Experimental Investigation of the Power Generation Performance of Floating-Point Absorber Wave Energy Systems

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Experimental Investigation of the power generation performance of floating-point absorber wave energy systems

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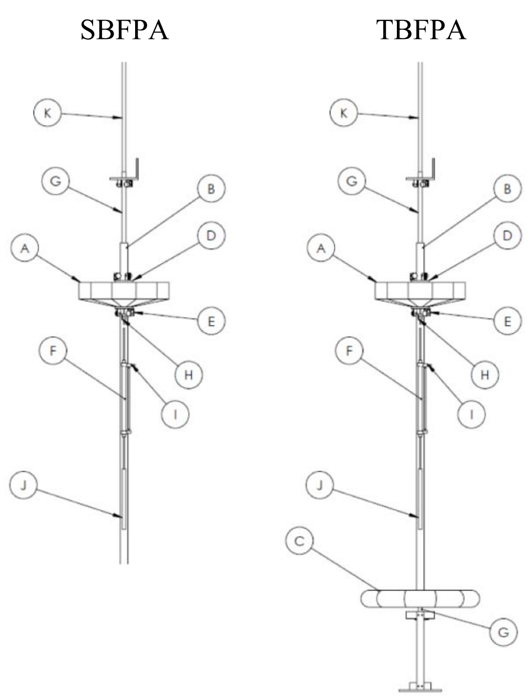
1 Introduction

The extraction of energy from ocean waves has gained interest in recent years (Thorpe 1999). The floating-point absorber (FPA) is one of the most promising devices among a wide variety of wave energy conversion technologies (Falcão 2010). Early theoretical studies mainly focused on understanding the hydrodynamics of the system and on predicting the maximum power that could be extracted by a heaving body (Budal and Falnes 1975, Evans 1976, Mei 1976, and Newman 1976). These studies evolve from the investigation of floating-body interactions in offshore engineering and naval architecture disciplines. For more information on this topic, see the comprehensive reviews provided by Falnes (2002) and Falnes (2007). To our best knowledge, no systematic study has been reported about the investigation of the power generation performance of an FPA with a close-to-commercial design. A series of experimental tests was conducted to investigate the power extraction performance of an FPA system. Herein, we present a preview of our experimental study.



Component	Mass in kilograms (Kg)
A. Float	3.220
B. Central column	0.745
C. Damping plate	1.108
D. Top roller	0.115
E. Bottom roller	0.117
F. Cylinder and clamps	0.205
G. Heave guides	0.116
H. Load cell	0.012
I. Needle valve	0.015
J. Linear potentiometer (short)	0.077
K. Linear potentiometer (long)	0.114

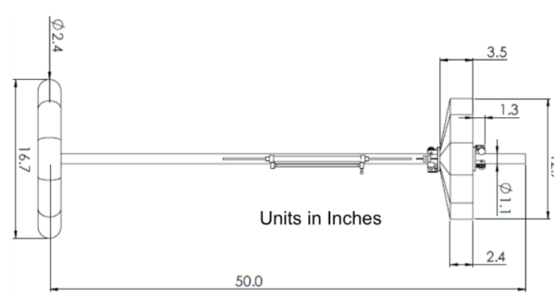


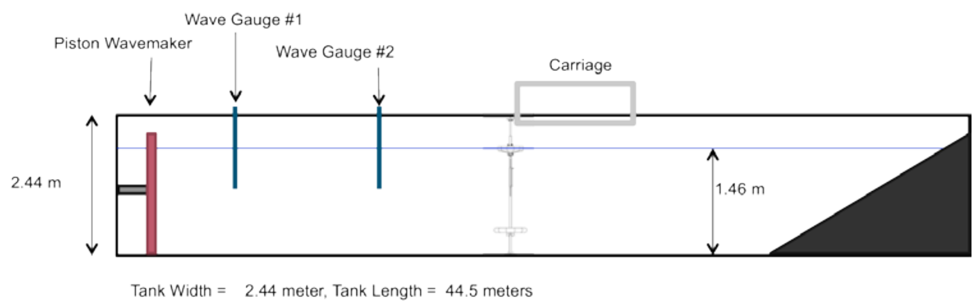
Figure 1. Design of the floating-point absorber: (left) geometry sketch and (right) properties in model scale

