Study on Wave Buoy Legged Spider Power Device

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ABSTRACT

This paper studied on Wave Buoy Legged Spider power device, a floating wave energy system based on linear generator. The device contains horizontal cylinders arranged such that it looks like the legs of a spider. Inside cylinders will be equipped with a linear generator. During wave motions, some rotors of the linear generators slide forward and backward, thus generating electricity. As a case, a conceptual design of the Wave Buoy Legged Spider device using floating balls of Malaysian wave buoy for an ocean site in Terengganu, West Malaysia is presented. The wave energy was approximately assessed based on observed wave data. Furthermore a method to determine the directional wave spectra by using nonlinear programming has been proposed with introducing a correction factor in order to avoid the concentration of power spectral density. The capability of this method has been verified by the analysis with the data of the experiments of the floating ball response.

KEY WORDS: *Conceptual design; Wave Buoy; Wave Power; Directional; Energy; Device*.

1.0 INTRODUCTION

This paper presents an efficiently wave buoy legged spider of wave power device that used the floating balls [1] from Malaysian wave buoy. As we know that a wave power device will convert the energy of wave motion into the high-speed rotation of generator. The process can be divided into three steps, i.e., collecting wave energy, transmitting energy and generating electricity by generator [2]. The procedures usually make a wave power device complicated, and increase energy loss, hence lowering the energy efficiency of the device, such as Archimedes Wave Swing [3] and Wave Dragon [4] may need high construction cost, but not for the new wave power device, called wave buoy legged spider. This power device utilizes linear generators and thus is able to simplify energy transmission and decreases energy loss during conversion. The device is also constructed by simple structure and low cost, and will show high energy efficiency in the case study section.

2.0 WAVE BUOY LEGGED SPIDER

As showed in Fig. 1, the Wave buoy legged Spider device is a floating system incorporating eight horizontal cylindrical members, called power antennas. The antennas look like the leg of a spider. The major components of the device include power antennas, floating balls, an energy conservation control center (or control center), a buoyant plate, submarine electrical cables, mooring lines, connecting bars, and elastic ropes.

The power antennas are rigidly connected to the buoyant plate through connecting bars. Four floating balls that used Malaysian wave buoys are attached on each power antenna. Inner floating balls may be connected together through flexible elastic ropes so as to integrate the power antennas. Buoys are also attached at the ends of each power antenna to provide additional buoyancy.

The control center incorporates an energy storage box and a series of components used for power storage and transmission, such as transformer and rectifier. The energy storage box could be a kind of typical small battery system as described in [5], which is able to conserve a small portion of electricity generated by the power antennas. The stored power is used for the device's own maintenance, and the majority of the generated electricity will be

transmitted to the shore via submarine electrical cables.

The floating balls enable the power antennas to absorb surface wave energy to the greatest degree when the device is fluctuating with wave. In addition, adaptive variable damping may be employed to enhance the efficiency of the Water Spider device. Adaptive variable damping can be used to achieve the best damping given random waves ([6]; [7]). The Wave buoy legged Spider device is anchored at seabed by mooring lines.
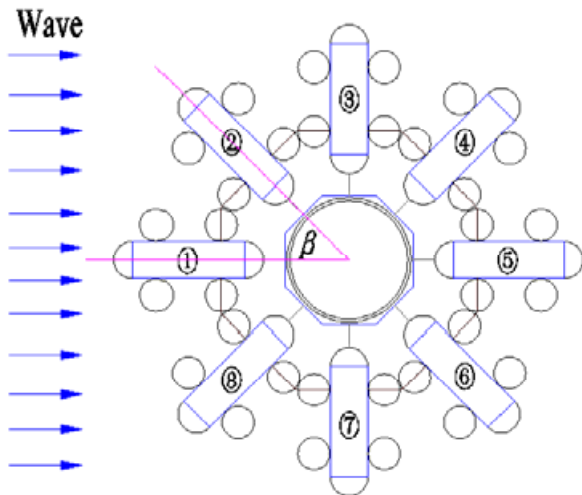

Figure 1: Wave Buoy Legged Spider

2.1 Power antenna

As the component of the Wave buoy Spider device, the power antennas convert wave energy into electricity. The power antennas adopt the wave power capsule technology developed by Zhang et al. (2010). The capsule technology uses linear generators, which generate electricity by the sliding of their rotors (Zhang et al., 2010). As shown in Fig. 2, a power antenna accommodates a sliding rotor, a stator, and insulating rubber materials.

