STATION-KEEPING SIMULATION OF A NON-MOORED WEC

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1. INTRODUCTION

While wave energy has significant potential to contribute to national power needs [1], the unique capabilities of the resource may also be applied on smaller scales. These applications can offer near-term market opportunities with less risk than utility-scale generation.

While most concepts for wave energy revolve around anchored or tethered wave energy converters (WECs), untethered WECs may have broader potential applications. The lack of an anchor simplifies deployment and recovery operations and eliminates a component of the WEC that constitutes approximately 10% of the capital expense [2].

Several applications that could be enabled by the ease of deployment and recovery for free-drifting WECs, include autonomous underwater vehicle (AUV) and oceanographic sensor charging (similar to that proposed by Hamilton, et al. in [3]), offshore, mobile aquaculture operations, and desalination or emergency power for disaster relief in coastal regions. Such a device may be well suited for these unique applications due to its portability, and added costs required by such applications may be more than offset by the removed costs of mooring and cabling to shore.

While the dynamics of an unmoored WEC should be simpler than for a moored device, these have not been well explored, such as the implications for station-keeping control. Similar dynamics are likely for minimalist mooring concepts that could reduce conflict between wave energy development and other users of the ocean (e.g., fishing, crabbing, shipping [4]).

We explore the dynamics of an unmoored WEC using numerical simulations of a free drifting WEC under various environmental forcing conditions. The feasibility of device station keeping is also assessed.

2. METHODS

2.1 WEC Description

The WEC used in this study was designed by Columbia Power (Corvallis, OR). It is a heaving point absorber consisting of a cylindrical nacelle with a connection to cylindrical floats on both sides. The WEC floats and nacelle are in line with one another and the axis of rotation is parallel to the surface of the water. A conical heave plate hangs about 60 m below the nacelle. Wave motion causes the floats to rotate about the axis of the nacelle, and this motion is harnessed by rotary electrical generators. The device is visualized in Figure 1 and a partial set of device properties are given in Table 1.

TABLE 1. WEC PROPERTIES

Parameter	Value	Units
Nacelle Diameter	0.5	m
Nacelle Length	2.5	m
Nacelle Mass	454	kg
Float Diameter	0.7	m
Float Length	2.5	m
Float Mass	250	kg
Heave Plate Mass	350	kg
Heave Plate Line Length	57	m
PTO damping	2400	N-m-s

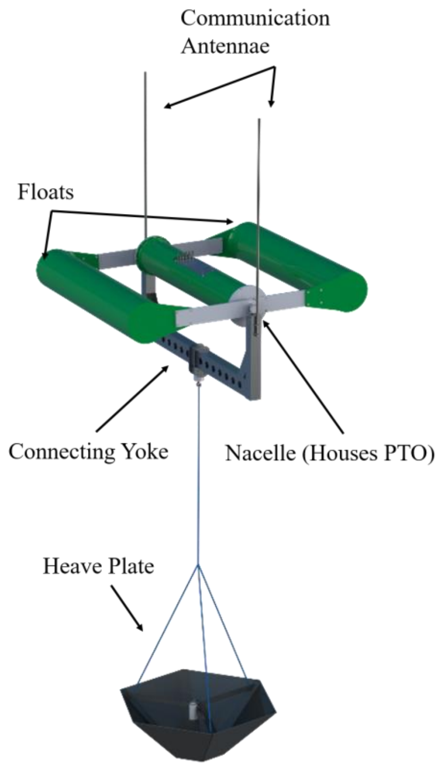

FIGURE 1. WEBS SCHEMATIC.

2.2 Simulation

ProteusDS (Dynamic Systems Analysis Ltd.) was used to model the WEC and environmental conditions. ProteusDS is a hydrodynamics modeling software that simulates the response of mechanical systems to various environmental conditions found in open water [5]. The fluid domain is discretized into a three-dimensional mesh, and rigid bodies are discretized into surface meshes. The software solves for the forces imparted on the system by user-defined environmental conditions using the Morison equation: calculating drag, Froude-Krylov, and inertial forces acting on the body (including added mass). The coefficients of drag and added mass are prescribed by the user, rather than evolving from the simulation (as for unsteady computational fluid dynamics), which significantly decreases computational cost. The software simulates the response of the body in the time domain, but the body does not influence the environmental conditions in the surrounding water (one-way coupling). The rigid body response to these forces is governed by the Newton-Euler equation of motion. Further details on the numerical implementation is available in [5]. The WEC nacelle and floats were modeled using ProteusDS-defined objects, and the heave plate was modeled in SolidWorks (Dassault Systems) and imported as a surface mesh. ProteusDS allows the specification of wave, wind, and current forcing in a number of configurations. It includes a Pierson-Moskowitz spectrum and JONSWAP spectrum to produce irregular wave fields, as well a number of wind and current profiles. In simulation, the WEC is free to move in response to environmental forcing.

