directed towards improving the overall characteristics of the self-rectifying turbine for a wave power generator are reported. First, biplane axial turbines with various setting angles have been manufactured and tested in a computer-controlled wind tunnel, which can simulate arbitrary oscillating flows. The effects on the turbine performance of the blade setting angle, gap-to-chord ratio, solidity and arrangement of the biplane rotor have been examined. The results have been compared with those of the air turbine with self-pitch-controlled blades and the biplane Wells turbine from the viewpoints of the running characteristics and starting characteristics. As a result, a choice of design factors has been suggested. Next, the hysteretic characteristics of the turbine have been examined in order to establish a design method. The hysteresis is more sensitive to the solidity and arrangement of the biplane rotor and less sensitive to the setting angle and gap-to-chord ratio.

NOMENCLATURE

b : span of blade
C_A : output coefficient defined by Eq. 4
C_T : torque coefficient defined by Eq. 1
Bi : biplane
f : frequency of wave motion
F_1 : nondimensional output torque = $T/(\pi\rho V_a^2 r_R^3)$
G : gap of rotors
I : moment of inertia
ℓ : chord length
Mo : monoplane
p^* : total pressure coefficient defined by Eq. 2
Q : flow rate
r : radius
S : nondimensional frequency = $r_R f/V_a$
t : time
t^* : nondimensional time = tf
T : output torque
T_L : loading torque
U : circumferential velocity
v_a : mean axial velocity
V_a : maximum value of
W : relative velocity at inlet
X_I : dimensionless moment of inertia = $I/(\pi\rho r_R^5)$
X_L : dimensionless loading torque = $T_L/(\pi\rho V_a^2 r_R^3)$
z : number of blades
γ : setting angle
ΔC_A : difference in C_A due to hysteresis
ΔC_T : difference in C_T due to hysteresis
ΔP_o : total gauge pressure in air chamber
η : efficiency
$\overline{\eta}$: mean efficiency for sinusoidal wave
ρ : density of air
σ : solidity
ω : angular velocity of rotor (rad/s)
ω^* : dimensionless angular velocity = ω/f

Subscripts
R : mid span
S : steady

Received February 16, 1990: revised manuscript received by the editors December 12, 1990.
KEY WORDS: Biplane axial turbine, wave energy, wave power turbine, wave power generator, hysteresis.

INTRODUCTION

One of the renewable energy sources that has received close attention is the energy contained in ocean waves. There are various techniques for extraction of energy from waves. Some are based on a power train system of hydro-pneumatic-mechanical-electrical energy conversion in which an air turbine is an essential element.

The Wells turbine for a wave power generator is a self-rectifying air turbine that is available for an energy conversion in an oscillating water-air column without any rectifying valve. There are several reports on the performance of the Wells turbine both as to the starting and running characteristics (Raghunathan et al., 1985, 1986; Inoue et al., 1986a, 1986b; Kaneko et al., 1986; Setoguchi et al., 1986). According to these results, the Wells turbine has inherent disadvantages: low efficiency, poor starting characteristics and high axial thrust in comparison with the conventional air turbines. Therefore, it is necessary to improve these points in order to develop a practical wave power generator system.

The purpose of this study is to develop a new self-rectifying turbine with relatively high efficiency and lower operating rotational speed. The turbine proposed here consists of two rotors (biplane turbine) with several symmetrical airfoil blades with setting angles. In this paper, first, the biplane turbine with various setting angles has been manufactured and tested to investigate the effects on the turbine performance of the blade setting angle, gap-to-chord ratio, solidity and arrangement of the biplane rotor. The results have been compared with those of the air turbine with self-pitch-controlled blades (Hamakawa et al., 1988) and the biplane Wells turbine (Inoue et al., 1986c) from the viewpoints of the running and starting characteristics. A suitable choice of design factors has been suggested. Next, the hysteretic characteristics of the