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Rotational characteristics and capture efficiency of a variable guide vane wave energy converter

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ABSTRACT

The work presented in this paper focuses on evaluating the rotational characteristics and capture efficiency of a novel variable guide vane wave energy converter (WEC). The rotation of the guide vanes under the action of waves drives the rotation of the vane wheel, generating electricity. The vane wheel always rotates in one direction, regardless of the rotation direction of the guide vanes. The optimal maximum turning angle of the guide vane is determined using a simplified model run with commercial CFD software [25], which is then validated by experimentation. Experiments were conducted on a 1:4 scale model using guide vanes set at the optimal maximum turning angle under conditions both with and without a generator. It is observed in these tests that the device intermittently pauses when the velocity of the water particles at the height of the vane wheel is less than 0.211 m/s under no-generator conditions. Capture efficiency is approximately 7% because of the short time, small area, and small range of the device for harnessing the wave energy. An electronic load with a resistance varying in the range of 1–500 Ω is then connected to the generator, and the working performance of the WEC is investigated. Finally, two alterations intended to improve the capture efficiency of the variable guide vane WEC are proposed and evaluated, and the capture efficiency of a scaled-up model is discussed.

1. Introduction

The marine environment provides many different possibilities for the generation of clean and renewable energy, including marine current power (using the movement of water in the sea), tidal power, ocean thermal energy, osmotic power, salinity gradient power, and wave energy [1]. Ocean waves in particular contain a large amount of energy that can be used to generate electricity and produce fresh water, among other applications. Wave-energy conversion is also one of the most active areas of renewable energy research, and numerous devices, concepts, and patents have been proposed in the process, including wave energy convertors (WECs) such as the oscillating water column (OWC), overtopping, and oscillating body systems [2,3].

The OWC is currently the most widely used wave energy conversion method in the world. Facilities that employ the OWC approach typically consist of a chamber inside which air is trapped above the free surface of ocean water. The incident waves produce an oscillating motion upon the free surface of the water, causing the volume of the air chamber to change, in turn producing an expulsion or sucking of air through an air turbine such as a Wells turbine or an impulse turbine that drives an electrical generator [4]. Notably, however, Martins-Rivas and Mei [5,6], demonstrated that the compressibility of air can have a non-negligible effect on the power extraction capabilities of an OWC device. Several researchers have integrated OWC-type wave energy extraction systems into caisson breakwaters [7,8], and floating-type OWC devices have also been developed [9].

Overtopping systems are a way of converting wave energy into electrical power by storing incident wave water in a reservoir located at a higher level than the average free-surface level of the surrounding sea. This technology is similar to a low-head hydraulic power device. An offshore, floating overtopping convertor developed in Denmark using a reflector, ramp, and reservoir is called the Wave Dragon [10]. The Floating Dish is the first model of such a device in China, put to use in the sea in 2011, generating 5 kW of electricity [11].

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Oscillating bodies are offshore WECs that are either floating or fully submerged. The oscillating body WEC, the motion of which directly drives the Power Take-Off (PTO), is more efficient than OWC and overtopping systems because there are fewer conversion stages between the raw waves and the generator input [12–14]. Because of this higher capture efficiency, as of today, increasing deployment of oscillating body WECs have been proposed worldwide, e.g., the Pelamis [15,16], Oyster [17], Wavebob [18], and heaving buoy [19] systems. The variable guide vane WEC evaluated in this paper is considered a new concept in the oscillating body WEC paradigm.

The variable guide vane WEC, presented in Fig. 1, is inspired by a patent by Song [20]. This WEC consists of a support, principal axis, generator, and 1.6 m diameter vane wheel. The support is able to translate vertically according to wave height and water depth, ensuring that the vane wheel is able to capture as much wave energy as possible. In this system, the vane wheel, attached to the principal axis, is equipped with several guide vanes (there are four guide vanes shown in Fig. 1 (b)). The guide vanes are arranged such that they can rotate around their own axis within a certain angle under the action of a wave, hence this device is often known as a variable guide vane device. When a guide vane rotates around its axis, the axis is subjected to a horizontal force, and the resulting torque is applied to the vane wheel. The rotation of the vane wheel (and attached axis) drives a generator to produce electrical energy. The vane wheel always rotates in one direction as shown in Fig. 2, regardless of which direction the guide-vane is turned.