2.3 Free Drift in Waves

The WEC was forced by both a Pierson-Moskowitz (P-M) and a JONSWAP wave spectrum with a significant wave height of 2.5 m and peak period of 7 s. Though the wave field was irregular, a seeding option allowed for repeated generation of the same 'random' wave field. No current or wind forcing was applied. These simulations used a wave spectrum consisting of 270 'wave segments'. This term refers to the number of wave elements making up the spectrum. Earlier simulations used 10 wave segments, which caused repeated wave forcing every 18 seconds. With 270 wave segments, the wave forcing repeats about every 500 seconds. With typical simulation lengths of 1800 seconds, the shorter repeat time allowed significant error accumulations. Simulations longer than 500s were chosen to produce an ensemble average of power in a given sea state, since the WEC experiences the repeated forcing in different orientations.

2.4 Motion Control

Without an anchor, the WEC's position will change over time when exposed to winds, waves, or currents. If it is desirable to maintain WEC position to a given tolerance, either thrusters or other hydrodynamic control must be employed. First, to roughly quantify the forces required for control in various conditions, a forcing study was conducted in which constant forces of varying magnitude were applied to the heave plate and to the nacelle in quiescent water, and the terminal velocity of the WEC determined. For controlled motion, a Proportional-Integral (PI) controller specifies thrust to minimize the distance between the device and the desired long-term station position. Simulations tested the effect of PI controller gains and the effectiveness of a controller attempting to maintain the position of the nacelle versus the heave plate.

3. RESULTS

Simulation results of device performance from ProteusDS (not shown) were found to be in good quantitative agreement with independent simulations conducted by Columbia Power in Aqwa (ANSYS).

3.1 Free Drifting Study

Results from two-1800 second simulations can be seen in Figure 2. Drift tracks for the WEC in both a Pierson-Moskowitz (P-M) and a JONSWAP spectrum are shown. The WEC experienced average drift rates of 0.13 m/s and 0.14 m/s for the P-M and JONSWAP spectra, respectively. For the equivalent regular wave field (i.e., 2.5 m, 7 s waves), the expected Stokes drift [6] is 0.12 m/s. The device drifts faster than the expected Stokes drift for most of the wave conditions, and simulated drift rates are closest to Stokes drift near these conditions (the wave specifications used for design).

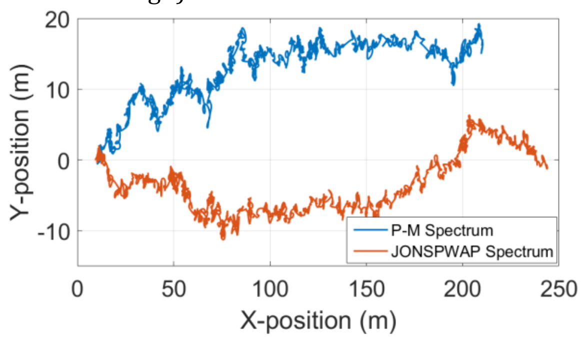

FIGURE 2. WEC DRIFT TRACK IN WAVE CONDITIONS, 1800 SECOND SIMULATIONS. WAVES PROPAGATE FROM LEFT TO RIGHT.

3.2 Motion Control Study

As shown in Figure 3, the correlation between thruster force and steady-state WEC speed diminishes slightly with increased force. This also suggests that, for typical inspection class remotely operated underwater vehicle (ROV) thrusters with maximum force outputs of ~250 N, the WEC would be able move with a maximum speed of around 0.25 m/s.

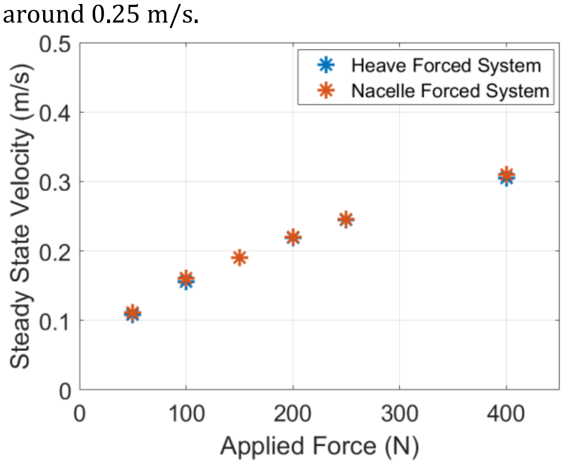

FIGURE 3. WEC STEADY STATE VELOCITY FOR FORCES APPLIED AT THE HEAVE PLATE AND NACELLE.

