International Journal of Offshore and Polar Engineering
Vol. 4, No. 1, March 1994 (ISSN 1053-5381)

Aerodynamics of Monoplane Wells Turbine — A Review

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ABSTRACT

The Wells turbine is an air turbine suitable for wave energy conversion. The principles of operation and factors controlling the performance of single plane Wells self-rectifying air turbines are discussed. Techniques to improve the turbine performance and methods of prediction are also given in this paper.

NOMENCLATURE

A_b : blade plane from area
AR : blade aspect ratio ℓ/c
c : chord length
C_A : blade normal force coefficient $C_\ell \cos \alpha + C_d \sin \alpha$
C_d : blade drag coefficients $D/{}^1/_2\rho v^2 A_b$
C_ℓ : blade lift coefficient $L/{}^1/_2\rho v^2 \mathrm{A_b}$
C_T : blade chordwise force coefficient $C_\ell \sin \alpha - C_d \cos \alpha$
D : drag force
$C_{t,h}$: turbine tip diameter, hub diameter
f : frequency
f^* : nondimensional frequency fc/U
F_A : axial force on the blades
F_T : tangential force on the blades
g : blade offsetting ratio
h : hub-to-tip ratio D_h/D_t
ℓ : blade height
L : lift force
M : Mach number
n : number of blades
N : number of cycles
Q : volume of flow rate through the turbine
Δp : pressure drop across rotor
p^* : nondimensional pressure drop $\Delta p/\rho\, \omega^2 D_t^{\,2}$
r : radius
R : blade tip Reynolds number $U_t\, c/\upsilon$
t : blade thickness
t_c : tip clearance
T_u : turbulence level
U, U_t : mean peripheral velocity, tip velocity
V : relative velocity $\sqrt{}U^2 + V_A^{\,2}$
V_A : axial airflow velocity
W : power output
W^* : nondimensional power output $W/\rho\, \upsilon^3 D_t^{\,5}$
C_τ : thickness ratio t/c
τ_c : tip clearance ratio t_c/c
α_m : average incidence between tip and hub
ϕ : mean flow coefficient V_A/U
ϕ_t : flow coefficient at tip V_A/U_t
η : efficiency $W/(\Delta PQ)$
η : average cyclic efficiency
σ : turbine solidity $2nc/\{\pi D_t(1+h)\}$
σ_t : turbine solidity at the tip $nc/(\pi D_t)$
ω : angular velocity
ρ : air density
υ : kinematic viscosity of air

INTRODUCTION

Several of the wave energy devices currently studied in the United Kingdom, Japan, Portugal, Norway and other countries make use of the principle of oscillating water-air column (Whittaker et al., 1985a; 1985b) for converting wave energy to low pressure pneumatic energy which in turn can be converted into mechanical energy of rotation by a Wells turbine (invented by Wells, 1976). This turbine rotates in a single direction in an oscillating airflow and therefore does not require a system of non return valves (Raghunathan et al., 1981; White, 1981; Grant et al., 1981). Other applications of the Wells turbine include navigation buoys (Whittaker, 1985b).

This paper reviews some of the theoretical and experimental studies directed towards an understanding of the aerodynamic performance of the Wells turbine. In wave energy devices where the available pressure drop (damping) is higher than a monoplane could accommodate, then a multiplane Wells turbine could be used (Raghunathan et al., 1981). This review is directed towards a monoplane turbine only and includes: (a) principle of the operation of the turbine; (2) effect of various factors controlling the performance; (3) prediction methods (4); starting behaviour of the turbine; and (5) techniques to improve the performance.

PRINCIPLES OF OPERATION

The Wells turbine rotor consists of several symmetrical aerofoil blades set around a hub at a stagger angle of 90° as in Fig. 1. For absolute airflow velocity V_A which is axial at the inlet and tangential velocity of rotor U at a radius r from the axis of rotation, the relative velocity W is at an angle α to blade chord. This would generate a lift force L and a drag force D normal and parallel respectively to the relative velocity W. These forces can be

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Received December 7, 1990: revised manuscript received by the editors November 18, 1993. The original version (prior to the final revised manuscript) was presented at the First International Offshore and Polar Engineering Conference (ISOPE-91), Edinburgh, United Kingdom, August 11-16, 1991.

KEY WORDS: Wave energy, turbomachinery, aerodynamics.