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Design Method of Wave Power Generating System with Wells Turbine

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ABSTRACT

This is a report of a fundamental study on the design method that takes into account the interaction between the air chamber and the turbine, using the rule of similarity in the nondimensional form of the governing equations. We present how to analyze the power absorbed in irregular waves by using both their spectrum and probability. It is shown that the linear theory of water wave is applicable to the evaluation of the absorbed power in air chambers. Turbine performances in irregular waves are easily shown with the probability density distribution, that is, Gaussian distribution. This paper also presents a design method that will lead to minimum construction cost. Cost is now a very important factor in the construction of wave power generating systems.

NOMENCLATURE

a : amplitude of incident wave
A_T : annulus section area of Wells turbine$= \pi(R_t^2 - R_h^2)$
A_T^{OWC} : factor affecting turbine size of OWC characteristics
A_W^{OWC} : factor affecting air chamber size of OWC characteristics
A_T^T : factor affecting turbine size of turbine characteristics
A_W^T : factor affecting air chamber size of turbine characteristics
A_W : water surface area in air chamber (OWC) $= BW$
B : length of air chamber
$C_T(\phi)$: torque coefficient based on tip speed
$C_T(\alpha)$: torque coefficient based on relative velocity at tip
D_0 : load damping coefficient of air chamber
f : wave frequency
g : gravitational acceleration
h : water depth
H : wave height
k : wave number
K : wave number at infinite water depth $= \omega^2/g$
$\mathbf{P}(x)$: probability density distribution
R_t : radius of rotor
$S(f)$: spectrum of irregular wave
T : turbine torque or period of wave
U : tip speed of turbine rotor
V_a : axial velocity of turbine
v_W : heaving velocity of water surface
$V_{W\sigma}$: standard deviation of v_W
W : width of air chamber
W_i : incident regular wave power
w_{OWC} : output of OWC in regular water wave per unit length
W_{OWC} : output of OWC in regular water wave
α : angle of attack
ΔP : pressure drop over turbine
ϕ : flow coefficient
ϕ_m : amplitude of flow coefficient
η_G : efficiency of generator
$\tilde{\eta}_{OWC}$: efficiency of OWC for irregular wave
η_T : efficiency of turbine
ρ : air density
ρ_W : water density
ω : angular frequency
ψ : pressure drop coefficient over turbine

Superscripts

$*$: nondimensional
$-$: time average in regular wave
$\sim$: time average in irregular wave

Subscripts

i : incident wave
PW : constant input power
σ : standard deviation
$1/3$: significant wave

INTRODUCTION

A wave power generating system of an oscillating water column (OWC) type is composed of a turbine generator and an air chamber in which the OWC converts wave energy into oscillating airflow (Raghunathan, 1995; Washio et al., 2000). A Wells-type turbine is used for the air turbine because it is suitable for the operation in the oscillating airflow. The Wells turbine will always rotate in the same direction irrespective of the direction of the oscillating airflow. Further, the Wells turbine has a simple configuration and structure. This is why the Wells turbine is very commonly used for conversion of wave energy. Since the Wells turbine has a special wing arrangement (90° stagger angles), the efficiency becomes low (approximately 65%) in a steady flow. But the time average efficiency in an irregular wave is about 45% with guide vanes (Suzuki et al., 2000), which is a small loss (about

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KEY WORDS: Wells turbine, wave power generation, OWC, optimum design, turbomachinery.