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Analysis of the effect of a spring constant of 980 N/m on a wave energy converter device due to heaving

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Abstract: Indonesia is a country with a larger sea area compared to its land area. Therefore, utilizing ocean current or wave energy as a renewable energy source, specifically for generating electricity through Wave Energy Converters (WEC), is a suitable solution. Wave Energy Converters (WEC) work on the basic principle of converting wave energy into linear motion or rotation to drive a generator and then convert it into electricity. The rotation is generated by the up-and-down movement of the pontoon affected by the pontoon's spring constant, which originates from sea waves. Hence, this study aims to analyze the effect of the spring constant on the pontoon due to heaving motion in response to sea waves. The study uses a spring constant of 980 N/m and is conducted with and without a planetary gear system. The highest voltage and current were achieved at a wave height of 0.35 m, producing a voltage of 84.5 V with a current of 8.26 A and a power of 698 Watts for the generator with the planetary system. For the generator without the planetary system, it produced a voltage of 1.73 V with a current of 0.046 A and a power of 0.0795 Watts with a gearbox shaft rotation of 37.32 RPM. The lowest voltage and current were observed at a wave height of 0.15 m, producing a voltage of 39.6 V with a current of 3.58 A and a power of 141.8 Watts for the generator with the planetary system. For the generator without the planetary system, it produced a voltage of 0.53 V with a current of 0.021 A and a power of 0.0111 Watts with a gearbox shaft rotation of 21.62 RPM.

Keywords: Wave energy converter (WEC); heaving; planetary.

1. INTRODUCTION

The countries in the world, Indonesia has the most islands—16,506 named, coordinated, and registered islands [1]. Indonesia is an archipelagic nation with a greater sea area than land area [2]. Thus, using wave energy or ocean currents as a renewable energy source is appropriate, especially when using Wave Energy Converters (WEC) to generate power [3][4].

Wave Energy Converters (WECs) can be used to convert renewable energy sources, such as ocean currents or wave energy, into electrical power [5][6]. An apparatus called a Wave Energy Converter (WEC) is used to transform the kinetic energy of sea waves into electrical energy [7]. A Wave Energy Converter's (WEC) fundamental function is to convert wave energy into rotational or linear motion, which powers a generator, and then back into electricity [8]. Using the up-and-down motion produced by waves on a pontoon, such as heaving action, one can accumulate this energy [9].

The undamped forced vibration method is the basis of the Wave Energy Converter (WEC) machine's operation [10]. When waves arrive, the initially motionless pontoon will heave as it floats on the water's surface [11]. The pontoon will automatically conduct heaving action dynamically with the oncoming waves because the waves are the dynamic energy input [12]. The WEC machine receives the energy from the pontoon and uses it to compress the spring. This process powers take-off (PTO), which produces electrical output from the generator [13][14].

The purpose of this study is to ascertain how the heaving motion in the sea waves at Tanjung Pasir Beach, Tangerang, affects the performance of the Wave Energy Converter (WEC) when the spring constant value is set at 980 N/m.

2. METHOD

The procedure is shown in the research flow below, which begins with a review of the literature and continues with the field testing of the Wave Energy Converter (WEC) machine, data collecting and processing, and presentation of the findings and conclusions of the WEC machine testing. Figure 1 shows the specifics.

