Response Analysis of Pendulum and Pontoon on Ocean Wave Energy Conversion System (OWCS) – Double Pendulum System

Ridho Hantoro[1, a)] Erna Septyaningrum[1,b)] Bariz Irfan Ridho[1,c)] Ahmad Wildan Mahmashani[1,d)]

[1]Department of Engineering Physics, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[a)] hantoro@ep.its.ac.id
[b)]Corresponding author: septyaningrum@its.ac.id
[c)]bariz.irfan.iz@gmail.com
[d)]mahmashani@gmail.com

Abstract. The growing energy need and the limitation of fossil fuel encourage many researchers to develop renewable energy technology. The good availability and the environmentally friendly of renewable energy, make it to be the best choice for energy production. One of the renewable energy sources comes from the sea, ocean wave energy has the potential to be extracted sustainably. Devices that convert ocean energy into electrical energy are called Ocean Wave Energy Conversion System (OWCS). This work proposed the new technology of OWCS, known as OWCS-Double Pendulum. The analysis of catamaran pontoon dan pendulums was carried out by utilizing the Computational Fluid Dynamics method. The numerical analysis shows that the smaller the wave period value, the greater the pontoon pitching value. The wave (amplitude and period) and pendulum (length and mass) parameters were variated to know the pendulum response toward the design parameter. Meanwhile, the greater the wave amplitude value, the greater the pontoon pitching value. The largest pontoon pitching value was obtained when using the 2.32 s wave period with a pitching value of 5.51°. When using a 2.32 s period and an amplitude of 0.6, the pitching pontoon value was 23.81°. When using the ocean wave period 2.32 s and the ocean wave amplitude 0.1 m, the largest pendulum deviation value is obtained when using a pendulum arm length variation of 1.25 m with a value of 109.57°. When using the variation of wave period 12 s and wave height 0.1 m, the pendulum deviation value is higher when using a load mass of 100 kg with a value of 61.7°.

INTRODUCTION

The energy demand continues growing along with the increasing human population growth in Indonesia. According to the General Planning for National Energy, Indonesia produced 382.9 MTOE and consumed 110.5 MTOE in 2017 [1]. Meanwhile, in 2018, the energy production was 411.6 MTOE and the consumption was 114 MTOE [2]. The energy consumption in Indonesia increases by 3.5 MTOE every year. Nowadays, Indonesia facing the decrement of energy production especially in the petroleum sector, on the contrary, the demand for petroleum is increasing every year. As most of the electricity is produced by coal-fired power plants, Indonesia has a bid dependence on fossil fuel supply. Energy diversification is very urgently needed to reduce the dependency on fossil fuel.

Renewable energy technologies have been proposed as the solution of the issue since this is an environmentally friendly technology and the resource is abundantly available. Renewable energy technology is often site-specific technology, in which the implementation of the technology is based on the potential of the region. The three most developed marine energies are tidal energy, wave energy, and ocean thermal energy. The ocean wave energy conversion system (OWCS) is the most attractive to be exploited sustainably [3].

The development of OWCS was a worldwide project. America, Europe, China, and India are at the forefront of developing strategies to increase the share of an ocean wave in their energy mix [4,5]. Researchers had proposed many concept and design of wave energy conversion. There are three main categories of OWCS, i.e. (1) Oscillating Water

Columns (OWCs), (2) Oscillating Bodies, and (3) overtopping system. OWCS is characterized by the interaction of the device and the ocean wave. The challenges for OWCS ranging from the availability of suitable wave and the survivability of the material in the severe environmental condition, [6,7]. The commercial of technology is still rare. Most of its development activities are still in the prototyping and model test stages. Some of the existing OWCS technologies include DEXA WEC (26 kW/m) [8]; Danish Wave Energy Program System [9], Weptos (sea trail phase) [10]; Pelamis [11] and soon. Due to OWCS technology is a site-specific technology, the design for OWCS in Indonesia must be adapted to the characteristic of the ocean waves in Indonesia

The current research is conducted on a design and simulation study of ocean wave energy conversion system using a double pendulum, which is adapted to the characteristic of an ocean wave in Indonesia. It is included in the oscillating body category. This technology consists of a catamaran ponton and pendulum system, as shown in Figure 1. The wave energy will be received by the ponton, further, it converted into mechanical energy by the pendulum system, following the simple oscillation concept. The mechanical component takes an important role in matching the pendulum output (RPM and torque) and the generator specification.

