International Journal of Offshore and Polar Engineering
Vol. 6, No. 1, March 1996 (ISSN 1053-5381)

Performance of the Contrarotating Wells Turbine

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ABSTRACT

This paper describes an experimental investigation of the contrarotating Wells turbine for a wave power plant. The tests were conducted in a unidirectional steady air flow rig. Measurements taken included the overall performance of the turbine as well as detailed measurements of the radial distribution of velocity and pressure, upstream, downstream and between the rotor planes, for two different solidity turbine models and different rotor speed ratios. Experimental results show that the use of two twin rotors rotating in the opposite direction to each other is an efficient means of recovering the swirl kinetic energy without the use of guide vanes. Also, it was shown that the stall could be postponed by increasing the velocity of the downstream rotor relative to that of the upstream rotor.

NOMENCLATURE

c	: blade chord
c_L	: lift coefficient
c_{L0}	: isolated aerofoil lift coefficient
E	: pressure plus kinetic energy flux
G	: gap between rotors
k	: cascade interference factor
L	: lift, energy loss per unit of time
p	: pressure
Δp_o	: energy available to turbine per unit volume fluid
Δp_o^*	: $\Delta p_o/(\rho\omega^2 R^2)$
P	: turbine power output
Q	: volume flow rate
r, θ, x	: cylindrical cordinate system
r^*	: r/R
R, R_i	: outer, inner radius
Re	: Reynolds number
S	: solidity, total blade area/annular area
T	: torque
T^*	: $T^*/(\rho\omega^2 R^5)$
t	: cascade pitch
U	: inlet flow (average) velocity
U^*	: $U/(\omega R)$, flow rate coefficient
V, W	: absolute, relative velocity
w	: blade work per unit mass of fluid
(x, y)	: Cartesian coordinate system
α, β	: angle of absolute, relative velocity (Fig. 1)
ϕ	: flow coefficient in two-dimensional flow
Φ	: ratio of flow rates
η	: turbine efficiency
ρ	: density
ω	: rotor angular speed
ψ	: coefficient of pressure difference in two-dimensional flow

Subscripts

C	: far downstream of rotor (plenum chamber)
d, u	: downstream, upstream
x, θ	: axial tangential velocity component
0, 1, 2, 3, 4	: far upstream (in the atmosphere), upstream of 1st rotor, downstream of 1st rotor, upstream of 2nd rotor, downstream of 2nd rotor

Superscripts

*	: dimensionless value

INTRODUCTION

The motion of ocean waves has long been recognised as a potential source of renewable energy. Several different principles have been developed, such as the oscillating water column (OWC), which translates the wave motion into a reciprocating air flow. This can be converted into unidirectional shaft power without the need of any rectifying valves, by the turbine invented in 1976 by A. A. Wells. It is an axial flow turbine which consists essentially of a rotor with untwisted aerofoil blades of symmetrical cross-section, set radially at a 90° angle of stagger (Raghunathan and Tan, 1983a; Gato and Falcão, 1984). Wells turbine models have been studied with and without guide vanes, while one medium-scale turbine is operational in Europe at the Islay wave energy plant in Scotland (Raghunathan et al., 1995). In the biplane Wells turbine, the rotor blades are placed on two planes, in order to allow for greater total bladed area and improve the response to larger differences of air pressure across the turbine without the blade speed exceeding acceptable limits (Raghunathan and Tan, 1983b; Inoue et al., 1986).

Theoretical and experimental results for the flow field about a Wells turbine rotor, in the absence of stator guide vanes, indicate that a considerable amount of exit kinetic energy is lost in connection with the swirl component of the flow velocity (Gato and Falcão, 1988). Work has been undertaken to investigate the recovery of swirl energy with the use of guide vanes (Grant and Johnson, 1979; Kaneko et al., 1991; Gato and Falcão, 1990; Gato et al., 1991, 1993). This was successful for the monoplane turbine but with a reduction of the turbine flow operational range (Gato et al., 1993).

An alternative method of recovering the swirl energy when a

Received May 1, 1995: revised manuscript received by the editors August 16, 1995. The original version (prior to the final revised manuscript) was presented at the Fifth International Offshore and Polar Engineering Conference (ISOPE-95), The Hague, The Netherlands, June 11-16, 1995.
KEY WORDS: Wells turbine, wave energy, turbomachinery.