2 Device Design

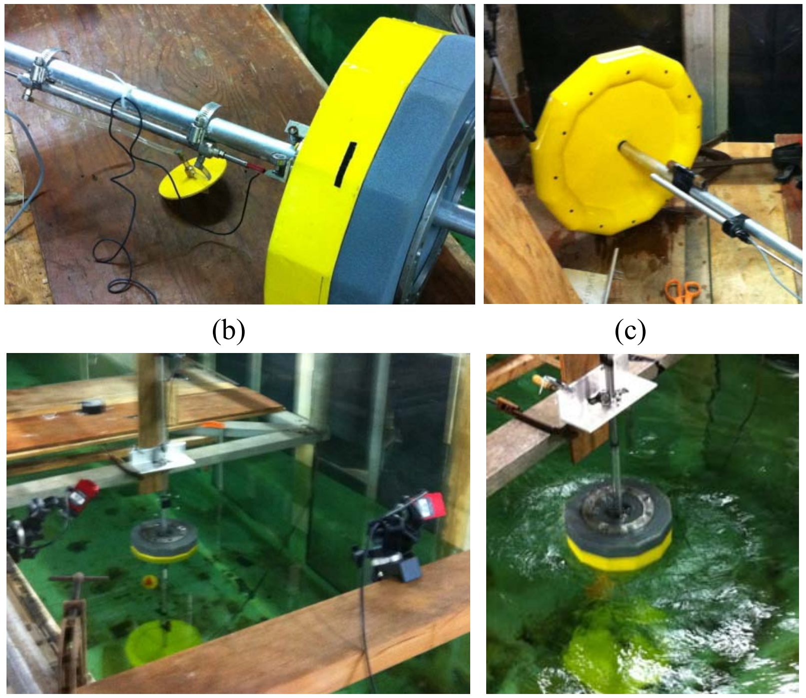
Typically, an FPA is a single buoy that reacts against the seabed or a multi-body system that generates energy from the relative motion between the oscillating bodies. The latter is generally designed for deeper water deployment, with a depth between 40 meters and 100 meters, while the single buoy system operates in shallower locations. Here, we consider a single-body FPA (SBFPA) system and a two-body FPA (TBFPA) system. A 1:33 scale model was built and the details of the model geometry and properties are shown in Figure 1. Both systems contain a float and a central column, and the TBFPA system includes an additional damping plate. The float and the central column are connected with a miniature hydraulic cylinder in closed circuits with a needle valve to provide damping to the relative motion to represent the power take-off (PTO) mechanism. The PTO damping is controlled by turning the needle valve.

3 Experimental Setup

The experimental test was conducted at the wave tank in Scripps Institution of Oceanography at the University of California, San Diego, in late summer 2011. Figure 2 shows the dimension of the wave tank and the experimental settings. The wave tank is 44.5 meters long and 2.44 meters wide, and the water depth is 1.46 meters (Figure 2a). The test apparatus for both the SBFPA and the TBFPA was designed to only allow heave motion. Specifically, the float was allowed to move along the central column and the system generates energy based on the relative motion between the float and the fixed carriage (for the SBFPA) or the float and the reaction plate (for the TBFPA).



