A STUDENT DESIGNED AND BUILT WAVE ENERGY CONVERTER

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INTRODUCTION

A small, point absorber-type wave energy converter (WEC) was developed by undergraduate teams to provide educational experience as well as a thoroughly documented device for comparison with computer simulations. The design process included identifying a basic concept, using analysis to optimize component specifications, fabricating and testing individual components, assembling the system, and at-sea testing off the NH coast.

The present system is the culmination of three University of New Hampshire (UNH) senior design teams – academic year 2013-2014 (3 members), academic year 2014-2015 (10 members), and 2015-2016 (2 members). The faculty and graduate student authors of this contribution served as advisors. Funding from UNH Sea Grant, the UNH Marine Program and Mechanical Engineering department totaled about $3000 per year. The first team established the basic design concept and completed the first version using no-cost, repurposed floating body components. They were able to bring it to the tank testing stage. The large, second year team redesigned the floating components and the power-take-off (PTO) unit and were able to conduct the first at-sea tests. The present, much smaller team is focused on addressing the myriad of mechanical and data acquisition issues that arose from the ocean trials.

The design configuration consists of a spar buoy, a float that slides axially on the spar, and a PTO driven by the relative movement of the spar and float (see Figure 1). The spar has a lower extension terminating in a circular heave plate. The 5 foot diameter, foam float is constrained to slide axially on spar. The PTO unit is mounted on top of the spar and is driven by a connecting rod attached to the frame mounted on the top of the float. The PTO has two rack-and-pinion sets with one-way bearings to convert oscillating motion to continuous rotating shaft motion in one direction. The output shaft drives an off-the-shelf generator designed for small wind turbine applications. This straight-forward design was intended to be representative of many point absorber-type WECs and, therefore, suitable for testing and evaluating mathematical models and computer simulations for WEC performance. The authors (but not the student teams) are presently applying the Department of Energy simulation WEC-Sim [1], as well as a linear, heave motion only, single frequency (frequency domain) model [2] to this design.

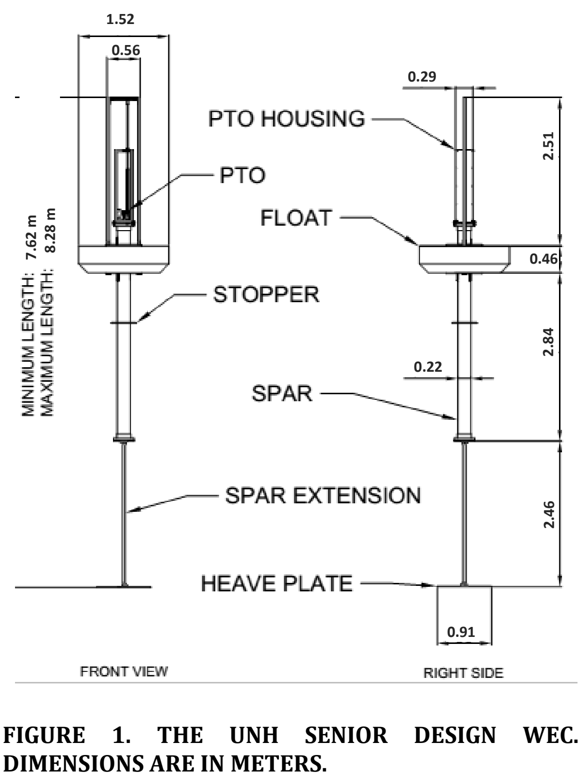

FIGURE 1. THE UNH SENIOR DESIGN WEC. DIMENSIONS ARE IN METERS.

DESIGN PROCESS

In general, student teams first developed a conceptual understanding of how the system and each component should function. Then hydrostatic analysis and dynamic estimates of heave motion were used for the determination design specifications. To build on prior coursework and in view of limitations on student time, mathematical models incorporated simplifying assumptions. Lab testing of components was then used to complete the quantitative evaluation.