The stator is mainly composed of metal coils, insulating barrier, and insulating rubber layers. The outside of the metal coils is coated with insulating paint.
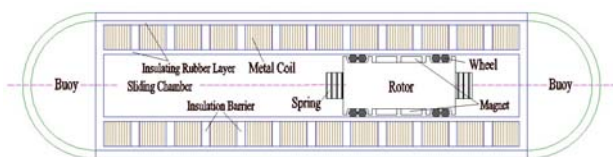

Figure 2: Power antenna capsule

The rotor consists of permanent magnet with strong magnetic field, wheels, and springs ([8]; [9]). The wheels reduce the friction between the rotor and the sliding chamber. The spring can buffer the collision between the rotor and the end wall of the sliding chamber. The deformation of the spring results in the exchange between the kinetic energy and the potential energy of the rotor, thus helping the sliding of the rotor in the chamber. If the air in the chamber is expelled, the energy loss may be further reduced because of decreased air resistance.

Given wave motions, the rotor in the linear generator slides forward and backward, leading to the change of magnetic flux in the metal coils. As a result, the induced electromotive force converts wave energy into electrical energy. The power generated by the linear generator is transmitted to the control center via the connecting bars attached at one end of the power antenna.

2.2 Floating ball

The floating ball is a Malaysian wave buoy as shown in Fig.3 which follows the movements of the water surface, and monitors waves by measuring the vertical acceleration of the buoy. The discrepancy between vertical movements of the wave buoy and the movement of the sea surface is small. When an attached wave buoy follows the waves, the force of the flexible elastic ropes will change. This force is produced by changing immersion of the buoy, resulting in an error of maximum 1.5%. With decreasing wave length, the buoy motion will deviate from the wave motion if the wave length is less than 4 m (wave period below 1.6 sec). If the wave length is less than 2.5 m (wave period 1.25 sec) the response of the buoy decreases fast with increasing wave frequency.
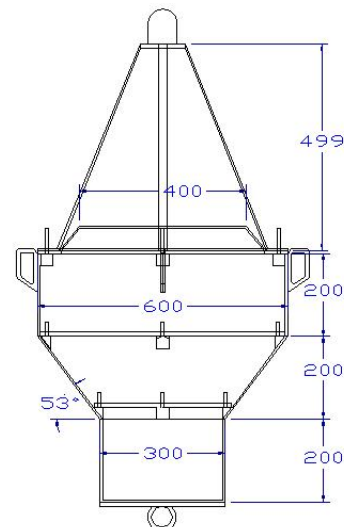

Figure 3: Floating ball (unit in mm)

Wave data which was measured by the accelerometers inside the floating ball are collected to provide essential information for the design, construction and performance monitoring of wave buoy legged spider power device.

2.2.1 Accelerometer

For an accelerometer to accurately sense and generate useful data, it must be properly coupled to the test object. This requires that the accelerometer mounting be rigid over the frequency range of interest. The methods for mounting an accelerometer usually

depend on the accelerometer and the text structure. In order to obtain vertical displacement, the acceleration signal is integrated twice. The integration process limits the response of the wave rider buoy at low frequency to prevent slow changes in the accelerometer output and electronics to appear on the wave record

2.2.2 Wireless System

The wireless system block diagram is as shown in Fig. 4. The analog data from the accelerometer are converted to digital data; it will be sent to transmitter. Transmitter will than transmit the digital data to through antenna to receiver. When the antenna receiver receives the data by the omni-directional antenna, it will amplify the data before sending to receiver. After the data pass through the receiver, it will than pass through the SOC will then be sent to computer by USB. At the computer, the data will be displayed, and processed.
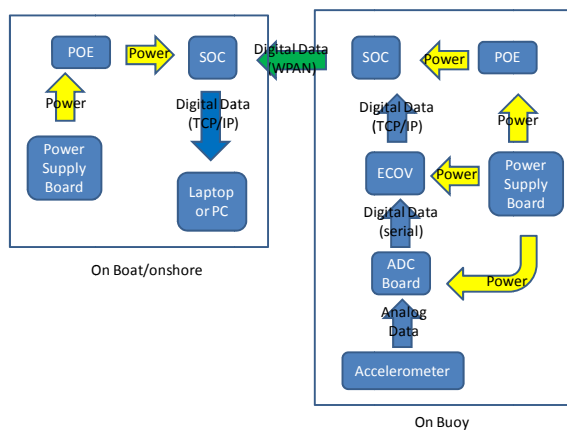

Figure 4: Wireless system

For equipment installation at the wave buoy, the preparations on telemetry system are wireless devices (e-COV converters, gyro meter, Inline Power Injector POE, Wireless Outdoor Client Bridge / AP), power supply circuit and 12V rechargeable battery. The 4 rechargeable batteries were installed at the middle part of the buoy and reacted as ballast for the wave buoy while the wireless devices were installed at the inner platform.