(a)



(b) (c)

(d) (e)

Clockwise NREL/PIX 0980, 0981, 1002, 004

Figure 2. Experimental setup: (a) configuration sketch, (b) load cell, (c) linear potentiometer, (d) camera system, and (e) a snap shot

Throughout the test, a linear potentiometer (Figure 2c) was used to record the relative motion between the float and the central column. In order to ensure the linear potentiometer measurement quality, a camera tracking system was implemented. Four cameras were arranged in a semi-circle around the model (Figure 2d) to ensure the camera system was able to fully capture the dynamic response of the device. To evaluate the power generation performance of the system, PTO force measurements were needed, and these values were obtained using a load cell (Figure 2b). In addition, a National Instruments USB 6009 data acquisition system was used with LabVIEW software to record, calibrate, and process the test measurements. The data for each run was sampled at a rate of 100 hertz for 60 seconds.

4 Results Discussion

Due to the page limitation, only a few preliminary results are presented here. The relative velocity of the motion between the float and the central column is calculated by differentiating the motion with respect to time. The power is calculated by multiplying the load cell force with the relative velocity obtained above.

4.1 SBFPA Results

Figure 3 shows the power generation performance of the SBFPA system in waves with a height of 2 meters. The averaged power that can be extracted by the system is plotted against the wave period. Note that the natural period of the float is around 4.3 seconds, which was obtained from the decay test, and that the SBFPA system did not perform close to resonance in the study. Therefore, the power extraction efficiency, or Power/EL, where E is the wave energy flux per unit crest length and L is the capture width, of this SBFPA is only around 10% for a typical wave period of T=10 seconds. The test of the SBFPA system was conducted to analyze the effect of the PTO damping, and the results can be useful for validating our computational fluid dynamics (CFD) simulation in the future.

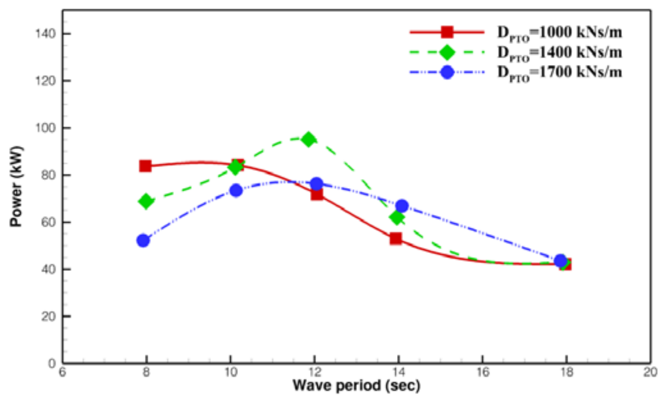


Figure 3. Power generation performance of the SBFPA system (full scale)

4.2 TBFPA Results

The damping plate in the TBFPA provides extra damping compared to the SBFPA system, which increases the natural period to 8 seconds. The TBFPA system is designed to have a natural frequency in heave that is close to the typical peak frequency of real seas in order to maximize the power generation performance. To test this, we conducted a series of experimental studies on the power extraction performance of the TBFPA system under waves with a height of 2.5 meters.

Figure 4 shows an example of the time history data from measurements, including the damping (reaction) plate motion, the relative velocity between the float and the central column, the force measurement from the load cell, and the power prediction. To evaluate the power generation performance of the TBFPA system, the averaged power is plotted against the incident wave period (Figure 5). The power is scaled by the square of wave height in order to compare the experimental results with existing CFD simulations. The results show that the maximum power extraction efficiency for this TBFPA is around 30%, when the system is close to the resonance. It is noticed that the experimental and CFD results show a similar trend, and both have maximum peak power generation performance that is close to the natural period of the system. However, the two results have different maximum values. This is expected and may be caused by (1) different incident wave conditions, where nonlinear waves and FPA motion effects are essential in waves with larger wave heights (Yu and Li 2011), and (2) the differences in the FPA geometries. Note that model used in the experimental test has a larger float height to reduce the chance of wave overtopping and a rounded reaction plate, which helps reduce the viscous damping effect due to flow separation.

4.3 Summary and Future work

In this work, we find that 1) the viscous effect significantly affect the power output of the FPA, particularly the viscous effect caused by the reaction plate design; and 2) within acceptable engineering range, the larger the device, the more cost-effectiveness. However, this is rather a speculation than a solid conclusion; it needs further investigation of the PTO mechanism and other components of the device, e.g., mooring lines and anchors.