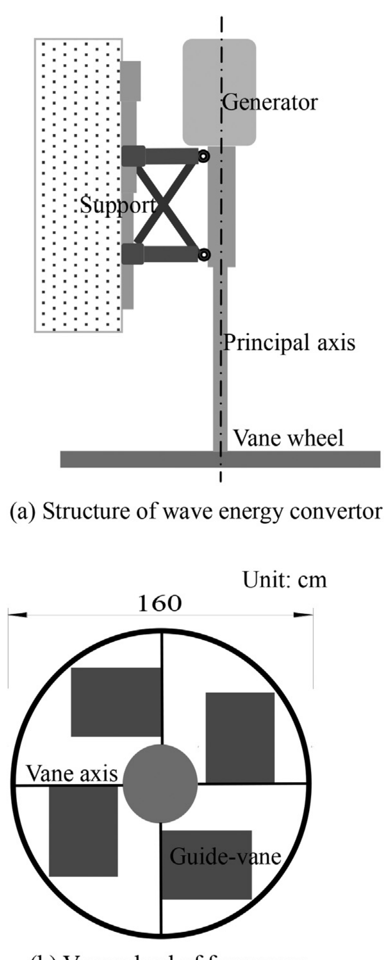

Fig. 1. Idealization of a variable guide vane WEC.

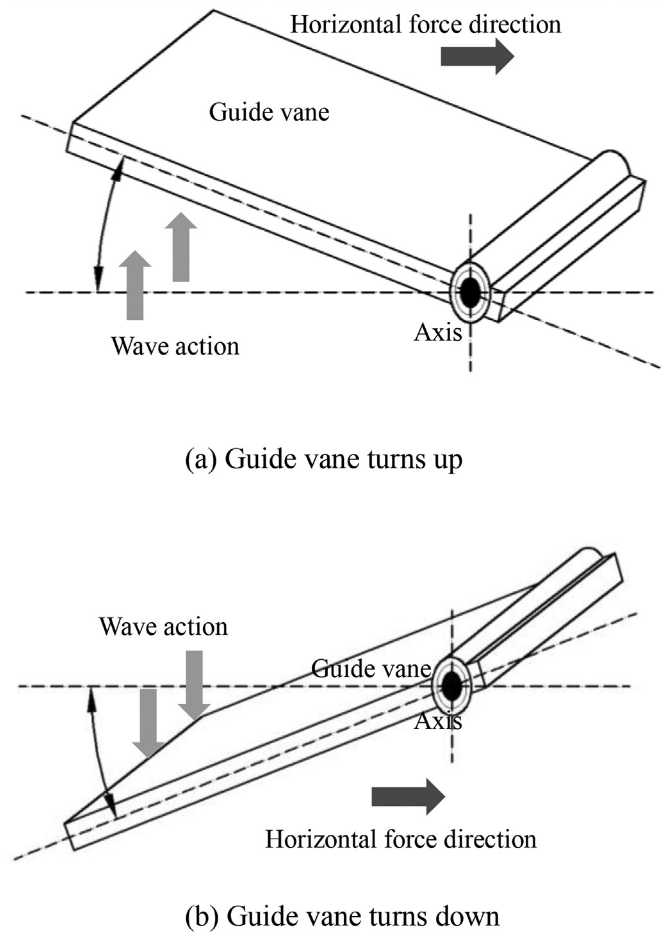

Fig. 2. Sketch of loading on avane under wave action.

Numerical analysis and experimental evaluation are the two primary methods employed to investigate the hydrodynamic performance and capture efficiency of any WEC. Typically, a numerical hydrodynamic model is used for numerical analysis, whereas in experimental evaluation, physical test flumes are designed, and measurements of device behavior are taken. Nader [21] built an FEM model to study a single OWC device and three different array configurations, taking the interactions between the devices as well as air compressibility into account. Gomes [22] presented a numerical study on the hydrodynamics of bottom-hinged plate WECs in both regular and irregular waves. Kim [23] conducted experiments and several numerical studies on the PTO system of a novel floating WEC. Liu [24] performed experiments investigating the hydrodynamic characteristics of heaving buoys under damping effects. Theoretical approaches also have been used to predict the capture efficiency of novel WECs, although some parameters are often, by necessity, neglected. Shi [19] developed a new theoretical analysis to investigate buoy behavior considering the hydraulic system, and this theoretical solution agrees well with experimental results.

Because the device introduced in this work is a novel device, there is no published literature on the motion of a variable guide vane WEC. Accordingly, the hydrodynamic performance and capture efficiency of this device are investigated by both numerical and experimental methods in this study. This article is structured as follows. In Section 2, the optimal maximum turning angle of a guide