Designing Wave Energy Converting Device

Jaimie Minseo Lee

The Academy of Science and Technology
The Woodlands College Park High School, Texas
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Abstract

Even though many different wave energy converter have been proposed using unique engineering principle, there are still many technical challenges for cost effective wave energy conversion. This project focused on and studied the aspects of converting the momentum of the ocean’s waves into energy. The goal of this project was to create an effective wave energy converting device that captures the most wave movement possible to create the most amount of electricity energy.

The engineer has designed two wave energy converting devices – Oscillating Water Column (OWC) and Wave Energy Extracting Turbine (WEET). The performance of two devices has been tested in a small-scale wave tank. In order to improve the performance, several guide plates have been attached.

Based on test results with different wave periods and various appendages, the engineer found that the geometry of devices and wave periods play an important role in how much wave energy can be extracted, and concluded that OWC has a better performance at the longer wave periods while WEET shows overall good performance at the shorter wave periods. The effectiveness of the OWC bottom guide plate is inconclusive at this experiment. The back guide plate of the WEET significantly improves the wave energy extracting performance.

The results from this project can benefit the world by providing people with clean and inexhaustible energy. It can also help guide WEC engineers to design future wave energy extracting devices. In the future, a bigger prototype of WEET can be tested with several more factors – such as different angled turbine flaps, reduced mechanical friction, flexible/bendable turbine flaps, etc. – to improve the wave energy extraction efficiency.
1.0 Introduction

Although oil and gas are great energy resources, they are nonrenewable resources. Once they are all used up, people will no longer have access to them until a century later (Aust, 2014). Another challenge that people are facing is the pollution caused by the use of nonrenewable resources (Matthews, 2015). These are problems that are starting to become more prominent, which is why it is important to find a long-lasting, reliable source of energy. Wind, solar and wave energy as renewable resources meets these criteria.

Wind and solar energy are very common ways to receive energy for green energy. However, it has been stated that wave energy may be able to provide ample amounts to meet society’s needs (Levitan, 2014).

Figure 1 shows a pyramid of renewable energy like a food chain. The sun initiates wind. Wind provides energy for ocean waves. Since water is about a thousand times denser than air, the wave energy density is higher than all other renewable energy resources (Lehmann, 2015) making wave energy more effective when it comes to generating more electricity (Bureau Ocean Energy Management, 2007).
Many types of wave energy converter have been proposed using different engineering principles – such as pressure differential principle, mechanical flexing and bobbing principle, overtopping principle, and hydraulic flapping principle. Wave energy converters that follow the pressure differential principle operates with variations of air pressure inside of a closed, hollow chamber. With the movement of the waters, water levels inside the chamber cause the air pressure to build up and release through a turbine. A good example of a wave energy converter that operates like this is an oscillating water column (Lim, 2013).

In the mechanical flexing and bobbing principle, wave energy converters move relative to the water altitudes or have hinge points. The converters move through wave induced mechanical movements. Attenuators and point absorbers are examples of converters that follow this principle (Lim, 2013).

Wave energy converters, following the overtopping principle, capture wave energy in the form of potential energy. The seawater enters a tapered channel into a slightly raised reservoir and is controllably released through a hydraulic turbine to generate electricity. Overtopping devices operate in this manner (Lim, 2013).

Wave energy converters that follow the flapping principle are oriented perpendicular to the water surface, otherwise the wave direction. Wave movement is absorbed upon impact and the structure is deflected which creates “flapping motion” when waves move in and out continuously. An example of this is the Oyster wave energy converter (Lim, 2013).

Even though many different wave energy converter have been developed, there are still many technical challenges for cost effective wave energy conversion. This project focused on and studied the aspects of converting the momentum of the ocean’s waves into energy. The goal of this
project was to create an effective wave energy converting device that captures the most wave movement possible to create the most amount of energy (Hares, 2010).

2.0 Test Methods

2.1 Materials

A water tank with wave maker, oscillating water column and wave energy extraction turbine are made of PVC pipes, plastic sheeting, wooden plates and metal plates. The list of materials used to build each model and measurement is presented below.

