International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 30, No. 4, December 2020, pp. 403–413; https://doi.org/10.17736/ijope.2020.mm25

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Performance Evaluation and Optimization of a Hinged-type Wave Energy Converter

Wei Meng, Meng Chen, Heather Peng and Wei Qiu*
Department of Ocean and Naval Architectural Engineering, Memorial University
St. John's, Newfoundland and Labrador, Canada

This paper presents the numerical analysis and optimization of the wave energy converter, Sea Wave Energy Extraction Device (SeaWEED), which is considered as an improved attenuator consisting of four modules connected by rigid truss structures. A potential-flow-based frequency-domain program based on the Lagrange multiplier method was developed to predict the hinged motions and the power takeoff (PTO) of SeaWEED. The numerical method was validated by using experimental data. Optimization studies were further carried out by considering various parameters, including damping coefficients of the PTO systems, lengths of truss structures, and draft of the device. The uniform design method was used for sampling, and the response surface method was employed for surrogate construction. An optimal combination of parameters was determined for an intended operation site.

INTRODUCTION

Over the past decades, renewable wave energy has become an interest because of the increasing energy assumption demand and environmental concerns. Compared to other renewable energy, wave energy has relatively less impact on the environment, larger energy density, and greater power output efficiency (Drew et al., 2009). The globally available wave power was estimated as 3.7 TW, which is in the same order of magnitude as the world consumption of electrical energy, according to Mørk et al. (2010).

Many wave energy converter (WEC) devices have been proposed. They can generally be categorized into overtopping devices, oscillating water columns (OWCs), and oscillating bodies based on their working principles (Day et al., 2015).

Overtopping devices capture power as waves flow up a ramp and over the top into a storage reservoir and the water passes through turbines. Typical examples include the fixed-type seawave slot-cone generator (SSG) (Margheritini et al., 2009) and the floating-type Wave Dragon (Kofoed et al., 2006). OWCs extract energy using the oscillation of the seawater inside a chamber, such as the Pico Wave Power Plant (Falcão, 2000) and the Mutriku Breakwater Wave Plant (Torre-Enciso et al., 2009). Among oscillating body WECs, PowerBuoy (Mekhiche and Edwards, 2014) and the Oyster (Renzi et al., 2014) are examples of point absorbers. McCabe Wave Pump (Kraemer, 2001) and Pelamis (Carcas, 2003) are multibody attenuators, and the Seapower Platform (Seapower, 2008) and M4 (Stansby et al., 2015) are those with two bodies connected by a single hinge joint.

While many novel WECs have been proposed, devices to extract ocean wave and wind energy is another area of exploration. For example, Muliawan et al. (2012) proposed a concept for a hybrid wind and WEC device by combining a spar-type wind turbine and a torus point absorber WEC.

A multibody floating WEC, SeaWEED, with hinged units has recently been proposed by Grey Island Energy, Inc. (GIE). The SeaWEED consists of floating sections linked by trusses or rods and universal joints. The device has semisubmerged floats on the free surface and inherently faces into the direction of waves with a single-point mooring system. The wave-induced motions of the floats are converted to electricity through the hydraulic power takeoff (PTO) systems. The trusses can be customized in length to archive high efficiency for a specified site. The device is considered as an improved attenuator in comparison with Pelamis (Carcas, 2003). The design also attempted to address the wave topping and slamming issues encountered by Pelamis. A complete device has two PTOs, and each PTO is located in the back end of the producing module, as shown in Fig. 1. Each PTO consists of four double-acting hydraulic rams to capture energy from pitch motions. The use of the rigid truss structure would allow for a higher power output per unit mass and also reduce the side loading due to tidal currents, local wind, or bimodal swells in comparison with other attenuator devices.

As for the operational limits of SeaWEED, each section can articulate up to 30 degrees from the neutral axis in any direction before the end-stop becomes an issue. Air-pressured ballast tanks, highlighted in green in Fig. 2, are designed to increase the survivability of the device. In extreme sea conditions that could damage the system, air valves on these ballast tanks would open and release air, allowing the tanks to be filled with seawater and the whole device to semisubmerge.

Initial conceptual studies have been carried out to evaluate the performance of the first generation device by testing a 1:16

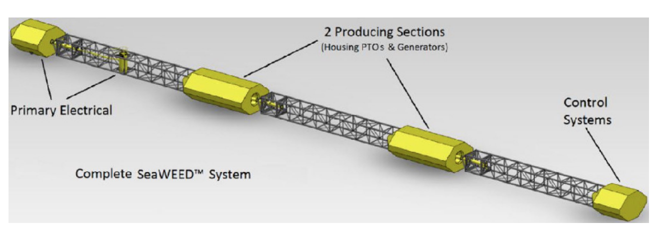

Fig. 1 SeaWEED system (Peng et al., 2020)

*ISOPE Member.

Received June 18, 2019; updated and further revised manuscript received by the editors March 11, 2020. The original version (prior to the final updated and revised manuscript) was presented at the Twenty-ninth International Ocean and Polar Engineering Conference (ISOPE-2019), Honolulu, Hawaii, June 16–21, 2019.

KEY WORDS: Wave energy converter, constrained motion, Lagrange multiplier method, optimization, uniform design, response surface method.