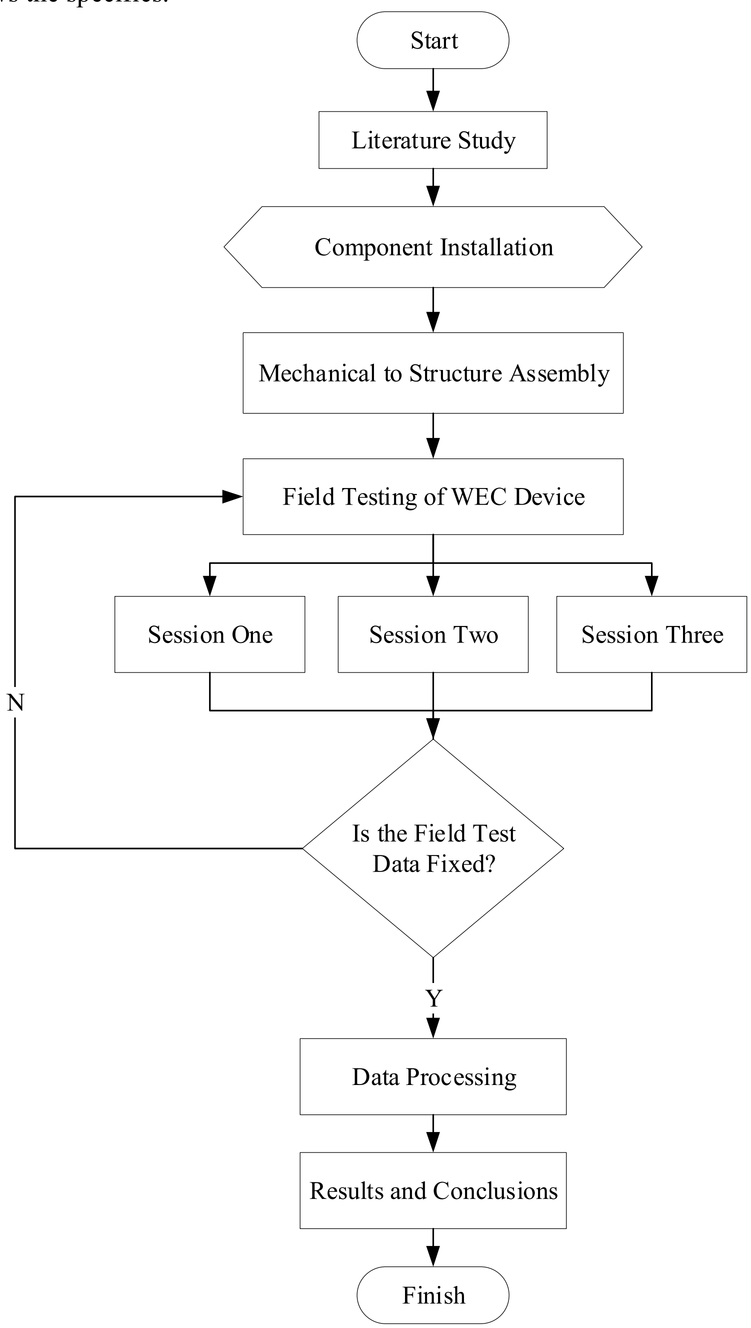

Figure 1. Research flow.

References are examined and noted during the literature study process, whether they come from books, journals, the internet, or earlier studies from domestic and foreign sources. Understanding the theories or computations about the research being done is the goal of this step. Following the conclusion of the literature review, as seen in Figure 2, material preparation and component installation are completed. The Wave Energy Converter (WEC) machine is tested after assembly is finished.

a) Preparation b) Assembly

Figure 2. Wave energy converter assembly.

Measuring the spring constant is the first step before testing the Wave Energy Converter machine, as Figure 3 illustrates.

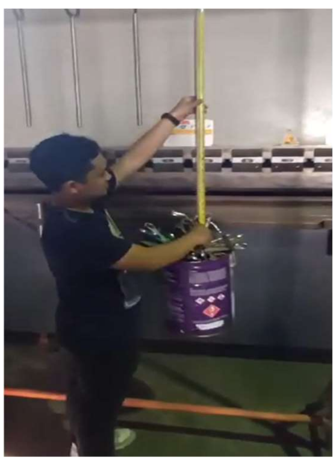

Figure 3. Spring constant measurement.

The following equation (1) can be used to compute the spring constant after measuring with a 40 kg load and receiving the measurement corresponding to the applied load [10]:

$$W = m \, x \, g \quad (1)$$

$$K = \frac{W}{\Delta x}$$

Where:

W : Weight (Newton)
m : Mass (kg)
g : Gravitational Acceleration [m/s^2]

Equation (1) is used to obtain the spring constant, and then the Wave Energy Converter machine is tested again. By performing direct field tests, this machine testing employs an experimental research methodology. The goal of this study is to confirm the procedures followed by the instruments and

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materials, as well as the location and timing of the data collection on the Wave Energy Converter (WEC) machine, as seen in Figure 4.

