Analysis of pontoon multi pendulum motion response trimaran model at ocean wave power plant based on pendulum system (PLTG-SB)

I K A P Utama¹, R Hantoro², E Septyaningrum², Q Khasanah², J Prananda¹ and I S Arief³

¹Department of Naval Architecture, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
²Department of Engineering Physics, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
³Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

Abstract. Ocean waves are one of the renewable energy potentials for an archipelago country like Indonesia. The development of Wave Energy Converter presented in the research carried out is a system that uses a pontoon with a pendulum for energy extraction, which is called the Pendulum System Wave Power Plant (PLTG-SB). The shape of the pontoon uses a trimaran model with a cylindrical shape as the main body and support. The simulation of the response of the pontoon with multi pendulums shows the maximum RAO pitch value of 1.15 ° / cm in the 6 second wave period and the response to the change in deviation is the maximum value in the 6 second wave period with a deviation of 198.07°. The variation in the length of the pendulum arm gave the largest deviation value of 106.7 cm, while in the variation of the number of pendulums the largest deviation occurred on the pontoon with the number of pendulums n = 2.

1. Introduction
Indonesia is an archipelago that has a wider water area than the land area, which is about 3.5 million km² [1]. Because the area of Indonesian waters is wider than land, there is a potential source of marine energy that it is be converted into electrical energy. According to the theory of global marine energy resources equivalent to 17,400 TWh/year [2]. Compared to other renewable energy sources such as solar and wind energy, ocean wave energy provides up to 90% availability with an unlimited potential area [3]. Until now, several types of WECs have been developed in the world, including Wave Activated Bodies (WABs), Oscillating Water Columns (OWCs) and Overtopping Devices [4].

In several countries, WECs have been developed as an alternative energy substitute for fossil energy. In 2015 China through the Guangzhou Institute of Energy Conversion (GIEC) developed a Sharp Eagle WEC prototype with a size of 36m x 24m x 16m with a power capacity of 100kW on Wanshan Island [5]. Yoshio Masuda developed a buoy that was later called a floating oscillating water column and was developed in 1965 [6]. Denmark has also developed a WECs type overtopping device called Wavedragon [7]. Norway is also developing WECs of a similar type called the Tapered Channel Wave Power Device (Tapchan) [8].

In this research, a tool for converting ocean wave energy into electric energy in the pendulum system (PLTG-SB) has been developed. This research was first conducted by Zamrisyaf in 2002[9].
working principle of PLTG-SB is a system that has been designed in the form of a pontoon, placed to float above sea level. Then the system will follow the motion or wave flow according to the frequency of the ocean waves, causing the pendulum to move like a bell. This movement is then transmitted in a rotating motion to drive the dynamo which then becomes electrical energy. The power generated by the PLTG-SB is much influenced by the dimensions of the pontoon, the length of the pendulum, the mass of the pendulum, and the arrangement of the pontoon [9].

Research related to the multi-pendulum pontoon has been conducted [10]. This research was conducted using an octagonal pontoon with \( n = 3 \) pendulums placed horizontally to determine the amount of electrical energy and the resulting characteristics of the pendulum mass variation, pendulum arm length, wave frequency and amplitude. The results of this study indicate that the stress value will increase as the number of pendulums increases.

Based on the research that has been done, further research is needed regarding the multi-pendulum pontoon to the changes in the deviation of each pendulum due to ocean waves. This paper attempts to convey the results of a CFD simulation study related to the relationship between changes in pendulum length, pendulum number, and wave period to the response of the multi-pendulum pontoon motion to determine the characteristics of the pontoon.

2. Methodology

2.1. Pontoon and Pendulum Design

The design of the pontoon and the pendulum as in previous research, shown in Figure 1, varies the number of pendulums, the length of the pendulum arm, and the period of the wave hitting the pontoon. The ratio of the pontoon is 1:1 with the dimensions as in Table 1.

