Mooring Experimental Study of Motion Response for Pendulum Wave Energy Converters

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Abstract. Wave Energy Converters (WECs) is the type of Ocean energy need continual motion while operation for producing steady electricity. The mooring configuration as the answer for making sustainable WECs during operational life on the rough sea. The authors are researching trimaran pontoon of pendulum WECs type with anchors and four cables of mooring. The purpose of this research to determine the heave, pitch, and roll response from the pontoon. In this research, there are variations of wave height and wave periods. Experiment located at hydraulics laboratory in regular wave condition. The scale-up of the pontoon is (1:10) compared to real dimension. IMU (Inertial Measurement Unit) sensor used in this experiment to detect pontoon motion. Pontoon has the optimum condition at wave periods at 0.6s and height 0.4 m. Heave motion best displacement is 0.372m, Roll motion value is 1.425 degree and Pitch is 4.6164 degree. The pontoon needs fairlead for placed the mooring cables.

1. Introduction

People use energy as a primary necessity in everyday life. As the growth from economic life, the energy needs will be increased. Each year the demand for electrical energy escalates up significantly. According to BP (British Petroleum) data from 1995 to 2015, energy demand increased annually by 2.2% [1]. Indonesia's energy needs by 2020 are projected to exceed 250 TWh per year [2]. Every year, Indonesia has to build a new power plant to fulfil the electricity demand.

Power plants in Indonesia are still dominant sourced from fossil fuels (coal, gas, oil). According to statistical data in 2015 by the Directorate General of Electricity, more than 80% of power plants in Indonesia supply from fossil fuel [3]. In order to reduce the dependence of power plants on fossil fuels, The Ministry of Energy and Mineral Resources (ESDM) has a target 23% the total electricity supply will be produced from Renewable Energy by 2025 [4].

Ocean energy is the type of renewable energy which captured the energy from the ocean. Ocean energy classified into several types, tidal range energy, tidal stream energy, wave energy, and ocean thermal energy conversion (OTEC) [5]. INOCEAN (Indonesian Ocean Energy Association) in 2011 has ratified Indonesia's ocean energy potential. The wave energy has the practical potential of 1.2 GW, tidal energy of 4.8 GW [6]. Indonesia’s shoreline is number 4 longest in the world after Russia (95,181 km) [7]. It shows that Indonesia has huge potential for capturing wave energy.

Pendulum system is type Wave Energy Converters (WECs), its motion based on the movement of ocean waves, the waves will make rotational movement on the pendulum. The pendulum will be coupled with the generator and convert to electricity [8]. The factor of the dimensions and the total
mass of pontoon will affect the total power will be generated by generator [9]. One of the most important aspect to convert electricity successfully in WECs is Foundation and Mooring, its secured The WECs device to the bed of the ocean [10]. Researchers had done several previous studies of motion response on the pontoon. However, anchoring and mooring system still needs to be proved for making the good device in extreme wave condition. Catenary mooring system study was presented in [11], Paredes had been tested using three cables. The experiment results had good performance in the rough sea waves test at the laboratory. The motion of heave, pitch and surge also have maximum amplitude value.

The purpose of this paper is to investigate the motion response of trimaran pontoon in regular wave conditions. When we found the motion, it will predict the pendulum oscillation. The authors did a variation test in wave period and wave height, we added mooring cable in portside and starboard of the pontoon. For finding the motion, we used the IMU (Inertial Measurement Unit) Sensor to detect heave, pitch, and roll motion. Strouhal equation had been used to show the scale-up of the pontoon. The pontoon we used scaled in (1:10).

2. Theory and Method
2.1 Experimental Case Study
The experiment located in the Hydraulics Laboratory of Institut Teknologi Sepuluh Nopember. Regular wave condition was conducted, two variations of wave height (H) at 0.2 m and 0.4 m. The three variations of the period established with 0.4 s, 0.6 s, 0.8 s. As we look the Laboratory in Figure 1, The laboratory could also generate the irregular waves.

Figure 1. Hydraulics Laboratory of Institut Teknologi Sepuluh Nopember.

The trimaran pontoon scaled (1:10) to the real dimension, the length of the pontoon is 49.5 mm; the width is 32 cm. The total mass of pontoon is 2.248 kg, the centre of gravity located at 2.2617 cm below the centre of the large cylinder. The moment inertia of the trimaran pontoon is (0.0109 0.0319 0.0308) Nm. The shape of the trimaran pontoon similar to jukung (Indonesian fisherman boat) shown in Figure 2. The real scale dimension of trimaran pontoon will be used in shallow water near the coastline.

Figure 2. Trimaran Pontoon (a) and Jukung Fisherman Boat (b).
In Figure 3 below, the pontoon arrangement. There are four anchors; each anchor has 1 kg of mass. The anchors made from rock stone, the properties from anchor will be ignored. All cables mooring located 135° apart on portside and starboard. Wave direction (μ) come 0° from the pontoon, known as following waves [12]. Look for Figure 4, Inertial Measurement Unit (IMU) sensor we used is MPU-9250. It has three features gyroscope, accelerometer, and magnetometer. It can capture 20 data for each second [13]. The authors average the data to make conclude every second. The sensor located over the pontoon, we used only gyroscope and accelerometer for finding heave, pitch, and roll motion.