If station keeping of the WEC is desired, this could be achieved with a thruster mounted on the device. Preliminary results indicate that simple PI control of the heave plate yields more stable performance than PI control of the nacelle (for nacelle-controlled simulations in waves, the controller quickly becomes unstable and a watch-circle is not maintained). This is because wave motion is negligible at the depth of the heave plate, such that the controller reacts only to the net drift of the WEC, rather than wave-to-wave variability. To keep the WEC in a tight watch circle (less than 10 m diameter) in the wave-only case discussed previously (7 s, 2.5 m, P-M spectrum), thruster output peaked at around 300 N, which similar to the range of thrust provided by inspection class ROV thrusters. Results from this simulation can be seen in Figure 4.

For a nominal WEC PTO efficiency of 90%, an average power output of 480 W was calculated for the WEC under these conditions. Typical, low power thrusters producing around 200 N of thrust, require about 2.5 W/N (Max Kawaky, personal communication). Consequently, maintaining station with this WEC in a 7 s, 2.5 m P-M wave spectrum would require an average power of 430 W (i.e., the majority of power generated would go into station keeping). In general, the WEC produces more power around its resonant period (5 s), while Stokes drift is inversely proportion to the cube of the wave period. Consequently, the practicality of station-keeping would be expected to vary with sea state.

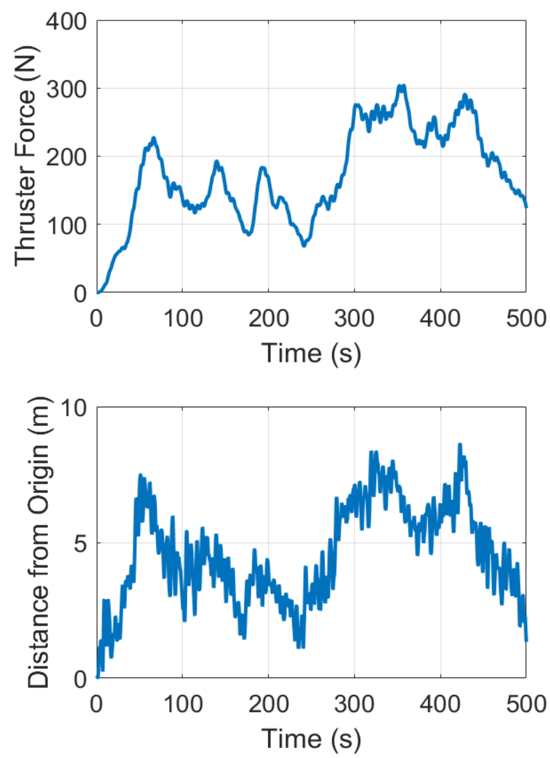

FIGURE 4. WEC RESPONSE TO HEAVE-BASED THRUSTER CONTROL IN A 7 S, 2.5 M P-M WAVE SPECTRUM.

DISCUSSION

Drift rates determine the interval for intervention for recovery and redeployment, and allow for an estimate of optimal deployment location based on expected future forcing. This would also be important information for an AUV using the WEC as a charging station. Forecasts of environmental conditions when the AUV leaves the WEC could inform a route planning algorithm where the WEC will be days later, leading to a more efficient AUV mission.

The forcing test indicates the maximum speed of the WEC for varied applied forces. As expected, greater applied force results in higher device speed, although this relationship diminishes with increased force due to changes in the orientation of the WEC that increase form drag. Using realistic, stock ROV thrusters, the WEC would be limited to station keeping in conditions with a drift rate of less than 0.25 m/s, regardless of energy reserves on board the WEC. This limit could be exceeded during a strong storm or if the WEC were to be deployed in an ocean current.

When considering control, there are benefits to applying thrust at either the heave plate or the nacelle for station-keeping. Applying thrust at the heave plate yields more stable performance, since there is limited orbital motion at this depth. This filters out much of the wave-to-wave motion experienced by the nacelle and floats, allowing the controller to expend most of its energy responding to the net drift of the device. On the other hand, knowledge of heave plate position is made more difficult by its submerged position (i.e., no GPS signal).

FUTURE WORK

Additional simulations will continue to build an understanding of device dynamics over a range of environmental conditions. Free drift tests will be conducted to cover a matrix of wind, wave, and current conditions. Through this, the most influential conditions may be identified, and links between conditions and device drift rates determined. If superposition of forcing is linear, this will allow for faster extrapolation of WEC reaction to a broad range of conditions.

CONCLUSION

This study provides preliminary results from the simulation of a free-drifting WEC and forces required to achieve station-keeping objectives. Free drifting WECs have simpler logistics and lower costs than moored WECs, but, depending on the application, may require thrust to maintain station. Prediction of device motion in various environmental conditions would prove key for a number of applications, while station keeping or controlled device motion would be employed in others.

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