![Figure 1. Design 3D Pontoon 1:1.](image)

| Parameter            | Unit (cm) |
|----------------------|-----------|
| Diameter of Big Cylinder | 165      |
| Diameter of Small Cylinder | 40       |
| Length of Big Cylinder  | 320      |
| Length of Small Cylinder | 320      |
| Height of Jukung      | 83        |
| Length of Plate       | 320      |
| Width of Plate        | 170      |

Table 1. Geometry of Pontoon.
2.2. Simulation

Simulations were carried out to determine the interaction of the waves with the pontoon using AQWA Hydrodynamics Diffractions and Hydrodynamic Responses, and to determine the response of the pontoon to the pendulum using Rigid Dynamics. In this simulation stage, computational fluid dynamics (CFD) are carried out through the pre-processing, processing, and post-processing stages.

In the pre-processing stage, a setup is carried out by inputting data in the form of:

- water size, on the x and y-axes in the geometry section.
- Water draft.
- Center of gravity (COG) at the point mass.
- Input of inertia at the point mass.

Then meshing is performed by inputting the defeaturing tolerance and maximum element size. In the smaller pendulum, mesh sizing is added.

Table 2. Boundary condition of Pontoon Modelling.

| Parameter            | Unit     |
|----------------------|----------|
| Water size X         | 15000 cm |
| Water size Y         | 5000 cm  |
| Water draft          | 1/2 D    |
| Center of Gravity    | 57 cm    |
| Input of Inertia     |          |
| $I_{xx} = 4095482247.7 \text{ kg.cm}^2$ | |
| $I_{yy} = 9219950155.6 \text{ kg.cm}^2$ | |
| $I_{zz} = 7330776665.4 \text{ kg.cm}^2$ | |

Table 3. Detail of Mesh.

| Parameter               | Unit     |
|-------------------------|----------|
| Defeaturing Tolerance   | 4 cm     |
| Max Element Size        | 10 cm    |
| Total Nodes             | 29915    |
| Total Elements          | 29934    |

The processing stage is carried out by wave simulation by inputting the wave period and wave direction used. This stage is performed during the simulation on AQWA Hydrodynamics Diffractions. Meanwhile, the AQWA Hydrodynamics Response simulation includes data in the form of wave
amplitude and wave period with regular wave types. The final stage of simulation (post-processing) is a solution or result in the form of a pontoon response due to ocean waves, then the RAO (Response Amplitude Operator) graph.

In the simulation using Rigid Dynamics, the data entered is in the form of the actual response value from AQWA to determine the value of the pendulum deviation due to the motion of the pontoon. In the pre-processing stage, the data entered is in the form of a point mass for each component. Then given the connections in the form of joint cylindrical to define the relationship between the pontoon with the ground and the pontoon with the pendulum. Furthermore, at the processing stage, the input is given in the form of actual response data in the Joint - Rotation section. Then the post-processing stage, the results of the simulation shown by the change in the deviation value due to the motion of the pontoon on each pendulum on the joint probe are displayed.

3. Result and Discussion

3.1. The response of the pontoon motion to the wave period

The response of the pontoon motion to the wave variations hitting the pontoon is the RAO (Response Amplitude Operator) value and the actual response. The RAO pitch value has the same characteristic tendency towards variations of the pontoon with different arm lengths. The pitching value decreases as the wave period is enlarged. This provides a confirmation with the greater the value of the wave period so that the pitching angle is getting smaller, but the pitching speed will get bigger. Under these conditions, the frequency of the pontoon oscillation will increase and make it easier for the pendulum to oscillate [11].

![Graph showing RAO pitching at arm’s length of pendulum 106.7 cm.](image)

RAO pitching peaks occur at the same variation in the 6 second period in all variations of the number of pendulums. The maximum RAO pitching value with the number of pendulums n = 4 (four) also experienced the same condition in the 6 second period. The maximum pitching values at variations in the length of the pendulum arm (106.7; 110; 130 and 165 cm) were 1.06° / cm, 1.15° / cm, 1.05° / cm and 1.14° / cm, respectively.
Figure 3. RAO pitching at arm’s length of pendulum 110 cm.