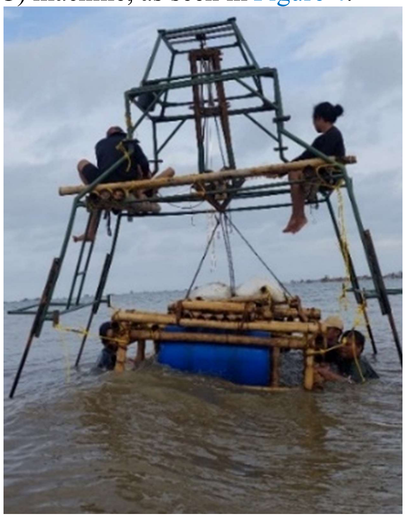

Figure 4. Wave energy converter machine.

The framework of the Wave Energy Converter machine measures 1.5 meters in width, 1.5 meters in length, and 4.5 meters in height. A gearbox, which is used to modify the power or torque from the spinning motor, and a generator, which transforms the mechanical energy produced by the gearbox into electrical current, are two of the energy-generating accessories of this WEC machine. Furthermore, the pontoon is an essential component of the WEC device because it is the main driver of the gearbox.

At Tanjung Pasir Beach in Tangerang, the Wave Energy Converter apparatus was tested using heaving action with a 40 kg mass and a spring constant of 980 N/m. This test was conducted throughout six studies, each consisting of three one-hour data collection sessions. Measurements of voltage, current, and RPM were made during the testing.

Heaving motion, or the vertical up-and-down movement of floating structures on wavy water, was used in the testing of the Wave Energy Converter machine. When a floating structure deviates from its equilibrium position, the lifting motion of the structure creates vibrations that result in opposing forces. The equation for heaving motion makes use of Newton's Second Law, which is:

$$mx + kx = F(t) \tag{2}$$

Where:

$m\dot{x}$: Mass load [kg]
kx : Spring constant [N/m]
F(t) : Wave exciting force [N/m]

The frame, gearbox, spring, pontoon, and generator, available in both planetary and non-planetary forms, make up the Wave Energy Converter apparatus [15]. The construction, which has dimensions of 2.5 m x 2.5 m and a height of 4.5 m, is constructed from 4x4 galvanized hollow pieces and 1.5- and 2-inch galvanized pipes. Four 12-size gears and four 35-size gears are used in the gearbox, which has a 1.5-meter height. The spring is 50 cm long, 4 cm in diameter, and 3 mm thick. It is composed of stainless steel. The pontoon is made of an H-beam-style structure made up of three 200 ml water drums arranged to form the letter H. The planetary generator utilizes a P50B04010DXS4E model with a gear ratio of 1:50 and a voltage capacity of 200 V AC, while the generator uses an RS555 model with a voltage capacity of 12 V DC.

This research involves the development of a pontoon; an I-beam-type pontoon was utilized in earlier studies, but an H-beam-type pontoon is employed in this study. As the principal driver of the gearbox, this pontoon is an essential component of the WEC device. Its job is to capture wave motion and send it to the gearbox.

a) I-Beam Type Pontoon

b) H-Beam Type Pontoon

Figure 5. Pontoon.

We can calculate the output power of the Wave Energy Converter machine by converting the voltage and current measurements into power [Watt] after they have been made. Equation (3) can be used to compute the output power.

$$PPTO = V \times 1[Amp] \tag{3}$$

Where:

$PPTO$	= PTO power of the WEC machine [Watt]
V	= Voltage [Volt]
I	= Current [Amp]

3. RESULTS AND DISCUSSION

The first step before field testing is to use equation (1) to calculate the spring constant with a mass load of 40 kg:

$W = m \times g$
$W = 40\ kg \times 9.8\ m/s^2$
$= 392\ N$
$\Delta x = x\ akhir - x\ awal$
$= 0.9\ m - 0.5\ m$
$= 0.4\ m$
$K = W/\Delta x$
$= (392\ N)/(0.4\ m)$
$= 980\ N/m$

