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The Performance of a Wells Turbine with 3D Guide Vanes

M. Takao
Matsue National College of Technology, Shimane, Japan

T. Setoguchi*, T.H. Kim and K. Kaneko
Saga University, Saga, Japan

M. Inoue
Kyushu University, Fukuoka, Japan

ABSTRACT

A Wells turbine has inherent disadvantages in comparison with conventional turbines: relative low efficiency and poor starting characteristics. In this case, the guide vanes in front of and behind the rotor may be one of the most effective items of equipment for the improvement of the turbine's performance. Several papers have demonstrated the usefulness of 2-dimensional (2D) guide vanes so far. In order to achieve further improvement of the performance of the Wells turbine, the effect of 3-dimensional (3D) guide vanes has been investigated experimentally by a model testing under steady flow conditions. And then, the running and starting characteristics under sinusoidally oscillating flow conditions have been obtained by a computer simulation using quasi-steady analysis. As a result, it is found that the running and starting characteristics of the Wells turbine with 3D guide vanes are superior to those with 2D guide vanes.

NOMENCLATURE

D : drag
f : frequency of wave
G : gap between rotor and guide vane
l_r : chord length of rotor blade
L : lift
r_R : mean radius
T_L : loading torque
U_R : blade speed at r_R
v_a : mean axial velocity
v_1 : absolute velocity at inlet
v_2 : absolute velocity at exit
V_a : maximum value of v_a
w_1 : relative velocity at inlet
w_2 : relative velocity at exit
X_I : dimensionless moment of inertia $= I/\pi\rho_a r_R^5)$
X_L : dimensionless loading torque $= T_L/(\pi\rho_a r_R^3 V_a^2)$
z_g : number of guide vanes
z_r : number of rotor blades
$\alpha_{w/o}$: angle of attack in case without guide vanes
ν : hub-to-tip ratio
σ_g : solidity of guide vane $= z_g l_g/(2\pi r)$
σ_{gR} : solidity of guide vane at $r_R = z_g l_g/(2\pi r_R)$
σ_{rR} : solidity of rotor at $r_R = z_r l_r/(2\pi r_R)$

*ISOPE Member.

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KEY WORDS: Fluid machinery, Wells turbine, guide vane, natural energy, wave energy conversion, ocean wave 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 the oscillating water column for converting wave energy to low 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, several self-rectifying air turbines with different configurations have been proposed, including the Wells turbine (Gato et al., 1988; Inoue et al., 1986a, 1986b; Kaneko et al., 1986; Raghunathan et al., 1987, 1994; Raghunathan, 1995; Setoguchi et al., 1986; 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., 1996), an impulse turbine with fixed guide vanes (Setoguchi et al., 2000) and so on (Kaneko et al., 1992). Among them the most promising turbine at present from the viewpoints of cost and maintenance is the Wells turbine.

There are several reports on the Wells turbine performance and the factors which influence it (Raghunathan, 1995). According to these results, turbine efficiency is lower in comparison with that of the conventional turbines. In this case, the guide vanes in front of and behind the rotor may be one of the most effective items of equipment to improve turbine performance.

The performances of the Wells turbine with guide vanes were studied theoretically (Sturge, 1977; Gato and Falcao, 1990; Suzuki and Arakawa, 2000) and experimentally (Inoue et al., 1985; Arakawa et al., 1987; Setoguchi et al., 1998). However, the studies were almost always performed by the use of 2D guide vanes. In the case of 2D guide vanes, the angle of attack near the hub is larger than in the case without guide vanes, as shown in Fig. 1. A flow visualization study on a monoplane Wells turbine by Suzuki et al. (1985) has indicated that the boundary layer separation on the suction surface of a blade occurs first near the hub and then