Figure 4. RAO pitching at arm’s length 130 cm.
3.2. Effect of Wave Period, Pendulum Length, and n-Pendulum on Pendulum Oscillation

The response to the pontoon movement in the form of an actual response causes changes in the pendulum oscillation motion. Analysis of the pendulum motion is carried out by varying the wave period, the pendulum length, and the number of pendulums used on one pontoon.

3.2.1. Responses of Pendulum with Variation of Wave Period

Analysis of the pendulum motion due to variations in the wave period (6, 8, 10, and 12 seconds) was carried out at an amplitude of 20 cm and laden with water 1 / 2D. The effect of period changes on pendulum drift can be seen in Figures 6 - 9.

Figure 5. RAO pitching at arm's length 165 cm.

Figure 6. Deviation of pendulum with wave period of the pendulum length 106.7 cm.
Figure 7. Deviation of pendulum with wave period of the pendulum length 110 cm.

Figure 8. Deviation of pendulum with wave period of the pendulum length 130 cm.

Figure 9. Deviation of pendulum with wave period of the pendulum length 165 cm.
In the variation of the pontoon with (n = 2, 3, and 4) the pendulum and the length of the arm (106.7; 110; 130; 165 cm), it shown that the change in pendulum deviation will decrease with increasing wave period. This is made possible by the magnitude of the wave period which is inversely proportional to the deviation value as described in equations (1) and (2). The pitching value that gets smaller with increasing wave period also affects the magnitude of the deviation change in the pendulum. When viewed from Figures 6 to 9 it has the same deviation change characteristics where the largest deviation occurs on the pontoon with n = 2 pendulums during 6 seconds of the period.

\[
\theta = \frac{2\pi t}{T} \tag{1}
\]

\[
Y = A \sin \frac{2\pi t}{T} \tag{2}
\]

3.2.2. The Motion of Pendulum with Variation of n – Pendulum

Pendulum motion analysis is also seen from the variation in the number of pendulums used, namely 2, 3, and 4 pendulums in one pontoon. Based on the results of this simulation, it is hoped that the effect of changes in pendulum deviation on the number of pendulums shown in Figures 10 to 13.

**Figure 10.** Relation of n-pendulum with wave period of 6 second.

**Figure 11.** Relation of n-pendulum with wave period of 8 second.
Based on Figures 10 to 13, shown that the maximum deviation value occurs on the pontoon with the number of pendulums $n = 2$ during the 6 second period with a value of 198.07°. The alteration of pendulum deviation with the number of pendulums is caused by the mass of the pontoon. When the number of pendulums in 1 pontoon is increasing, mass of the pontoon increasing too.

3.2.3. Motion of Pendulum with Variation of Pendulum Length

The analysis of the motion of the pendulum deviation changes was also reviewed for the pendulum length variations, namely 106.7, 110, 130, and 165 cm. Based on the simulation results, the value of the change in pendulum deviation to the pendulum length variation is obtained as shown in the graphs in Figures 14 to 16.
Based on the Figures 14-16 of the pendulum length relationship to the deviation change, shown the same change characteristics. The longer the pendulum arm has the smaller deviation change. This is the following equations (2) and (3) where the value of the pendulum arm length is directly proportional to the wave period and inversely proportional to the deviation so that it can result in a smaller deviation as the arm length increases. From the Figures above, the maximum deviation value occurs at the arm's length of 106.7 cm.

\[ T = 2\pi \sqrt{\frac{L}{g}} \quad (3) \]
3.3. Pendulum Motion with Irregular Wave
Simulation in irregular waves aims to determine the response of the pontoon motion in real conditions. This simulation uses Jontswap Hs with a peak frequency of 0.17 Hz, gamma 2 [12], and a wave height of 40cm. The cross swell is set with a 45° wave direction parameter.

Figure 17. Deviation of pendulum in irregular wave.

Figure 17. shows the simulation results of irregular waves where there is no phase difference between the 1st pendulum to the 4th pendulum. The speed of motion is relatively the same, although the angle of deviation is different. However, the difference between them is minor. In the 1st pendulum, the
maximum deviation formed is 119°. This is the biggest deviation by the 2nd, 3rd, and 4th pendulums. The difference that occurs due to the pontoon is caused by pitching motion.