![Figure 3](image1)

**Figure 3.** Pontoon arrangement from the top view.

![Figure 4](image2)

**Figure 4.** IMU Sensor MPU-9250.

### 2.2 Scaled Up Equation

Strouhal equation used to finding real period and wave height in real sea condition. However, the equation derived from the Froude number as a comparison between Velocity (V) and Length (L) of the pontoon in real dimension and scaled. Froude Number Thus,

\[
\frac{V_m}{\sqrt{gL_m}} = \frac{V_p}{\sqrt{gL_p}}
\]  

(1)

L<sub>m</sub> is the length of a real model dimension, and L<sub>p</sub> is Length of prototype scaled. Through gravitational constant its similar, so the velocity ratio:

\[
\frac{V_m}{V_p} = \left(\frac{L_m}{L_p}\right)^{1/2} = \sqrt{n}
\]

(2)

Results from equation (2) provide the scale factor of velocity be equivalent to the square root of the length scale factor known as \(n\). As McCormick mention, *strouhal number* need \(fL/V\). Where \(f\) is wave
frequency from offshore floating structure [14]. From the equation (1) and (2) on the design model we need,

\[ \frac{f_m L_m}{V_m} = \frac{f_p L_p}{V_p} \]  

As, \( f = \frac{1}{T} \), where \( T \) is wave period

\[ \frac{L_m}{T_m V_m} = \frac{L_p}{T_p V_p} \]  

Equation (4) can be used to finding a correlation of time-scaling,

\[ \frac{T_m}{T_p} = \left( \frac{V_p}{V_m} \right) = n^{3/2} \]  

3. Results and Discussion

The experiment tests six times; Table 1 shows the description of the test. Its conducted the regular waves condition in Laboratory with two variations of wave height. The experiment does not move the pontoon because its only tested in one heading wave (\( \mu \)) only. The waves come from after the pontoon for making a motion to the pontoon. When experimenting, the mooring cable attached occasionally shifting. It needs a place like a fairlead on the vessel to make the cable attached tightly. IMU Sensor while retrieving data use wireless tool to connect a laptop. We used a Java program called telemetry viewer v0.4 as shown in Figure 5; IMU sensor will process in real time whenever change motion conducted. Figure 6 until 8 provides the experiment results.

| Test | Height (m) | Wave Period (s) |
|------|------------|-----------------|
| 1    | 0.2        | 0.4             |
| 2    | 0.2        | 0.6             |
| 3    | 0.2        | 0.8             |
| 4    | 0.4        | 0.4             |
| 5    | 0.4        | 0.6             |
| 6    | 0.4        | 0.8             |

Figure 5. Telemetry viewer.
Figure 6. Time history of Heave Motion Response: H=0.2 m (left), H=0.4m (right)

Figure 7. Time history of Roll Motion Response: H=0.2 m (left), H=0.4m (right)

Figure 8. Time history of Pitch Motion Response: H=0.2 m (left), H=0.4m (right)

For all motion have a maximum value at 0.6 seconds period, except in roll motion. The roll motion at 0.2 meters has the highest value at 0.4 seconds wave period. Heave motion displacement affected depends on wave height and wave period change value. As we look on Figure 6 when H is 0.4 m, the highest displacement conducted at 0.4 m. When H is 0.2 m, the maximum heave displacement took only 0.1 m. Wave period at 0.6 s is the most optimum value for heave displacement. Significant value occurred at 37 seconds, the heave displacement up to 0.372 meters when the wave height is 0.4 meters. Based on Figure 7 roll motion when at H = 0.4 m have significant resonances from -2 to near 1.5 degrees. Big different occurred when compared at H = 0.2 m, the resonances significantly different. At 45 seconds, roll degree rose up to 1.425 degrees. It conducted because the attachment on the pontoon for cable mooring does not string tightly, so make the centre gravity of x-axis move slightly and affect the pontoon motion. Pitch motion graph investigation shown in Figure 8, the graphs
show quite different value on pitch degree either wave height condition. The pontoon motion around 4 degrees on the y-axis. The biggest value of pitch degree is 4.6165 when at 43 seconds, the wave height is 0.4 m the period is 0.6 seconds.

Based on the calculation of scaled-up pontoon in section 2.2 the pontoon working in condition at 2–4 meters of ocean wave height. The equation compared between period test in the laboratory and comparison the length of the scaled pontoon to the real dimension. If the real rough sea condition occurred more than 4 meters, It could damage the trimaran pontoon.

4. Conclusion
The motion response results between heave, pitch and roll motion have maximum value while wave height is 0.4 m. Heave and roll motion of the pontoon has optimum when at wave period 0.6 s, where the pitch motion has the best period at 0.8 s. Highest value on heave displacement is 0.372 m, roll motion degree is 1.425 and Pitch motion is 4.6165 degrees. For further research, the pontoon needs to be tested in irregular wave's condition to validation in the real rough sea condition. The variation of wave heading also becomes an important factor for WECs while in operation. The fairlead on pontoon has to be designed well to avoid shifting the cable.

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