The response of the ponton is continually following the wave characteristic such us wave amplitude and wave period [4]. Hence, it should be considered for the design and capacity determination of OWCS. Moreover, the design of the pendulum and catamaran is the main consideration to optimize the energy conversion process. Research carried out by [12] stated that the design parameter for the OWCS consist of (a) pontoon dimension and geometry, (b) pendulum mass and length, and (c) pontoon arrangement [12]. The catamaran designs in such a way that it has a maximum pitching angle resulting in optimum energy production.

The current work carried out the simulation study to analyses the response of the ponton and pendulum system toward the different wave characteristic and pendulum dimensions. The well-known method, Computational Fluid Dynamic is utilized as it is an effective and low-cost method to conduct the preliminary study before the design is fabricated and tested. The novel design of OWCS is proposed in this study. This technology is the alternative to provide electricity supply for the rural area in Indonesia, particularly which has potential wave energy resource. This is an easy operated and maintained technology. Moreover, it supports the diversification programs in Indonesia.

RESEARCH METODOLOGY

Wave Energy Conversion Design

The design of OWCS-Double Pendulum generally consists of several systems, i.e. catamaran ponton, pendulum system, mechanical system, and electrical system. The OWCS-Double Pendulum capture wave energy, which is converted to the pitching motion of the pontoon, then transferring this energy to move the pendulums above it. The one-way bearing system is employed to connect the generator and pendulum system. This electrical energy obtained can be used directly or stored in the battery.

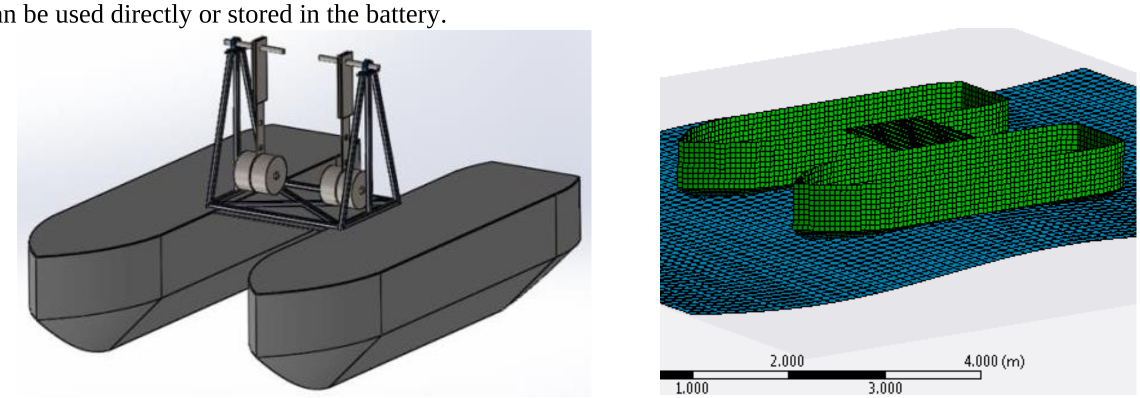


FIGURE 1. Design of OWCS – Double Pendulum (a) drawing; (b) mesh generation of the simulation

The catamaran ponton in the OWCS-Double Pendulum is designed to keep in the maximum pitching motion however it should be in the stable condition and not be sink. As the pendulum, mechanical or transmission system, and the electrical system is placed on the pontoon, the design of the pontoon must guarantee that it can support all loads, both the pontoon itself and the entire system above it. The catamaran design is chosen as it can capture more energy, indicated by a high Response Amplitude Operator (RAO). The adjustment of ponton hull can increase the RAO, which directly escalate energy production.

By considering the effect of each system to the ponton and pendulum response, the CFD simulation model is simplified, as depicted in Figure 1 (a). But the mass of all systems is taken into account. The pendulum arm length is varied by 1 m, 1.25 m, and 1.5 m. Meanwhile, the mass of the pendulum is varied by 100 and 152 kg. The choice of this variation considers the minimum torque that must be achieved for 1 KW generator 600 RPM.

Simulation Setup

The simulation is conducted through two steps, the first step is carried out to see the interaction of the incoming waves and the pontoon. The first step result is used as input data for the simulation, aiming to see the pendulum motion because of the pontoon movement. The input parameter for the first step simulation is a load of water, point of gravity, and point of the lift. This data can be obtained through the design software used. The assumption used in this simulation that the incoming waves are parallel to the x-axis, after which it is also included for variations of the wave height and period. In the simulation results, the deviation value of the pontoon due to waves will be obtained. The deviation from the pontoon taken is the movement of the pontoon that rotates about the y-axis or commonly known as pitching. And later this movement causes the pendulum to rotate. Later the data is used as the input of the pendulum motion simulation. The variation of the wave characteristic is adapted from the Indonesian wave data.