In future work, more details on the results and discussions will be discussed in a journal paper shortly. Additionally, if possible, the geometry of the FPA in the CFD model will be made the same as in the experiment. In the next step, we intend to conduct the following: (1) to optimize device size and geometry to increase the maximum power extraction efficiency, and (2) to develop optimal control strategies, which can provide a broader range of wave frequencies that are more efficient at absorbing energy.

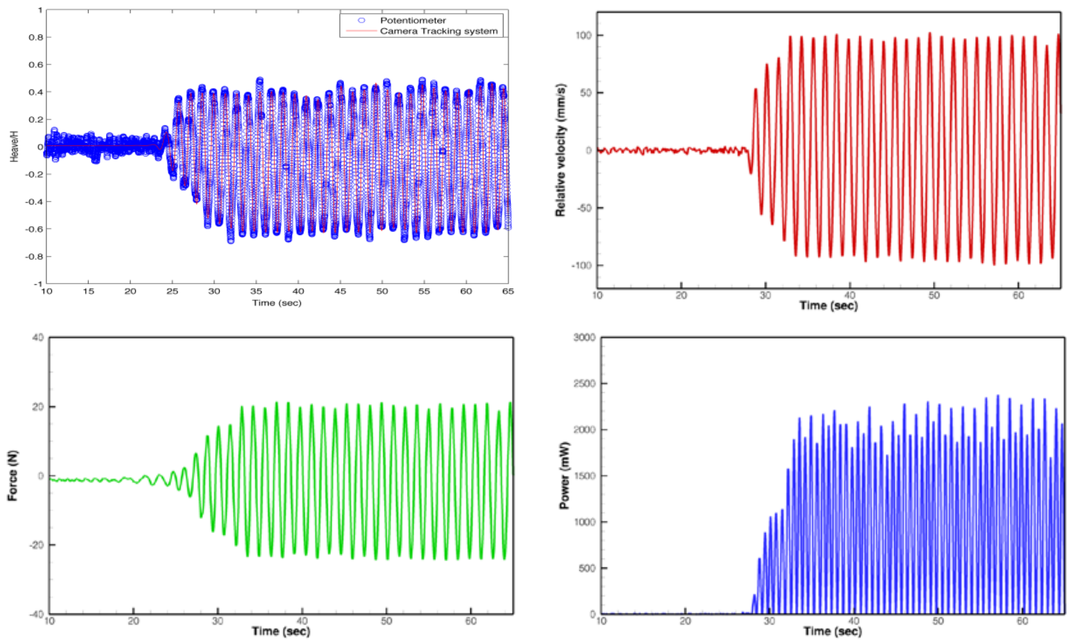


Figure 4. An example of the time history measurement data (T=1.39 seconds model scale)

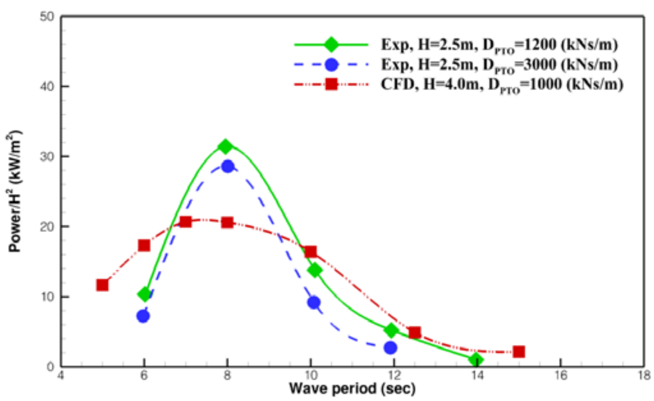


Figure 5. Power generation performance of the TBFPA system (full scale)

Acknowledgment

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