3.0 SITE CONDITION

The power potential of the Wave buoy legged Spider device for an ocean site in Terengganu, West Malaysia is approximately assessed as a conceptual application of the device. The floating ball has provided a typical observed wave record at the site, as showed in Figs.5 – 7. The average water depth is 90 m. The significant wave height (H1/3) is 0.64m, and the corresponding wave period is 5.2s. The average wave height is 0.45 m. It is assumed that the linear wave theory is applicable for the site. Conservatively, this case study considers H1/3 and the corresponding wave period as typical wave characteristics for energy evaluation. Therefore the kinetic energy (Ek) is estimated

to be 678 J/m2, and the corresponding power (Pk) to be 2.96 kW/m. The total wave power (Pw), which incorporates both kinetic and potential energies, is thus estimated to be 5.92 kW/m.
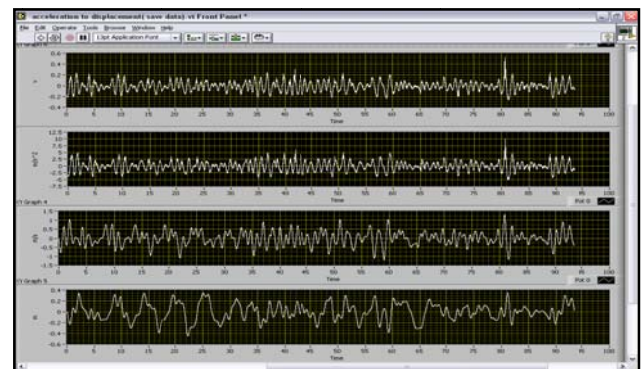

Figure 5: Site measurement
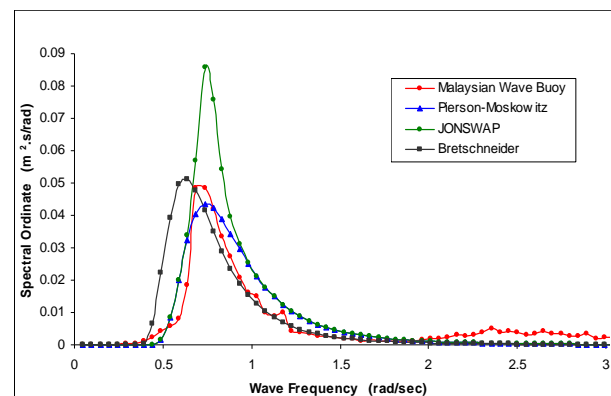

Figure 6: Data measurement

Figure 7: Wave spectrum data measurement

4.0 CONCEPTUAL DESIGN

The parameters of linear generator in other studies with similar wave climate are applied in this study for demonstrative purposes. Wu et.al [1] and Danielsson et al. [9] and Danielsson [10] conducted a linear generator study based on regular wave, in

which wave height and wave period were 1.5m and 4.5s, respectively. The wave characteristics are close to the significant wave height and corresponding wave period in this study, so the basic parameters of linear generator applied in Danielsson et.al [9] and Danielsson [10] are used herein, showed in Table 1.

A Wave buoy legged Spider device is hence conceptually designed, and Fig. 8 illustrates basic dimensions of the power antenna. An octagonal buoyant plate (side length 0.6 m) is adopted, and the diameter of the entire device is about 7.85 m. Considering the diameter of the device, the total output power for a unit width is 2.96 kW/m. In this case study, the total output power P^* is estimated to be 15.17 kW.
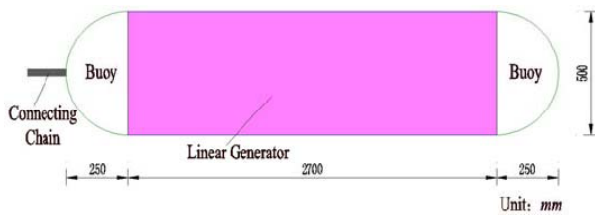