Wave Tank with Wave Maker:

- 20 of 0.61 m PVC pipe (1.27 cm diameter)
- 8 of 4-way-side coupling
- 8 of 3-way-corner coupling
- 2 of 91.4 cm x 182.9 cm x 0.4 cm plastic cardboard
- 3 of 3.04 m x 7.62 m plastic sheeting
- 2 of 0.5 cm diameter nail that is 1.5 cm long
- 2 of 0.5 cm diameter nail that is 1.6 cm long
- 46.2 cm x 14.9 cm x 1.3 cm wooden plate
- 3.8 cm x 7.6 cm x 2 cm wooden block
- 30 cm x 30 cm x 0.5 cm wooden plate
- 15 cm x 1 cm x 1 cm wooden stick
- 0.5 cm diameter nail 2 cm long

Oscillating Water Column (OWC):

- 30 cm x 15 cm x 0.5 cm wooden plate
2 of 28 cm x 15 cm x 0.5 cm wooden plates
Female coupler/adapter with diameter of 3.2 cm
7 of 0.5 cm diameter nail 0.7 cm long

Wave Energy Extracting Turbine (WEET):
20.32 cm x 20.32 cm metal plate sheet
2 of 0.79 cm nuts
3 of 0.82 cm hole diameter washers
Bearing with 8 mm bore
0.79 cm metal shaft 35 cm long
2 of rotator gear with 60 teeth
Rubber rotating gear chain designed for 60 teeth gear
5 of 30 cm x 15 cm x 0.7 cm wooden plate
DC motor (1000 RPM and 12 V)
Motor mount
2 of 3.81 cm x 30 cm plastic cardboard
2 wooden plates with diameter of 5.08 cm and thickness of 0.2 cm

Measurements:
Voltage multimeter
Anemometer
Metronome (Timer)
2.2 Test Set-up and Procedures

Figure 2 shows the experimental set-up. A wave tank has been built using eight (8) PVC pipes and connectors. The dimensions of tank is 1.8 m x 0.3 m x 0.3 m. Using the one of the plastic cardboards, the bottom and side walls of tank has been made. A boxing a knife was used to cut along the outlines previously made. The plastic cardboard box was placed within the assembled PVC pipes by taking off any few pipes and reattaching them. The PVC pipes were then secured into place using a hammer. The inside of the plastic cardboard box was wrapped with two clear plastic sheets of 3 m x 1.4 m to prevent any leakage. The tank was filled 2/3 of the volume with water, approximately 20 cm deep.

To make the wave maker, a 30 cm x 30 cm x 0.5 cm wooden plate and a 30 cm x 15 cm x 0.7 cm wooden plate are attached using the two 2 cm long door hinges. One wooden square stick was placed to the middle of wooden plate. The other stick was attached with a hinge joint. The stroke of wave maker has been limited by two wooden sticks that have been placed on the top of wave tank frame.

An oscillating water column (OWC) device in Figure 3 was made of four (4) wooden plates and supporting wooden sticks. The dimensions of OWC model were 15 cm x 28 cm x 30 cm. The top roof of OWC has 3.2 cm diameter of orifice, where air will flow when the water inside of OWC moves up and down. A front entrance guide plate of 29 cm x 15 cm x 0.5 cm has been added at the bottom of OWC with 60 degrees of slope.

A wave energy extracting turbine (WEET) device in Figure 3 consisted of a supporting structure and a turbine. The supporting structure of WEET was made of four (4) wooden plates and supporting wooden sticks. The dimensions were 15 cm x 28 cm x 30 cm. The turbine had four (4) metal blades, which were attached to two circular wooden disks. The overall dimensions of turbine were 7.6 cm of diameter and 20 cm of length. To make electricity, a 1000 RPM DC motor
was mounted on the top of WEET and connected to the turbine, which was designed to rotate along with wave particle circular motions. Two guide plates have been attached to see if the performance of WEET could be improved.

![Experimental Set-up](image1)

**Figure 2: Experimental Set-up**

![3D Sketches](image2)

**Figure 3: 3D Sketches of OWC (left) and WEET (right)**

### 2.3 Test Cases and Energy Conversion

Six (6) waves have been generated with 0.65s, 0.76s, 0.88s, 1.02s, 1.22s and 2.01s of wave period. The stroke of wave maker has been fixed to 8cm. To calculate the input wave energy waves
have been generated without wave energy extracting devices and its amplitude has been measured four times. The averaged wave amplitude has been used as the input variable for wave energy calculation.

Three different OWC configurations have been tested. OWC1 and OWC2 had 5.2cm and 3.2cm of the submerged depth of entrance, which has been measured from the mean waterline. As shown in Figure 3, OWC3 had a front entrance guide plate.

Each OWC device has been placed in the middle of the wave tank. Air flow velocity from the orifice at the top of OWC has been measured four times with an anemometer, which has been used to calculate the equivalent wind energy. The wave amplitude with the OWC device also has been measured to compare with the wave amplitude without any device.

