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Wave energy conversion utilizing vertical motion of water in the array of water chambers aligned in the direction of wave propagation

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Abstract

As a new technical approach, wave energy converter by using vertical motion of water in the multiple water chambers were developed to realize actual wave power generation as eco-environmental renewable energy. And practical use of wave energy converter was actually to require the following conditions: (1) setting up of the relevant device and its application to wave power generation in case that severe wave loading is avoided; (2) workability in installation and maintenance operations; (3) high energy conversion potential; and (4) low cost. In this system, neither the wall(s) of the chambers nor the energy conversion device(s) are exposed to the impulsive load due to water wave. Also since this system is profitable when set along the jetty or along a long floating body, installation and maintenance are done without difficulty and the cost is reduced. In this paper, we describe the system which consists of a float, a shaft connected with another shaft, a rack and pinion arrangement, a ratchet mechanism, and rotary type generator(s). Then, we present the dynamics model for evaluating the output electric power, and the results of numerical calculation including the effect of the phase shift of up/down motion of the water in the array of water chambers aligned along the direction of wave propagation.

Keywords: Along wave-water chambers; Up/down water motion; Float-type; Float's vertical motion; Movable body; Ratchet mechanism; Dynamics model; Phase shift in water's up/down motion

1. Introduction

A rising demand for energy coupled with the problem of environmental pollution has led to investigations into potential new energy resources (Evans, 1982; Sarpkaya and Isaacson, 1981). Wave energy represents one of the most dependable and predictable sources of renewable energy available which is free from the variations present in wind or solar energy. Various mechanisms for extracting wave energy have been developed but not fully realized due to structural strength and economic problems.

For the practical application of wave power, the following factors are important: durability of the device, workability (without difficulty in installation, maintenance and repair), high efficiency, and low cost. The durability of the device includes those of both the external structure and the power converting portion of the device. It can be said with certainty that the lack of fulfilment of the above mentioned conditions is the main reason that the wave power conversion technology has not reached a commercially generating stage (Nagai et al., 2002; Takahashi, 1993).

In order to meet these conditions, Hadano et al. (2013) designed the system which consists of water chambers array aligned along the wave propagation direction and the float-type wave energy converters each of which is installed in the chamber and utilizes the gentle up/down motion of the water in the chamber. In this system, neither the wall(s) of the

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chambers nor the energy conversion device(s) are exposed to the impulsive load due to water wave. Also since this system is profitable when set along the jetty or along a long floating body, installation and maintenance are done without difficulty and the cost is reduced. Waves near the jetty or a loosely moored long floating body will propagate toward the length of these structures. Therefore, an array of water chambers set along the jetty or a long floating structure is profitable in the sense that the outer wall is never exposed to severe wave loads.

The authors also considered the use of the float-counterweight type device (Hadano et al., 2006). This device consists of a float, a counterweight, a wire, pulleys, a shaft, a ratchet mechanism and an electric generator. The major advantage of the device is that due to the flexibility of the wire, it is free from major structural problems common to most of the movable body types. The device was designed to generate power utilizing the vertical motion of the float. However, experiments showed large surge motions of the float caused the float to slam with the walls of the water chambers. Hence, the authors have developed a new device which replaced the counterweight and the wire by a rack and pinion arrangement to remove the problem of the horizontal motion of the float. In addition, the device is more robust and compact than the float-counterweight device.

2. Proposal for the utilization of water chambers

The basic principle of energy extraction was proposed earlier (Hadano and Kan, 2013). The system consists of multiple water chambers set along the direction of the wave propagation as shown in Fig. 1. The motion of the water mass in these chambers is mostly vertical and is utilized for extraction of energy by the rack and pinion system installed in each of the chambers (Koirala et al., 2012). Fig. 1 is the schematic diagram of the total system and Fig. 2 shows the working principle of the rack and pinion system.

The array of water chambers can be set along a jetty (Fig. 3) or can be left to float independently using mooring. In either case, the impulsive impact of the incident wave is avoided by the wall set diagonally before of the front chamber and therefore the motion of water in the chambers is a gentle up and down.

2.1. Composition of the new system

The new system consists of the water chambers and the rack and pinion system. The rack and pinion system consists of a float, a rack and pinion arrangement, a ratchet system, a shaft, a gearbox and an electric generator to produce electricity. The vertical motion of the water in the chambers causes the float to move up and down. This motion is transferred into the rotational motion of the shaft using the rack and pinion arrangement. Although each of the shafts rotates individually, the output electrical power is synchronized later.

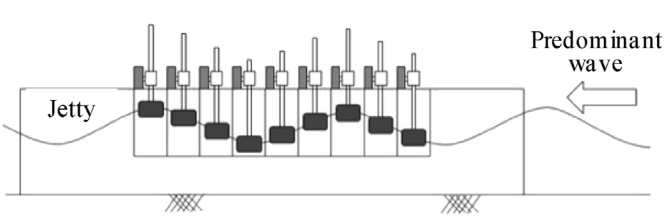

Fig. 1. Concept of the total system.

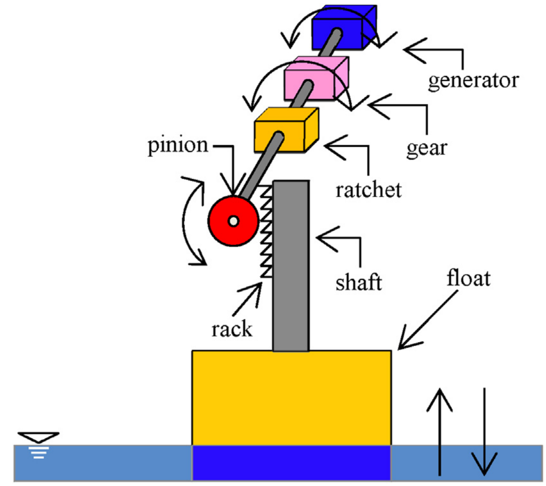

Fig. 2. Concept of the rack and pinion system.

2.2. Dynamics model

The dynamics model includes the equation of balance of the stationary free state of the float, equation of the vertical motion of the float, equation of the rotary motions and the equation of the electric generator.

2.3. Equations of the dynamics model

In the equations of the dynamics model, g: acceleration due to gravity, ρ_w: mass density of water, d_f: diameter of the float, M_f: mass of the float, h: draft of the float in stationary free state, x_f:vertical displacement of the float, x_w: water surface displacement, t: time in seconds, T: tension force in the shaft,

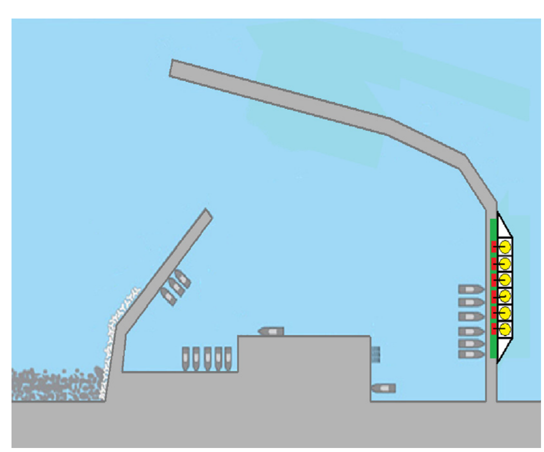

Fig. 3. Sketch of the system set along a jetty.