Fig. 8. Power antenna dimension

Tabel.1 Parameter of Linear Generator

Parameter	Value
Apparent power (kW)	10
Voltage (V)	200
Current (A)	29
Resistive (Ω)	4
Width of stator (mm)	460
Length of stator (mm)	2640
Width of magnet (mm)	55
Hysteresis Loss (kW)	0.52
Eddy current loss (kW)	0.07
Resistance loss (kW)	2.75

To evaluate the utilization rate of wave energy for the conceptual design, an energy efficiency of the small-scale floating wave device, such as Wave buoy legged Spider, however, the potential energy may not be effectively utilized in practice. Hence an energy efficiency of the device is defined.

$$\eta = \frac{P^*}{P_k} \qquad (1)$$

η is estimated to be 65.2%. It can be observed that considering the effectively usable energy P_k, the energy efficiency of the wave buoy legged spider device is relatively high.

5.0 Directional Wave Spectrum

Due to the directionality of waves, the power antennas of a Wave buoy legged Spider device may not reach the full capacity P_k, simultaneously. The effective output of a power antenna depends on a measured wave direction. The effective output (P_e) can be approximately estimated as follows:

$$P_e = P_k |\cos \lambda| \qquad (2)$$

where λ (=β) is the angle between the power antenna and wave direction (see Fig. 1)

When a floating ball buoy is facing in following seas, there is a range of the encounter frequency of the wave buoy, which cannot be related to the wave frequency by a single-value transformation. The method to overcome this difficulty has not been well established, although studies to evaluate the one-dimensional wave spectra as well as the directional wave spectra have been extensively carried out in recent years. To determine the directional wave spectrum by using a nonlinear programming, the ordinates of wave spectrum at an arbitrary wave frequency are used as design variables and the optimization by using a nonlinear programming is carried out in the range of encounter frequency of the buoy.

5.1 Optimization Procedure

In this section, we propose to determine the wave spectrum by using nonlinear programming [11], in which the ordinates of wave spectrum at an arbitrary wave frequency are specified as design variables and the optimization has been carried out in the encounter frequency of the ship. The procedures adopted in this paper are as follows.

1) Define the design variables which are the ordinates of the wave spectrum in the wave frequency ; $S_w(\omega)$

2) Estimate the spectrum of the buoy response, $S_x(\omega)$, by using the following relationship,

$$S_x(\omega) = S_w(\omega) x \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} [A_x(\omega, \chi_0 + \chi_c)]^2 D(\omega, \chi_c) d\chi_c \qquad (3)$$

Where: the directional function $D(\omega, \chi_0)$ is assumed to be $\cos^4 \chi_0$.

3) Transform the estimated spectrum of the buoy response in the wave frequency $S_x(\omega)$ to the one in the frequency of encounter $S_x(\omega_e)$,

4) Define the objective function F,

$$F = \sum_{\omega_e=0}^{\omega_{ec}} \{\widetilde{S}_x(\omega_e) - S_x(\omega_e)\}^2 \qquad (4)$$

$\widetilde{S}_x(\omega_e)$ and $S_x(\omega_e)$ are respectively the estimated and measured spectrum of the buoy response in the frequency of encounter.

5) Minimize F under the following constraints,

$$\int_0^\infty \widetilde{S}_x(\omega) d\omega = \int_0^\infty S_x(\omega_e) d\omega_e \qquad (5)$$

5.2   Transformation Spectrum

The spectrum of ship response in the frequency of encounter can be converted to the one in the wave frequency. However, there is the situation as shown in Fig. 9, in which one frequency of encounter is related to three values of wave frequencies. This is the reason why the transformation of the spectrum is difficult.
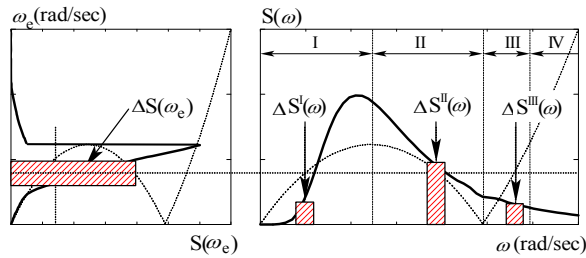

Figure 9: Transformation of spectrum from ω_e and ω_{ec} (for $\omega_e \leq \omega_{ec}$)