Three different WEET configurations also have been tested. WEET1 had only a turbine without any guide plates. WEET2 had one guide plate at the front while WEET3 had two guide plates at the both front and back sides as shown in Figure 3.

The voltage generated by the DC motor has been measured four times with a voltage multimeter, which has been used to calculate the equivalent electricity energy.

The following formula has been used to calculate the input energy power from measured wave amplitudes, the wind power from measured wind velocity of OWC and the electricity power from the measured voltage of WEET.

Wave Power $\sim T \times A^2 \times W$,

where, $T =$ wave period, $A =$ wave amplitude and $W =$ tank width.

Wind Power $\sim S \times U^2$,

where, $S =$ Orifice Area and $U =$ air flow velocity.

Electricity Power $\sim V^2/R$, 
DESIGNING WAVE ENERGY CONVERTING DEVICE

\[ V = \text{voltage} \quad \text{and} \quad R = \text{resistance}. \]

3.0 Results and Discussion

Three different OWC configurations tested are displayed in Figure 4. Table 1 summarizes the measured air flow velocities for each OWC configuration. The performance curves are plotted in Figure 5 and Figure 6. Based on the measured data and observations, the engineer found that the performance of OWC strongly depends on the wave period and the best performance occurs at the 1 second wave period, which corresponds to the resonance period of the water mass inside the OWC.

The wave energy converting efficiency depending on the submerged depth of OWC was compared. The efficiency of OWC2 with a shallow submerged depth was greater than the one of OWC1. The engineer also compared the performance of OWC with and without the front entrance guide. The performance curve of the OWC3 with front entrance guide has been changed but its effectiveness is inconclusive with the given test conditions.

**Figure 4: OWC Configurations**
Table 1: OWC Air Flow Velocity Measurement

<table>
<thead>
<tr>
<th>Wave Making</th>
<th>OWC Air Flow Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave Period</td>
<td>Wave Amplitude</td>
</tr>
<tr>
<td>(sec)</td>
<td>cm</td>
</tr>
<tr>
<td>2.01</td>
<td>0.3</td>
</tr>
<tr>
<td>1.22</td>
<td>0.5</td>
</tr>
<tr>
<td>1.02</td>
<td>0.5</td>
</tr>
<tr>
<td>0.88</td>
<td>1.5</td>
</tr>
<tr>
<td>0.76</td>
<td>1.3</td>
</tr>
<tr>
<td>0.65</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Figure 5: Comparison of Measured Air Flow Velocities

Figure 6: Relative Performance of OWC Configurations
Figure 7 shows three WEET tested. The measured voltages and performance curves are given in Table 2, Figure 8 and Figure 9. As shown in Figure 9, overall the WEET worked well with shorter waves. The wave energy converting efficiency of WEET depending on the location of guide plate was compared. Based on the data and observations, the performance/efficiency of WEET3 was much better compared to WEET1 and WEET2, in particular, at the long wave periods. The engineer thinks that the reflected wave from the back-guide plate contributed to the performance improvement of the turbine.

A direct comparison between OWC and WEET was not made due to the different measurement units. In general, WEET had more mechanical friction than OWC.

![Figure 7: WEET Configurations](image)

<table>
<thead>
<tr>
<th>Wave Making</th>
<th>WEET Generated Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave Period</td>
<td>Wave Amplitude</td>
</tr>
<tr>
<td>(sec)</td>
<td>(cm)</td>
</tr>
<tr>
<td>2.01</td>
<td>0.3</td>
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<td>0.76</td>
<td>1.3</td>
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<tr>
<td>0.65</td>
<td>1.1</td>
</tr>
</tbody>
</table>
The engineer has designed and tested two different types of wave energy converter – Oscillating Water Column (OWC) and Wave Energy Extracting Turbine (WEET). Based on test results with different wave periods and various appendages, the engineer found that the geometry of devices and wave periods play an important role in how much wave energy can be extracted, and came to the following conclusion:
• OWC shows a better performance at the longer wave periods, which are close to the natural period of inside water column.

• The shallow submerged depth of the OWC entrance is more effective for shorter waves.

• The effectiveness of the OWC bottom appendage is inconclusive at this experiment.

• WEET shows overall better performance at the shorter wave periods.

• The back-slope appendage of the WEET significantly improves the wave energy extracting performance at the longer wave periods.

The results from this project can benefit the world by providing people with clean and inexhaustible energy. It can also help guide WEC engineers to design future wave energy extracting devices. In the future, a bigger prototype of WEET can be tested with several more factors – such as different angled turbine flaps, reduced mechanical friction, flexible/bendable turbine flaps, etc. – to improve the wave energy extraction efficiency.
5.0 References