For the float and spar, Solidworks was used to keep track of weights and volumes, so the equilibrium vertical position of the float was mid-way between the upper and lower stops on the spar (and the PTO rack and pinions were at mid-position). The float and spar were also designed to individually have hydrostatic stability with respect to inclination. Hydrostatic analyses were checked by tank-testing in UNH's large engineering tank (without waves).

The strategy for wave dynamic response was to minimize vertical motion of the spar, and achieve relative motion by having a responsive float. Thus the spar has a small waterplane area and a heave plate, while the float is light with a large waterplane area. Estimates of undamped natural periods were made using waterplane area and estimates of virtual mass. The intention was to make the heave natural period of the spar as long as possible, and that of the float as short as possible. For typical wave periods between them, the spar response should be minimal, while the float would tend to contour the waves. Analytical estimates for natural periods were 9.8 seconds for the spar and 1.2 seconds for the float thus achieving the design goal for the 2 – 6 second waves typical of the test site. Calculated natural periods were verified in tank free-release experiments.

Another critical design decision was specifying the generator to match the available mechanical power from the relative motion of the float and spar. A PTO load too small would underutilize available power, while one too large would lock-up the system. For estimation purposes, a typical wave off the NH coast during testing was taken to have a wave height of 1 m and a period of 3 seconds. The float/spar relative motion amplitude was taken to be 20% of that of the wave. Estimates of buoyancy force and the relative motion amplitude assumption were used to compute mechanical input power. The generator was selected to match this power level at rotation speeds provided by the PTO system gearing. Bench testing of the generator included measurement of torque, shaft rotation speed, and output power for various resistance loads across the output terminals. For the design forcing described, a 100 ohm resistor resulted in the optimum output power of 20 Watts.

DATA ACQUISITION

Since one important use for the device is to provide data for model validation, data acquisition was integrated into the overall design. An on-board Arduino microcomputer is used to record voltage across the resister used to represent the output load. Thus power output data is acquired. A LIDAR system was also arranged to measure relative position of the float and spar. The wave environment was measured using a subsurface pressure sensor deployed from its own nearby mooring.

SEA TESTING

Sea trials for the complete system were done on April 16, 2015 and June 25, 2015. The present design's draft was too large for testing in the UNH wave tank, so going directly to sea was necessary. Short deployments took place in open water approximately one nautical mile southeast of the Portsmouth, NH harbor entrance buoy (2KR). The mooring system was designed to not impart vertical loads, as shown in Figure 2, and the pressure sensor was deployed independently. The student team worked with the captain of UNH's 55-foot research vessel to plan all phases of loading, transport, launching, observation and retrieval. The captain had rigid standards for safety, and this operation was new to him. Students used storyboards to convince him that all steps could be taken straightforwardly and with minimal risk.

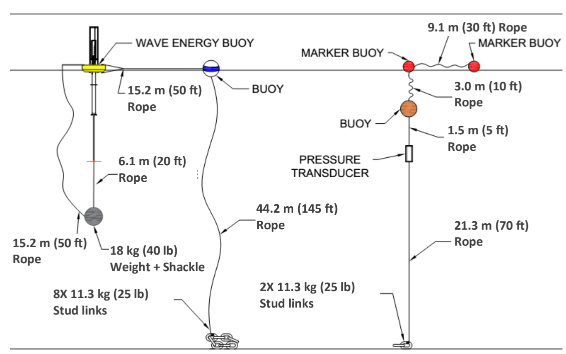

FIGURE 2. SCHEMATIC OF THE WEC AND PRESSURE SENSOR MOORING SYSTEMS.

Handling of the WEC during sea trials proceeded as planned. The WEC spar and float operated at their equilibrium waterlines, and relative motion, driving the PTO, was observed in both trials (see Figure 3). There were, however, minor mechanical failures in the PTO, and data acquisition was incomplete.

