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Design of a cylindrical buoy for a wave energy converter

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ABSTRACT

The purpose of this study is to determine the optimal size of a cylindrical buoy based on wave characteristics: wavelength, wave amplitude, wave velocity, and other factors. Waves are classified into long-period swell waves and short-period lippers. A lipper can provide ripple energy to a wave energy converter, this process can easily cause instability of the energy system, therefore a skirt design can be adopted to increase the cylindrical buoy's damping and to decrease the effect of the ripple energy source. A swell wave produces a dynamic and steady force on the cylindrical buoy, providing a stable energy source, and can be used to judge whether the converter can achieve the design value of the expected energy by capturing the periodic average potential energy.

1. Introduction

Oceans comprise more than 2/3 of the entire surface of the Earth. The rich resources found in the oceans can be regenerated and used without environmental pollution. Marine resources include waves, currents, tides, temperature differences, and so on. In wave energy, we use the different movements of waves (upward and downward, and horizontal transmission) to generate power. Many marine resources, are all available as new forms of green energy: ocean currents (the use of ocean currents to drive hydraulic turbines), tidal energy (the production of electric power using the potential energy difference of the flood and ebb tides), and ocean thermal energy (the use of sea temperature in surface and deep layers to cause vaporisation of the liquid that drives turbines) (World Energy Council, 2004; Bedard et al., 2010).

Sabzehgar and Moallem (2009) investigated wave power device systems and concluded that a turbine-style (oscillating wave columns) wave energy converter (WEC) has more impact on the environment than a buoy-style point absorber WEC. Thus, the buoy-style point absorber should be preferentially used in wave energy power to reduce impact on the environment. Drew et al. (2009) noted that the efficiency of wave energy conversion is slow, and wave energy conversion technology relies on random and oscillatory motion with high force; thus, an energy storage system is necessary for smooth power output.

There are several challenges in wave energy conversion designs that use a hydrodynamic mode, including fluid isolation, pipe seal leakage, efficiency, and maintenance; these problems should be avoided in future designs. To obtain smooth power output and increased efficiency of a WEC, the motion equation of the model structure can be used to provide the input and output relationship in the time domain. By adjusting the input and output parameters, the maximum energy absorption of a transient wave and a digital control can output smooth power and increase WEC efficiency (Kara, 2009; Ruehl et al., 2010).

The methods of a buoy design in a WEC are rarely mentioned in marine resource documents, but they are intensely researched in marine measurement studies. For example, Cozijn et al. (2005) discussed a model of the buoy's heave motion, roll motion, and pitch motion and reported that the design of the damping skirt is increasingly used to change the mode of motion. Sarpkaya and O'Keefe (1996) discussed the relationship between the drag coefficient and the Keulegan–Carpenter (KC) number when fluid flows through the plate and provided methods for damping design.

However, the marine measurements include water temperature, salinity, wave and current parameters, etc. There are various directional properties from the wave and current measurements; therefore, the marine measurements of buoy design must have more freedom to include these parameters. Unlike a buoy for WEC, this has a limited direction of movement to provide energy conversion. Therefore, marine investigation and analysis of wave characteristics and buoy dynamics can offer superior buoy designs.

2. Factors affecting the capture of buoy energy

The design of a buoy has great impact on energy capturing; thus, the relationship between the buoy and the wave had been described by Falnes (2002). Recently, Wang (2013) and Nazari et al. (2013) had

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investigated wavelength, wave amplitude, wave velocity and effectiveness of wave energy; therefore, we would explain the wave and buoy relations in more detail.

2.1. Wave characteristics

Waves are generally divided into long-period swell waves and short-period lippers. The swell wave is the predominant contributor in wave energy conversion. The lipper causes energy rippling, and should be eliminated in the design. Waves have three important factors in ocean transmission, namely, wavelength, wave amplitude, and wave velocity. As a point absorber, a buoy WEC is affected by these factors. Fig. 1 shows a WEC that when waves are transmitted, the buoy undulates with the waves in a manner similar to a particle, so long as the corresponding wavelength is not too short. The size of the WEC buoy is generally less than a tenth of the wavelength. A wavelength that is too short or is the same size as the buoy will cause the buoy to span the wave's crest and trough at the same time, and wave power will not be effectively captured as a result. The size of the wave amplitude is an important metric that determines the vertical potential energy of the buoy as well as the amount of captured energy. Wave velocity is the transferring speed and is relevant to the buoy's dynamic response. When the buoy dynamic response is slow under fast wave velocity conditions, the wave passes the buoy without causing any up or down motion. When the buoy dynamic response is fast under slower wave velocity conditions, the amount of captured wave energy decreases. Consequently, the buoy's design and the ocean wave survey must be complementary. The buoy's dynamic response is discussed in the following sections of this study.

