Experimental Investigation on Impact of Container Geometry on Efficiency of Non-Buoyancy Body Type Wave Energy Converter

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Abstract

The ocean is one of the biggest renewable energy resources. Energy harnessing from the ocean is an interesting area that is worth researching and full of promise for all energy engineers and researchers. There are a number of methods to follow in energy extraction from the ocean wave and tide. Point absorber is one of potent devices for energy extraction from the ocean wave. It could potentially afford a large amount of power in a relatively small device compared with the other technologies. It extracts the energy from the up-and-down movement of the buoy(s) on the ocean wave. To take full advantage of the device the point absorbers are designed to move freely along the wave. During rough weather condition, the wave exerts high buoyancy force on the buoy(s), forcing the device to face more stress and causing the device failure. To overcome this drawback, floating bodies in a point absorber were replaced by non-buoyant object in a certain research. That result showed that the ratio between the heave responses of the container and the corresponding wave amplitude (heave response ratio) of the device reached up to 2.6 so that the energy capture of this device was considerably raised per unit wave front. The results showed the energy production in the device being appreciably high at the range of 2.3-2.7s wave period and proportional to wave height under 30W and 60W electrical load condition. That experiment was conducted on a steel cylindrical container of diameter 0.4 m and height 0.7 m, used as non-buoyancy object. In this paper, a test was conducted to find the impact of the container geometry on the efficiency of non-buoyancy body type wave energy converter with existing result circumstance. The results obtained in the test on various shapes of the containers such as cylindrical, conical, inverted conical and double side conical, were plotted. The results showed that when using inverted conical shape of container, approximately 9% of output power could be increased compared with the using of existing cylindrical shape of container.

Keywords: Buoy(s), Cylindrical Shape, Energy Converter, Energy Harnessing

1. Introduction

Although enormous amount of energy possessed in the ocean waves, wave energy is unlikely least-known resource among the renewable energies. Although a slight amount of technologies and developments is continuing in this area. Several numbers of technologies are followed in energy conversion from the wave. Technologies for energy extraction from wave are basically classified according to method of capture, location at sea and power take-off system. The principle of this system is more efficient, more economic and safe than any other proposed devices1. The type of power take-off includes hydraulic ram, elastomeric hose pump, pump-to-shore, hydro
turbine, air turbine\textsuperscript{2,3}, and linear electrical generator. The locations of device mountings are near shore, off-shore and shoreline. The common approaches of wave energy capture are point absorber buoys, surface attenuators, oscillating water columns, and overtopping devices. The fundamental designs and operating principles of wave energy systems\textsuperscript{4} for energy conversion from wave and tidal is difficulty, because of non-consistence of wave formation in ocean. Due to many reason, the formation of wave is varied. Also according to location, the design of devices and concepts are having many differences, and more difficulties facing in erection of those systems. The paper reveals that the different container geometry was identified and its impact on efficiency of this wave energy converter was analyzed.

1.1 Methods of Wave Energy Conversion

The verities of techniques are followed to extract the energy from wave as follows; in surface attenuator the floating segments connected to one another are oriented perpendicular to incoming waves. A flexing motion is utilized to drive hydraulic pumps to generate electricity. Air compressed by oscillating water column in a chamber, compressed air forcing through an air turbine to create electricity. In overtopping device the wave velocity utilized to fill a reservoir to a greater level than the surrounding water level. The potential energy in the reservoir is then captured through low-head turbines. Oscillating wave surge converter typically consist a flat plate hinged at one end in seabed other end free to swing. Energy is collected from oscillating motion of the plate when wave passes over that device.

1.2 Point Absorbers in Heave

Point absorbers are the common method in wave energy harnessing. It consists of small buoys oscillating in the ocean waves. Which may submerged or floating on the water surface. According to wave motion, the floating body oscillates in up and down motion. By some drive mechanisms, the oscillating motion is converted into a rotary or directly utilized for power generation. A new technology is developed by Ocean Navitas Ltd\textsuperscript{5}, uses a unidirectional gearbox that produces continuous unidirectional rotation from the up and down motion of the floating body. Most of these systems are designed for offshore application. Floating, springs etc. are used as energy storing device in many point absorber\textsuperscript{6}. An improved model device employing deep-draft spar and annular saucer shaped buoy, by damping their motion, electricity is produced\textsuperscript{7}. Archimedes wave swing type system produces the compressed air by heave movement of devices\textsuperscript{8}. All the heave bodies are harnessing energy by up and down motion of water surface. To achieve maximum efficiency, the buoys are designed in various types. But there is some demerit, when in rough weather condition; the device gets damaged\textsuperscript{9}. To increase the efficiency in wave capturing, the concentration is focused on amplitude ratios. The higher float motion wants to ensure that the floating response does not exceed the allowable limit during extreme condition, since, the effect of extreme load reflected as failure mode. To prevent this kind of failures, the heavy mechanical structures and dampers are provided in the devices. The nature of rough waves can make any kind of failure in the devices and it can lead to the total device failure. The non-floating body for wave energy conversion devices eliminates this kind of issues and increases the conversion rate. Also it provides some additional advantages in installation and maintenances. That energy conversion system deals with the conversion efficiency on unique geometry shape of container\textsuperscript{10}.

1.3 Non-floating Body in Heave

The device liked as a conventional floater type point absorber but unique in its working principle. This energy converter improves the performance per unit wave front. And ensure the safety during extreme condition\textsuperscript{1}. The device consists of a cylindrical non-floating object, an oscillating arm, a unidirectional gearbox (converts alternative angular motion into continuous unidirectional motion), a step-up gearbox and generating unit. A water filled container act as a Non-floating body is kept hanging at one end of arm.