This year's student team is addressing these issues. They traced failure of the connecting rod/frame joint (see Figures 1 and 3) to "play" in the float/spar joint allowing axes misalignment and resulting side loads on the connecting rod. Joint guides were replaced by those having closer tolerances. In addition, shaft bearings were replaced and shaft positions were adjusted to improve easy working of the rack-gear systems. All the students had taken the required Mechanical Engineering machine design course, but for most of the students, this was their only hands-on, practical experience.

This year's student team is addressing these issues. A Spring 2016 deployment is planned with the goal of demonstrating the functionality of all components, as well as, generating the first data set that can be used in modeling studies.

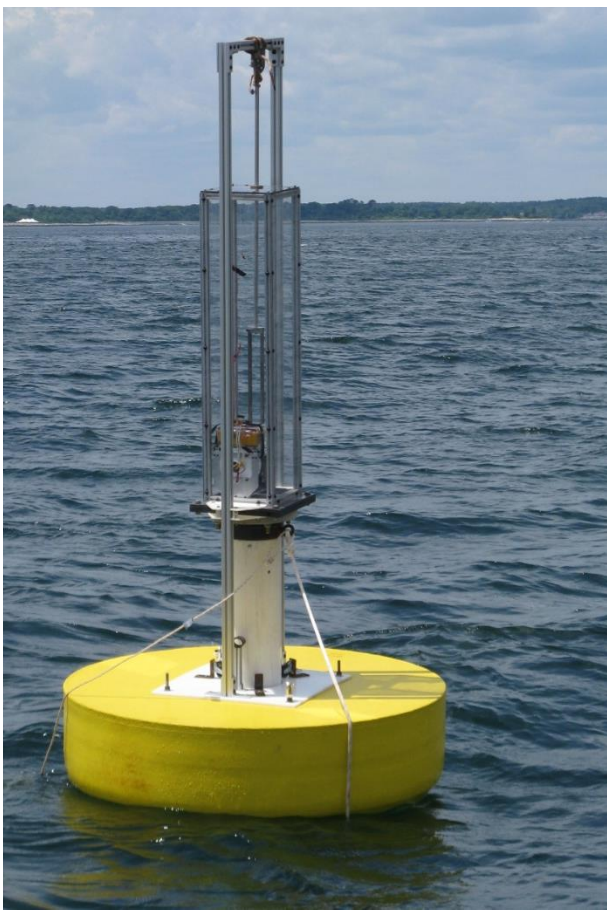

FIGURE 3. THE UNH STUDENT WEC OFF PORTSMOUTH NH. THE PTO MOUNTED ON TOP OF THE SPAR IS PROTECTED BY A CLEAR PLASTIC HOUSING. (THE SLACK LINES LEADING OVERBOARD ARE TAG LINES USED IN THE LAUNCHING AND RECOVERY PROCESS.)

CONCLUSIONS

UNH student design teams have had the educational experience of designing, fabricating and ocean testing a point absorber-type WEC. Many skills learned in their undergraduate courses, as well as new knowledge, were used in a series of senior design capstone courses. The WEC itself should be useful for continued research, particularly for the purpose of applying and evaluating computer simulations. It is also planned to employ the WEC in future ocean engineering laboratories as part of the new Bachelor of Ocean Engineering curriculum at UNH.

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2013-2014 Corey Sullivan, Carl Smith and Joe Henderson

2014-2015 Nate Bent, Nathaniel Brown, Corin Craig, Molly Curran, Pedro Da Masceno, Andrew Diorro, Kaare Francis, Ryan Kirby, John Pauley and Jeff Sweeney

2014-2015 Todd Michaud and Nathan Denoncourt

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REFERENCES

[1] Yu, Y., M. Lawson, K. Ruehl, and C. Michelen, 2014, "Development and Demonstration of the WEC-Sim Wave Energy Converter Simulation Tool," in Proceedings of the 2nd Marine Energy Technology Symposium, Seattle, WA.

[2] Wright, J., 2009, "Development and Validation of a Robust Analytical Model to Predict the Response of a WEC", MS Thesis, University of New Hampshire, Durham, NH, 60pp.