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The Effect of Rotor Blade Sweep on the Performance of the Wells Turbine

M. Webster
School of Engineering, Coventry University, Coventry, U.K.

L. M. C. Gato
Department of Mechanical Engineering, Instituto Superior Técnico, Lisbon, Portugal

ABSTRACT

An experimental investigation into the effect of rotor blade sweep on the performance of the Wells turbine is presented. The blades tested included 2 sets of symmetrical constant chord NACA 0015 blades: One set had a 30° backward sweep, whilst the other was unswept. The aim of the experiments was to investigate and compare the aerodynamic performance of the backward swept and unswept blades for two different rotor solidities. It was expected that the sweep of the blade would significantly alter the pressure distribution around the profile, so as to increase the critical Mach number. The turbine models were also fitted with guide vanes to investigate that effect on the overall turbine performance.

NOMENCLATURE

c : blade chord
Ma : Mach number
p : pressure
Δp_0 : energy available to turbine per unit volume fluid
Δp_0^* : $\Delta p_0/(\rho\omega^2 R^2)$
Q : volume flow rate
(r, θ, x) : cylindrical coordinate system
r^* : r/R
R : outer radius
Re : Reynolds number
S : solidity, total blade area/annular area
T : torque
T^* : $T/(\rho\omega^2 R^2)$
U : inlet flow (average) velocity
U^* : U/(R), flow rate coefficient
$\mathbf{V}$: absolute velocity
α : angle of absolute velocity
Λ : blade sweep angle, Fig. 1
η : turbine efficiency
ρ : density
ω : rotor angular speed

Subscripts

x, θ : axial, tangential velocity component
0, 1, 2, C : far upstream (in atmosphere), upstream of rotor, downstream of rotor, inside plenum chamber

Superscripts

$*$: dimensionless value

INTRODUCTION

The Wells turbine is an axial flow air turbine designed to equip wave energy extraction devices, particularly the oscillating water column (OWC). The turbine is self-rectifying, i.e., it can produce a unidirectional time averaged torque from a reciprocating flow. Several versions of the turbine have been considered and studied with and without guide vanes, e.g., the monoplane, the biplane, the contrarotating and the variable pitch Wells turbines (Raghunathan et al., 1981, 1983, 1995; Gato and Falcão, 1988, 1990; Gato et al., 1991, 1996; Beattie and Raghunathan, 1993; Curran and Gato, 1997; Sarmento et al., 1990; Inoue et al., 1986; Kaneko et al., 1991; White, 1981).

As in wings of high subsonic Mach number aircraft, unwanted compressibility effects may occur at the turbine rotor blades, and limit the blade tip velocity and rotational speed (thus preventing reductions in turbine size) in the same way as they limit commercial aircraft speed. Such effects can be reduced by sweep (virtually all high-subsonic-Mach-number aircraft have swept-back wings). Furthermore, the requirement of the variable-pitch turbine to have a stable rotor-blade pitch torque is accomplished by designing the blades with the pressure centre a little aft of the blades rotation axis (Taylor and Salter, 1996). This might be easily achieved by sweeping back the blades (Fig. 1).

A simplified theory for sweep effects in turbomachine blading has been given by Smith and Yeh (1963). Blades are said to have sweep when the flow direction is not perpendicular to the span-

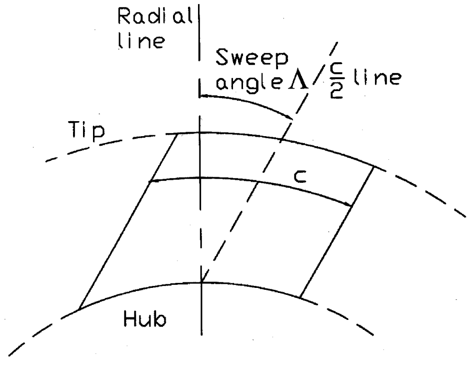

Fig. 1 Rotor blade sweep angle

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KEY WORDS: Wells turbine, wave energy, turbomachinery, blade sweep.