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Study on a Wells Turbine for Wave Power Conversion: Improvement of Performance by the Use of Porous Fences

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ABSTRACT

In order to improve the performance of a Wells turbine, porous fences have been installed on the hub wall upstream and downstream of the rotor. The effects of the gap between the porous fence and rotor, porosity and height of the porous fence have been investigated by model testing. The results have been compared with those of the case without porous fences. It is found that the starting characteristics are improved by the porous fences. Furthermore most of the configurations tested have shown improvements in the operation range primarily by postponement of stall. A suitable choice of design parameters for the turbine is suggested.

NOMENCLATURE

AR : aspect ratio of rotor blade
b : blade height
C_A : input coefficient defined by Eq. 4
C_T : torque coefficient defined by Eq. 3
D_t : tip diameter of rotor
f : frequency of wave
G : gap between rotor and porous fence
H : fence height
I : moment of inertia of rotor
l : chord length of rotor blade
P : porosity of fence
Q : flow rate
r : radius of rotor
r_R : mean radius of rotor
r^* : dimensionless radius = $2r/D_t$
S : dimensionless frequency $= r_R f/V_a$
t : time
t^* : dimensionless time $= tf$
T : output torque
T_L : loading torque
T_r : relative turbulence level = $\tilde{u}/w_1$
T_u : inlet turbulence level $\tilde{u}/v_a$
$\tilde{u}$: rms value of fluctuation velocity
U_R : blade speed at r_R
v : axial flow velocity
v_a : mean axial flow velocity
$v_{aw/o}$: mean axial flow velocity in case without porous fences
v_a^* : dimensionless velocity = $v/v_{aw/o}$
V_a : maximum value of v_a
w_1 : mean relative velocity at inlet
X_I : dimensionless moment of inertia = $I/(\pi\rho r_R^5)$
X_L : dimensionless loading torque = $T_L/(\pi\rho r_R^3 V_a^2)$
z : number of rotor blades
Δp : mean total pressure drop between settling chamber and atmosphere
$\bar{\eta}$: mean turbine efficiency
ν : hub-to-tip ratio
ρ : density of air
σ_R : solidity of rotor blade at r_R
ϕ : flow coefficient = v_a/U_R
Φ : flow coefficient = V_a/U_R
ω : angular velocity
ω^* : dimensionless angular velocity = ω/f

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KEY WORDS: Fluid machinery, Wells turbine, porous fence, wave energy conversion, ocean energy.

INTRODUCTION

Several of the wave energy devices currently studied in the United Kingdom, Japan, Portugal, India and other countries make use of the principle of an oscillating wave-air column for converting wave energy to low-pressure pneumatic energy which in turn can be converted into mechanical energy. In this case, the development of a bidirectional air turbine has come up as an important problem. So far, a number of self-rectifying air turbines with different configurations have been proposed, including the Wells turbine (Gato et al., 1988; Inoue et al., 1986a; Raghunathan et al., 1987; Raghunathan, 1995; Suzuki et al., 1985; White, 1995), a turbine using pitch-controlled blades (Raghunathan et al., 1997; Sarmento et al., 1987; Takao et al., 1997), an impulse turbine with self-pitch-controlled guide vanes (Setoguchi et al., 1993) and so on (Kaneko et al., 1992). Among them the most promising turbine at present is the Wells turbine.

There are several reports on the performance of the Wells turbine and the factors which influence its performance (Raghu-