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Impulse Turbine with Self-Pitch-Controlled Guide Vanes for Wave Power Conversion: Performance of Mono-Vane Type

T. Setoguchi, K. Kaneko and H. Maeda
Department of Mechanical Engineering, Saga University Saga, Japan

T. W. Kim and M. Inoue
Department of Mechanical Engineering for Power
Kyushu University, Fukuoka, Japan

ABSTRACT

An impulse turbine with self-pitch-controlled guide vanes was proposed by the authors in a previous paper. The unsteady characteristics of this turbine have been investigated experimentally by the use of turbine test equipment in which the sinusoidally reciprocating flow conditions are simulated. The results have been compared with those of a Wells turbine. Furthermore, in order to clarify the usefulness of quasi-steady analysis of this turbine, they have been also compared with the analytical results calculated on the basis of the experimental data obtained by the model testing of a turbine rotor with fixed guide vanes under steady unidirectional flow conditions. As a result, it has been clarified that the impulse turbine presented here is superior to the Wells turbine in overall characteristics, and the quasi-steady analysis is available for this turbine.

NOMENCLATURE

a, a' : major radius (see Fig. 3)
b, b' : minor radius (see Fig. 3)
C_A : input coefficient defined by Eq. 5
C_T : torque coefficient defined by Eq. 4
f : frequency of wave motion
F : nondimensional output torque = $T/(\pi\rho V_a^2 \gamma_R^3)$
h : blade height
I : moment of inertia
l : chord length
Q : flow rate
r : radius
S : blade space at mean radius (see Fig. 2)
S_f : nondimensional frequency = $r_R f/V_a$
t : time
t^* : nondimensional time = tf
t_a : width of flow path at mean radius (see Fig. 2)
t_t : thickness of rotor edge (see Fig. 3)
T : output torque
T_L : loading torque
U : circumferential velocity
v : absolute flow velocity
v_a : mean axial velocity
V_a : maximum value of
w : relative flow velocity
X_I : nondimensional moment of inertia = $I/(\pi\rho\gamma_R^5)$
X_L : nondimensional loading torque = $T_L/(\pi\rho V_a^2 \gamma_R^3)$
z : number of blades
α : incident angle of guide vane
γ : blade inlet angle
Δp : total pressure drop between settling chamber and atmosphere
$\overline{\eta}$: mean efficiency defined by Eq. 1
θ : pitch angle
θ_1 : setting angle of upstream guide vane (see Fig. 2)
θ_2 : setting angle of downstream guide vane (see Fig. 2)
λ : sweep angle (see Fig. 3)
ρ : density of air
ω : angular velocity of rotor
ω^* : nondimensional angular velocity = ω/f

Subscripts
g : guide vane
mi : minimum
r : rotor
R : mean radius

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KEY WORDS: Fluid machinery, wave, guide vane, impulse turbine, wave energy, wave power generator.

INTRODUCTION

In 1976, Dr. A. A. Wells proposed a form of self-rectifying axial flow air turbine, the so-called Wells turbine, as a device suitable for energy conversion in an oscillating water column. Several reports investigate the performance of the Wells turbine focusing on both the starting and running characteristics (Inoue et al., 1985, 1986a, 1986b, 1986c, 1986d, 1988, 1988; Kaneko et al., 1986, 1987; Raghunathan et al., 1982, 1987a, 1987d, 1987c, 1989b, 1989c; Setoguchi et al., 1986). According to these results, the Wells turbine has inherent disadvantages: lower efficiency, poorer starting and a high axial thrust in comparison with conventional turbine. So far, some new versions have been tried to overcome these points (Gato et al., 1990; Hamakawa et al., 1988; Inoue et al., 1986b, 1989; Kaneko et al., 1990; Raghunathan et al., 1987d, 1989a; Sarmento et al., 1987; Setoguchi et al., 1990, 1991).

On the other hand, a number of impulse turbines for wave power conversion have been presented so far. The McCormick turbine is one of them. It was constructed and tested (Richard et al., 1986), and the average efficiencies near 0. 3 appear to have been attained. Furthermore, the authors have proposed an impulse turbine with self-pitch-controlled guide vanes, which is designed to develop a practical wave power generator system