Newton's Second Law is applied in the heaving motion equation: $\Sigma F = m.a$. With consideration for the gravitational force resulting from the object's weight on the surface of the Earth, this equation can be used to determine the total force acting on an object with a mass of 40 kg. Consequently, the total force acquired is:

$\Sigma F = m.a$
$= 40\ kg.(9.8\ m/s^2)$
$= 392.27\ N$
Thus:
$mx + kx = F(t)$
$40\ kg + 980 N/m = 392.27\ N$

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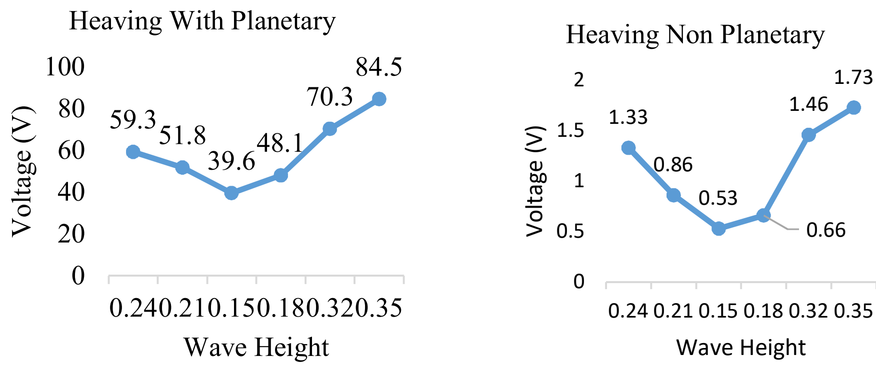
The Wave Energy Converter device was tested in Tanjung Pasir Beach in Tangerang, with a water depth of 1.5 m and wave heights ranging from 0.10 m to 0.35 m, after the spring constant was determined.

Matlab software was then used to evaluate the acquired data. The following graphs show the relationships between the different testing parameters.

Relationship between wave height and voltage

Following the acquisition of the voltage data from the wave energy converter device experiment, Matlab software was utilized for data analysis and computation. It was shown that the voltage values obtained are highly influenced by the wave height. The voltage values grow in tandem with the wave height. The graph depicting the relationship between wave height and voltage is shown in Figure *6*.



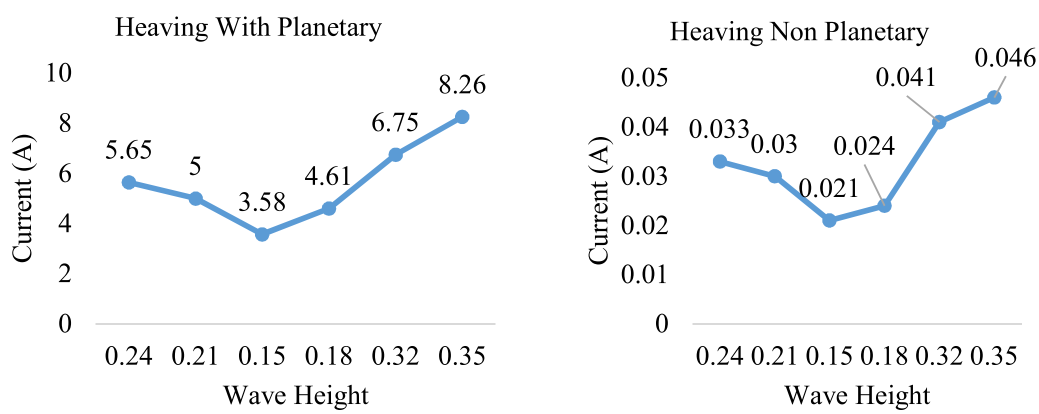
(a) Using Planetary (b) Non-Planetary

Figure 6. Relationship between wave height and voltage.

Figure 6, the voltage measured increases in tandem with the wave height. At a wave height of 0.35 meters, the maximum voltage is reached, with the planetary generator operating at 84.5 V and the non-planetary generator operating at 1.73 V. At a wave height of 0.15 m, the lowest voltage is recorded, yielding a value of 39.6 V for the planetary generator and 0.53 V for the non-planetary generator.