3.4. Torque and Power
The pontoon motion that causes the pendulum to move from equilibrium results in torque and power values. The torque is obtained from mass, length of the pendulum arm, and the angle of inclination of the pendulum from its equilibrium state. Meanwhile, the power value is obtained from the multiplication of torque and angular speed. The torque and power in each n-pendulum variation can be seen in Figures 18 to 20.

![Figure 18. Torque and power of ponton with pendulum n = 2.](image1)

![Figure 19. Torque and power of ponton with pendulum n = 3.](image2)

The maximum torque and power value on the pontoon with n = 2 pendulums in variation 1 has a torque value of 193 N/m and a power of 1167 Watt, this is different from variation 28 which has a large torque value of 303 N/m but gives a small power value of 387 Watt. The deviation that occurs in

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variation 1 is the maximum deviation in the pontoon variation with \( n = 2 \) pendulums of 198.07\(^\circ\), while in the variation of 28 the resulting deviation has a small value of 38.23\(^\circ\).

On the pontoon with \( n = 3 \), the pendulum also has the same phenomenon in the variation of 20, the maximum power generated is 1680.93 Watt with a torque value of 351 N / m. This value is quite small when compared to the maximum torque value at variation 32 which is 399 N / m, but the resulting power only 143.7 Watt. The deviation angles in variations 20 and 32 are 53.03\(^\circ\) and 37.83, respectively. This value is very small when compared to the deviation value in variation 1.

![Figure 20. Torque and power of ponton with pendulum n = 4.](image)

On a pontoon with \( n = 4 \) pendulums, the difference between the maximum torque and power values is not significant. Variation 12 has a maximum power value of 1750 Watt with a torque of 364 N / m, compared to variation 36 which has a maximum torque value of 406 N / m, with a power of 50 Watts. The large difference between the torque and the power produced is not only due to the size of the resulting pendulum angle of deviation but also the mass and length of the pendulum arm as described in equations (4) (5) and (6).

\[
\omega = \frac{v}{L} \tag{4}
\]
\[
\tau (torque) = m \times g \times L \cos^2 \theta \tag{5}
\]
\[
P = \omega \times \tau \tag{6}
\]

4. Conclusion

Based on the research objectives as well as the research that has been done on the ocean wave power plant pendulum system, it can be concluded as follows:

- Low wave periods can result in large pendulum deviations because the magnitude of the wave period is inverse of the deviation generated by the pendulum.
- The number of \( n \)-pendulums causes the pendulum deviation to get smaller because of the pendulum movements subtracting each other, so the deviation becomes smaller.
- The response of the pontoon motion at the Ocean Wave Power Plant Pendulum System (PLTG-SB) is influenced by changes in the wave period. When the wave period increases at an amplitude of 20 cm and 1 / 2D water-laden, the RAO pitching value tends to increase in 6 seconds.
- The change in pendulum deviation that occurs due to changes in the wave period shows the maximum deviation in 6 seconds with a value of 198.07\(^\circ\).
In the variation of the arm's length of the pendulum, the largest deviation occurs at the arm's length of 106.7 cm. While in the variation of the n-pendulum the largest deviation occurred on the pontoon with the number of pendulums n = 2.

The power generated due to the variation of the wave period, the arm's length of the pendulum, and the number of pendulums has a maximum value of 1167 Watt on the pontoon with the number of pendulums n = 2, 1680.93 Watt on the pontoon with the number of pendulums n = 3 and 1750.37 Watt on the pontoon with the number of pendulums n = 4.

This research still needs improvement, so for further research, the wave simulation is required to use a mooring system so that the pontoon does not move when it is hit by a wave. It is also necessary to simulate variations in the height and length of jukung to the response of the multi-pendulum pontoon motion and how it changes the deviation. Simulation of a multi-pendulum pontoon in real life by simulating using irregular wave types in more detail is needed too.

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6. Reference
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