1.3.1 Oscillating Arm Assembly

A rigid straight frame pivoted at its mid-point on the shaft. The shaft is supported by means of bearing. The shaft carries flywheel and its end is coupled with generator through unidirectional gear box. A various geometry modeled and size of cylindrical steel container (non-floating body) filled with water is suspended at one end of arm by means of a length adjustable steel wire and counter mass mounted at other end of the arm. To keep equilibrium of arm according to various geometry modeled containers, the counter mass is varied.
1.3.2 Unidirectional Gearbox

The oscillation of arm in the setup makes both positive and negative direction rotational motion. This is to be converted into continuous unidirectional motion to run the generator. There are many patented devices available for this function. The proposed type gear box is simple in construction and converts the bi directional motion into unidirectional rotational motion with the approximate efficiency of 95%. The schematic experimental setup is shown in Figure 1.

1.3.3 Step Up Gearbox

This energy harnessing setup is functioning based on the up and down motion of the wave. The amplitude of wave is limited, and hence the oscillation of arm in the setup is also a limited one. This angled motion is not sufficient to run the generator. So to increase the angular velocity for this conventional generator, the step up gear box is coupled between the output shaft of unidirectional gear box and generator.

1.3.4 Electrical Generator

It is a device, converts the mechanical energy into electrical energy. A conventional rotary electric generator is coupled with flywheel in the output shaft of energy harnessing setup.

1.4 Working

The wave passes on the semi immersed container, the water level raises around the container, so the effective mass (m) of the container get reduced due to maximum portion of body immersed on the water. Because of this effect the arm becomes unbalanced in its position. That is the mass of counter weight is greater than to container mass, hence the counter mass pulls the container up. Due to this action the arm makes upward displacement. When the wave at trough approach that mean the water level around the container is lowered from the mean level, the mass of container is greater than to counter mass and hence the container pulls down. This imbalanced repeated motion makes continuous oscillating motion in the arm and that oscillating motion is converted into continue rotary motion by means of unidirectional gearbox. Figure 2 shows the schematic view of oscillating arm.

2. Container Geometry

The possibilities of energy harnessing from ocean wave by non-floating body was identified and analyzed the device performance according to heave displacement and wave period. The experiment produces the result that the non-floating body produces greater energy conversion in linear wave. Also this device shows its high performs in the wave period between 2.3s and 2.7s in high wave amplitude. Also the results shows that the output of the device is obtained maximum at maximum wave amplitude in the wave period range of 2.3s–2.7s. Here the energy conversion is made by using the cylindrical container in various sizes. Throughout its height the container having uniform cross sectional area. Damping is not concerned there. The experiment was conducted by different geometry model as shown in Figure 3.

Figure 1. Experimental setup.

Figure 2. Schematic view of oscillating arm.

Figure 3. Container geometry used for testing.
The purpose of this study was to find the impact of container geometry on efficiency of non-buoyancy body type wave energy converter. To extract the maximum device output, the movement of the container in the water is to be concerned. If reduction is on the damping effect on the container movement, there may increase in the output. The damping effect was analyzed by different geometries of container with their output. The test was conducted with the following condition. Occupied surface area of container at the water surface (area of 243.5 mm diameter) is same and different surface area (area of 200 mm, 287.1 mm diameter) at container bottom as shown in Figure 4. The different surface area of the container is obtained by incline the container angle with respect to axis of container (+10°, 0, –10°). Annexure to it one more container is modeled by double cone, shown in Figure 4. The height of all containers is 500 mm. All model containers are tested with their damping impact on water.

3. Results and Discussion

The intention of this experiment is to analyze the impact of container geometry on efficiency of non-floating body type wave energy converter. The results show that the geometry influences in the movement of container in water. That is damping effects performance of the devices. By provide the better geometry for the container which improves the output of the device. The performance test was conducted for 2.3 s, 2.5 s and 2.7 s wave period with the electrical load of 30 W and 60 W and output electrical energy was observed through power analyzer. In all output data, the inverted cone and double cone container geometries give more output than other container and the energy capture is depended to the counter mass. And performance of the device is significantly raised according to wave amplitude.

The device performs high in 2.5 s wave period under 30 W and 60 W load. The higher area container surface having good response in movement of body in upward direction but low response in downward moment due to damping of surface in the water. In the damping analysis the impact of damping on geometry model with different wave amplitude in 2.3 s–2.7 s wave period is analyzed. The inverted cone is having low damping effect in the water and cone geometry is having high damping effect. The low damping geometry model produces high energy output in the device in both kinds of electrical load condition. Figure 5 shows the power output of the device for 2.3 s, 2.5 s and 2.7 s wave period with 30 W electric load and Figure 6 shows.

![Figure 4. Container geometry.](image)

![Figure 5. Impact of container geometry on generated power under 30W load.](image)
efficiency between 2.3–2.7s wave periods for cylindrical container. By change of container geometry such as inverted cone geometry container achieves approximately 6% and 9% of efficiency more than to double cone and cylindrical geometry container respectively. Change of angle in inclination of the generative surface in the geometry model or change of generative surface in curved profile may possible to increase the device performance in the future.

5. References

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Figure 6. Impact of container geometry on generated power under 60W load.

the power output of the device for 2.3s, 2.5s and 2.7s wave period with 60W electric load.

4. Conclusion

Designing of offshore energy converter faces more difficult in concern with safety of the devices. In safety aspect the non-floating body wave energy converter will not get spoiled in rough weather condition too, due to flexibility in movement of container. In conversion, it produces maximum efficiency between 2.3–2.7s wave periods for cylindrical container.