Wave Energy Absorption in Irregular Waves by a Floating Body Equipped with Interior Rotating Electric-Power Generator

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ABSTRACT
To realize a wave-power absorption apparatus in actual seas, we should consider the absorption efficiency of wave power in irregular waves and how it can be enhanced. For that purpose, first a theoretical study is made on how the maximum wave-energy absorption can be achieved in irregular waves by using the Fourier transform from the results in the frequency domain and taking account of the causality relations. It is shown that, if the maximum conditions are satisfied in the time domain, we can improve the wave-power absorption efficiency in irregular waves. Then based on the result of theoretical study, numerical computations are performed for a floating body inside which an electric-power generator is supposed to rotate without sliding along the interior circular surface of a symmetric floating body. However, since the maximum condition in the time domain does not satisfy causality in the present study, we need to resolve this problem for further improvement.

KEYWORDS: Wave-energy absorption efficiency; symmetric body; irregular waves; rotating pendulum-type.

INTRODUCTION
Recently much attention is focused on the utilization of marine renewable energies. Since the amount of resources of wave energy is enormous, the ocean-wave energy will play an important role in the future strategy for electric-power supply. A number of papers on the theoretical and experimental studies on various kinds of wave-power generator have been presented over the past years. The efficiency of wave-power absorption, in general, achieves high value in a limited range of wave frequency. However, the waves in actual seas are of irregular waves including various frequency components. Thus, in order to obtain a higher absorption efficiency of wave power in actual seas, wave-power generators should be adjusted to be active in a wide range of wave frequency. Various devices which can realize this objective have been studied so far by many researchers. We also aim to develop a system which can absorb the wave energy efficiently over a wide spectrum of the wave frequency.

A rotating pendulum-type wave-power generator in a regular wave was already studied by Kashiwagi et al (2012, 2013) to make the absorbing wave-energy efficiency higher over a wide range of wave frequencies and the conditions for maximizing the absorption efficiency were obtained. In the proposed model, the interior surface of a floating body is of circular cylinder with larger radius, and a smaller circular cylinder is assumed to rotate on the interior circular surface without sliding. An electric-power generator is set at the center of the smaller circular cylinder. Both floating body and smaller circular cylinder inside rotate due to wave actions and cross-coupling effects, and then the smaller circular cylinder generates the electric power when the relative rotational motion becomes large.

To realize the rotating pendulum-type wave-power generator in actual seas, we need to consider the absorption efficiency in irregular waves and how it can be enhanced. In order to understand the behavior of the apparatus in irregular waves, it is necessary to calculate the efficiency of wave-power absorption by the electric-power generator in the time domain. Study on the wave-energy absorption in irregular waves have been done by some researchers, e.g. Naito and Nakamura (1986). However the power take-off systems studied so far are different from that considered in our study.

In the present paper, after presenting the coupled motion equations for the floating body and smaller circular cylinder in the time domain with memory effects in hydrodynamic forces taken into account, the wave-power absorption efficiency by an electric-power generator is computed for irregular waves. Moreover, to improve the absorption efficiency in irregular waves, we use the conditions for maximizing the absorption efficiency obtained for regular waves. Namely, the maximum conditions obtained in the frequency domain are Fourier-transformed and converted into an expression in the time domain and then the wave-power absorption efficiency under this controlled situation is computed.

THEORY
Outline of wave-power generator and assumption
The cross section of a rotating pendulum-type wave-power generator is shown in Fig. 1, where the problem is treated as two dimensional. We consider a floating body whose interior surface is of circular cylinder with radius $R$, and a smaller circular cylinder with radius $r$ which rotates on the interior circular surface of floating body without sliding. By installing an electric-power generator inside the smaller cylinder with their