Before performing the simulation, it is necessary to determine the water load on the pontoon, this determination must be adjusted to the load supported by the pontoon. The calculation shows that pontoon with 0.45 m of water depth can support 1342.75 kg. Hence, it can support the heaviest load of the variation to be simulated, which is 1086 kg. The greater the maximum element size, the less accurate the result will be. Hence, the computational cost and requirement need to be considered in the discretization process. In this study, a maximum meshing element size of 0.1 m was used and a defeaturing tolerance size of 0.05 meters. [13] stated that the maximum element size is 0.5 m. Furthermore, it is also necessary to input the center of gravity and the floating-point of the pontoon. The total element generated in this simulation is 5687. The grid independent was carried out for four case, shown in Table 1, leading to the use of case 3 for this work.

TABLE 1. Mesh Independence Study

Case Number	Number of Element	Max Element Size (m)	The Highest Pitching (°)	The Highest Pendulum's Deviation (°)
Case 1	3162	0.14	5.461	106.5
Case 2	4503	0.12	5.507	106.86
Case 3	6587	0.1	5.51	106.87
Case 4	7876	0.09	5.513	106.93

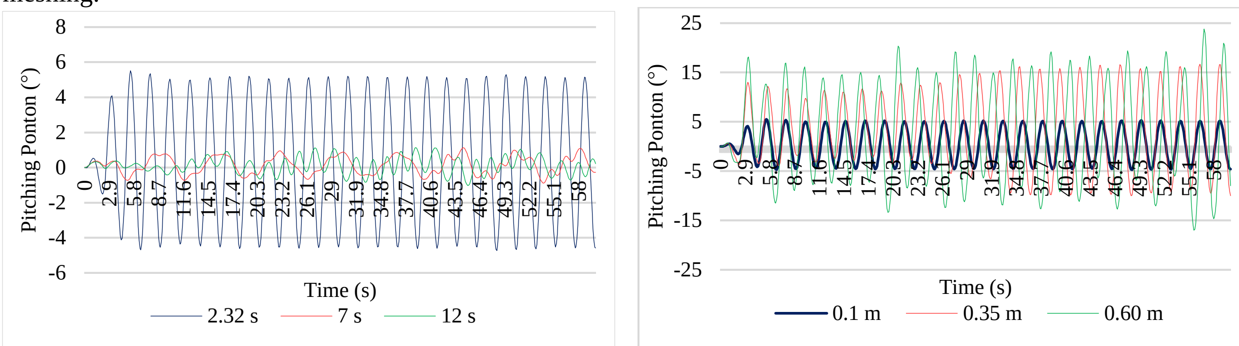
PAREMETER ANALYSIS

Response of Pontoon toward Wave Characteristic

The pontoon response analysis was carried out based on the variation of wave height, i.e. 0.1 m, 0.35 m, and 0.60 m, and the variation of the wave periods, i.e. 2.32 s, 7 s, and 12 s. Moreover, variations in the length of the arm and the mass of the pendulum load were also carried out, therefore the overall mass would increase and result in a shift in the center of gravity (will be explained in the next chapter). Figure 2 shows the comparison of the pontoon pitching with a pendulum mass of 100 kg and a pendulum arm length of 1 m. For the wave height of 0.1 m, the maximum pitching angle is obtained at waves period of 2.32 s, as depicted in Figure 2 (a). The shorter wave period indicates higher energy potential, which leads to maximizing energy production.

For the same pendulum dimension, the wave period is kept in the same value of 2.32 s however the wave height is variated to be 0.1 m, 0.35 m, and 0.60 m. Figure 2 (b) shows the change of pontoon pitching toward wave height variations. The wave height is proportional to the energy potential of the wave, leading to the maximum pontoon pitching. In this case, the highest pitching pontoon is obtained at an amplitude of 0.60 m.