When a spectrum of buoy response in the encounter frequency is transformed from the one in the wave frequency, the power spectral density concentrates only in the region $\omega_e \leq \omega_{ec}$. However, the measured spectrum of the buoy response in the encounter frequency has a power spectral density even in the region $\omega_e > \omega_{ec}$, and no concentrated power spectral density is appeared. Therefore, in order to deal with the concentration of the transformed spectrum in the region $\omega_e > \omega_{ec}$, the correction factor has been introduced.
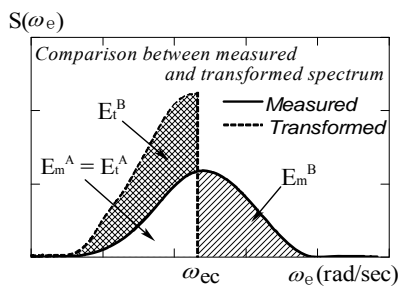

Figure 10: Transformation of spectrum from ω_e and ω_{ec} (for $\omega_e \leq \omega_{ec}$) using correction factor.

5.3   Estimated Wave Spectra

5.3.1   Experiments in Towing Tank

The experiments were performed in the towing tank of Universiti Teknologi Malaysia. The dimensions of the tank are 120.0m (length) by 4.0m (breadth) by 2.5m (depth). The buoy was freely drifted by towing under a carriage.

Fig.11 shows the non dimensionalized amplitudes of heave and

pitch in regular following waves. In the figure, the solid line shows the result of strip theory and the mark   corresponds to the measured values, they have the same trends theoretically and experimentally.
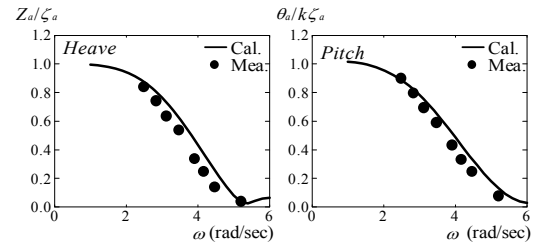

Fig. 11 Heave and pitch responses in regular wave

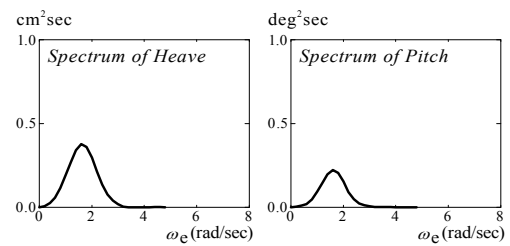Fig.12 gives the measured spectra of heave and pitch in irregular waves.

Figure 12: Measured spectra heave and pitch

5.3.2   Comparisons of wave spectra

Fig. 13 shows the comparison between the estimated and measured wave spectra. In Fig. 14, the spectra of heave and pitch response between the estimated and measured in the encounter frequency with correction are compared.
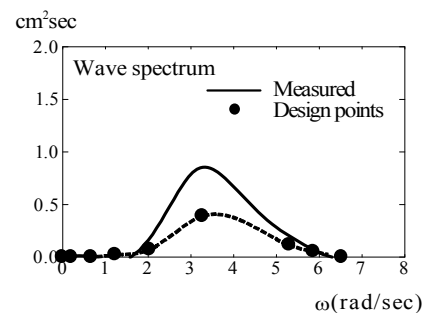

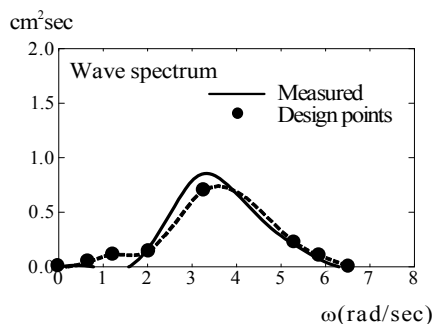Figure 13: Comparison between estimated and measured wave spectrum

Figure 14: Comparison between estimated and measured wave spectrum with correction.

6   CONCLUSION

The conclusions have been drawn as following items;

1. The small-scale wave device, the Wave buoy legged Spider concept is characterized by simple structure buoys, high energy efficiency, and convenient installation and maintenance. The device may provide a promising way for small-scale wave energy development.

2. For designing the Wave buoy legged Spider, a method to determine the directional wave spectra by using nonlinear programming has been used and the transformation of the spectrum has introduced a correction factor in order to avoid the concentration of power spectral density. The capability of this method has been confirmed by the analysis with the data of the experiments.

5.0 REFERENCE

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