Relationship between wave height and current

Following the acquisition of the wave energy converter device experiment's current data, Matlab software was used to evaluate and compute the data. It was shown that the acquired current values are highly influenced by the wave height. The current values grow in tandem with the wave height. The graph depicting the link between wave height and current is shown in Figure 7.



(a). *Using Planetary* (b). *Non-Planetary*

Figure 7. Relationship between wave height and current.

Figure 7, the obtained current increases in proportion to the wave height. The maximum current of 8.26 A for the planetary generator and 0.046 A for the non-planetary generator is reached at a wave height of 0.35 meters. At a wave height of 0.15 m, the lowest current is detected, yielding a current of 3.58 A for the planetary generator and 0.021 A for the non-planetary generator.

Relationship between wave height and power

Matlab software was used to examine and compute the voltage and current data once they were collected. It was shown that the power levels obtained are highly dependent on the wave height. The power levels increase in tandem with the wave height. The graph depicting the link between wave height and power is shown in Figure 8.

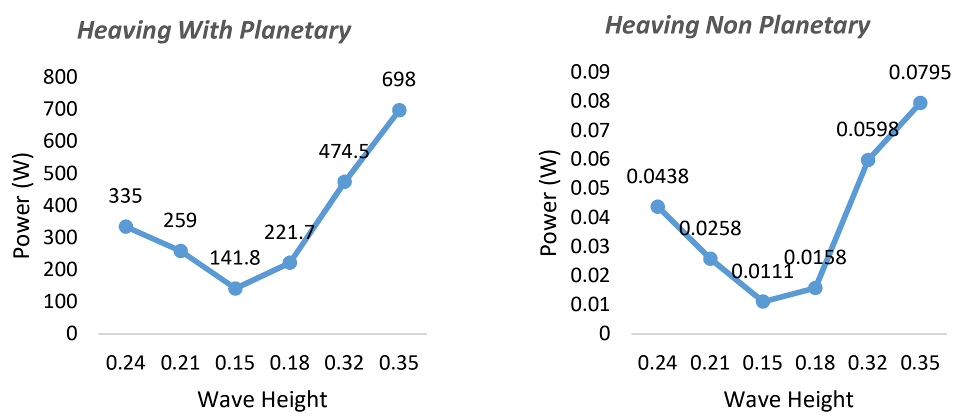


Figure (a). *Using Planetary* Figure (b). *Non-Planetary*

Figure 8. Relationship between wave height and power.

Figure 8, the power obtained increases with increasing wave height. At a wave height of 0.35 meters, the generator's maximum power is attained, with 698 watts coming from its planetary engine and 0.0795 watts from its non-planetary engine. At a wave height of 0.15 m, the lowest power is recorded, yielding 141.8 watts for the planetary generator and 0.0111 watts for the non-planetary generator.

The results of the WEC machine experiment with a spring constant of 980 N/m demonstrated in Figure 6, Figure 7, and Figure 8 that wave height has a substantial impact on this WEC device's power production. The output obtained during testing increases with wave size. The maximum voltage and current, which are 84.5 V and 8.26 A, respectively, at a wave height of 0.35 m are shown in Figure 6, Figure 7, and Figure 8. This results in a power output of 698 watts for the planetary generator. The non-planetary generator has a power of 0.0795 watts and a voltage of 1.73 V with a current of 0.046 A

4. CONCLUSION

It can be inferred from the findings of the studies on the heaving motion performance of the Wave Energy Converter machine using an H-Beam type pontoon and a spring constant of 980 N/m that the voltage and current acquired increase with wave height. At a wave height of 0.35 meters, the maximum voltage and current were recorded, yielding 84.5 V of voltage, 8.26 A of current, and 698 Watts of power for the generator that used planetary gears. The non-planetary generator had a gearbox shaft rotation of 37.32 RPM, a voltage of 1.73 V, a current of 0.046 A, and a power of 0.0795 Watts. At a wave height of 0.10 meters, the lowest voltage and current were recorded, resulting in a voltage of 39.6 V, a current of 3.58 A, and 141.8 Watts of power for the generator that used planetary gears. The non-planetary generator had a gearbox shaft rotation of 21.62 revolutions per minute, a voltage of 0.53 V, a current of 0.021 A, and a power of 0.0111 Watts.

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