2.2. Buoy response

The buoy's dynamic characteristics can be divided between a natural response and a forced response (Nise, 2000). The natural response is a system response. The decay time of a natural response is affected by the damping coefficient and the buoy mass. The design of the decay time is based on the wave velocity. The buoy will not be able to capture the wave energy following a wave undulation if the decay time is too long when the wave transmission is passing through the buoy. A forced response is the steady-state response under wave action, wherein the buoy will follow the wave undulating action. Therefore, undulation of the buoy is desired when designing the buoy response following a long-period swell wave to reduce or eliminate wave energy rippling by the lipper in a rapid natural response.

3. The buoy system model

The WEC generally consists of the mechanism and the hydraulic equipment; these methods can capture wave energy and output power. However, the principal part of the WEC is still the buoy. This section is divided into discussions of the buoy in a static horizontal plane model and in a wave model.

3.1. Equivalent stiffness of the buoy

Fig. 2 shows that the buoy moves up and down at the water surface due to buoyancy. The buoyancy, $\rho g A(z) z$, is equivalent to the buoy gravity, Mg, the buoyancy relationship of the buoy can be described as an equivalent mass spring:

$$\rho g A(z) z = Kz \quad (1)$$

The buoy can be described using the mass spring relationship, $K=\rho g A(z)$, where ρ is the liquid density, g is the gravitational acceleration, $A(z)$ is the sectional area of the buoy, K is the equivalent spring constant, and z is the buoy draft. In general, the horizontal sectional area of the buoy in Eq. (1) depends on the buoy draft. However, in the case of a cylindrical or tetragonal buoy, the sectional area is constant and does not depend on the buoy draft.

3.2. The buoy in the static horizontal plane model

The buoy is affected by lipper waves in the horizontal plane. The small amplitude of a lipper in a short period moves the buoy up and down quickly. The movement is similar to the effect of noise on a sine wave. The buoy is affected by noise, which is modelled as an impulse force that acts downward instantaneously and can be described as $F_\delta \delta(t)$, F_δ, the displacement of the buoy under excitation (Hover and Triantafyllou, 2009; Nunes et al., 2011). Therefore, the motion equation of the buoy can be expressed as

$$M\ddot{z}(t) + C\dot{z}(t) + Kz(t) = F_\delta \delta(t) \quad (2)$$

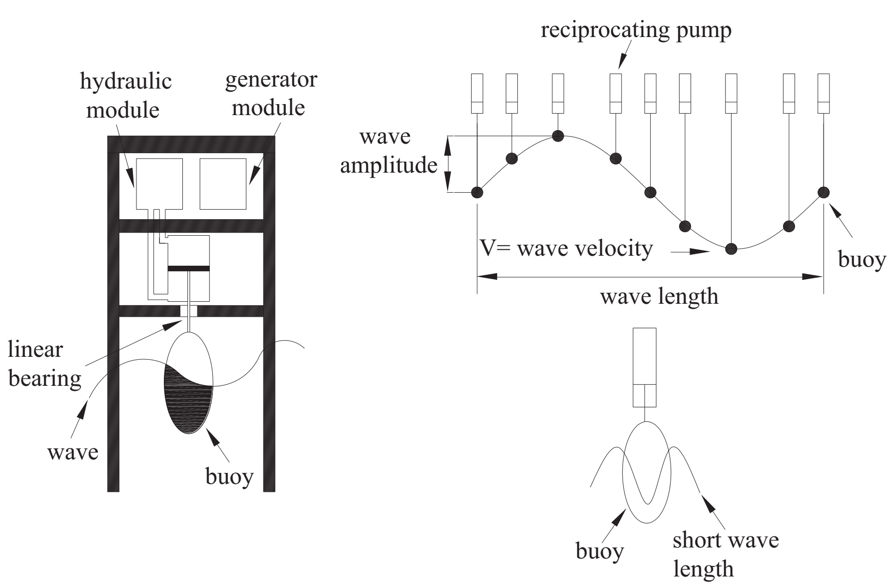

Fig. 1. Wave energy converter, wave parameters and wave transmission.