The response of the pontoon due to the waves is obtained from the CFD simulation. It is shown that the higher the wave height causes the pontoon to experience the greater the pitching value. On the contrary, the pontoon experiences the highest pitching angle at a short period wave. However, at the wave amplitude of 0.6 m and a period of 2.32 s, the movement of the pontoon cannot experience maximum pitching because the pontoon has not returned to a stable state and has been subjected to the next wave. But the pontoon experience highest pitching angle at a period of 7 s. According to the theory, if a wave with a small period or a large frequency will result in a greater movement of the floating object when compared to waves that have a large frequency [14]. Here is the result difference caused by meshing.



(a) (b)

FIGURE 2. Pontoon Pitching toward Wave Parameters (a) Wave Period; (b) Wave amplitude

Response of Pendulums toward Pendulum Dimension

The pendulum simulation shows the effect of pendulum length and mass toward pendulum response. The result of the simulation is represented in Figure 3. In this simulation, the wave characteristic is kept in the same amplitude and period, i.e. 0.1 m and 2.32 s respectively. Figure 3 (a) exhibits the effect of pendulum arm length at a constant pendulum mass of 100 kg. In this case, the highest pendulum deviation is obtained by 1.25 m pendulum length.

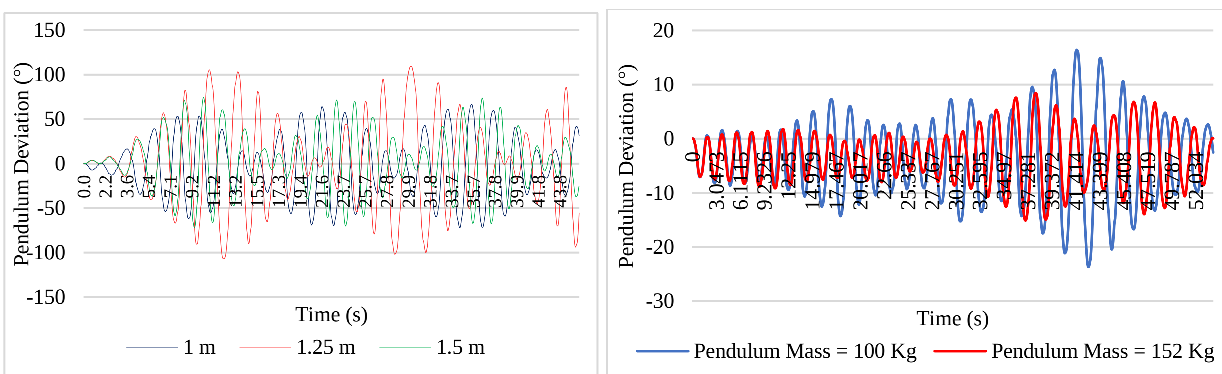


FIGURE 4. Comparison of Pendulum Deviation for variation of (a) Arm Length; (b) Pendulum Mass

Figure 3 (b) depicts the comparison of pendulum deviation for different pendulum mass. In this case, the arm length, wave period and wave amplitude are kept constant at 1 m, 12 s, and 0,1 m respectively. It can be seen that in this condition, the higher pendulum deviation is gained by a pendulum with 100 kg of mass.

Extend the length of the pendulum arm increases the height of the frame which supports the pendulum system, leading to shifting the point of gravity on the system. However, the variation used has the longest arm length of 1.5 m so that this variation has the highest point of gravity compared to other variations. From the simulation results, it is found that the location of the metacentric point is at an altitude of 1,961 meters while the location of the center of gravity is at an altitude of 0.4787 meters hence the location of the metacentric point is above the center of gravity. According to the pontoon theory, this condition is classified as positive stability. For variations in the change in the load mass of the two variations used, i.e. 100 and 152 kg, it was obtained that the higher pendulum deviation is for 100 kg pendulum. The best combination of arms-length and pendulum mass to get optimum energy conversion is 1.25 m pendulum length and 100 kg pendulum mass. Here is the result difference caused by meshing.

CONCLUSION

The smaller the wave period value, the greater the pontoon pitching value. Meanwhile, the greater the wave amplitude value, the greater the pontoon pitching value. The largest pontoon pitching value was obtained for the 2.32 s wave period with a pitching value of 5.51°. For a period of 2.32 s and an amplitude of 0.6, the pitching pontoon value was 23.81°. At the ocean wave period of 2.32 s and the ocean wave amplitude of 0.1 m, the largest pendulum deviation value is obtained by 1.25 m pendulum with a value of 109.57°. For the wave period of 12 s and a wave height of 0.1 m, the pendulum deviation is higher when using 100 kg pendulum, with a maximum deviation of 61.7°.

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This certification is awarded to

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