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LINEAR GENERATOR PROTOTYPE VERTICAL CONFIGURATION OF SEA WAVE POWER PLANT

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ABSTRACT

There are three types of potential energy sources in the sea: ocean wave energy, tidal energy, and ocean heat energy. Ocean wave energy is a source of considerable energy. Sea waves are an up and down movement of seawater where the energy of sea waves is generated through the effect of air pressure movement due to fluctuations in ocean wave movements. The Ocean Wave Power Plant can use ocean wave energy to convert it into electrical energy. A linear generator is a device that can convert the mechanical energy of linear motion into electrical energy. The application of the ocean wave energy conversion technology, a linear generator system is an electrical machine that functions to convert the mechanical energy of linear motion into electrical energy using the principle of electromagnetic induction. Wave Energy Converter (WEC) technology has been developed with various methods. From the various existing concepts and designs, in general, WEC technology can be classified into three main types, namely Attenuator (horizontal configuration), Point Absorber (linear configuration), Terminator (damping configuration).

Keywords: wave energy converter, attenuator, point absorber, terminator

INTRODUCTION

Electrical energy is energy that is very important for human life, both for industrial activities, commercial activities, and everyday household life. Electrical energy is needed to meet the needs of lighting and the operation of equipment and machines that require electrical energy. Considering how big and important electrical energy is, while power generation energy, especially from non-renewable resources, is very limited, so to maintain the sustainability of this energy source, strategic steps are needed that can support the provision of electrical energy in an optimal and affordable manner.

The occurrence of temporary disconnection and distribution of electrical energy in rotation shows that the availability of electrical energy sources is not able to meet the increasing demand for electricity in Indonesia. This occurs because the rate of increase in new energy sources and the procurement of power plants is not proportional to the increase in electricity consumption. Efforts to add power plants have been carried out by the government, but require large funds and the process is quite long.

One of the renewable resources that can be used is the ocean. Earth is an area dominated by the sea, where the sea has a lot of potential for food and potential as a source of energy. The diversity of marine animals such as fish species and even marine plants is a potential food in the sea. There are 3 kinds of potential energy sources in the sea, namely ocean wave energy, tidal energy, and ocean thermal energy. Ocean wave energy is one of the major sources of energy. Ocean waves are an up and down movement of seawater in which ocean wave energy is generated through the effect of air pressure movements due to fluctuations in wave movement.

Ocean wave power plants have advantages over other energy sources, including enormous and continuous energy potential, low operating costs, and environmental friendliness. In addition, this plant can be used for small islands in Indonesia, the majority of which use diesel engine power plants or do not have electricity. Against this background, the author designs a power plant using ocean wave power.

METHOD

SEA WAVE POWER, LINEAR GENERATOR, AND SEA WAVE POWER PLANT

II.1. Sea Wave

Ocean waves are the movement of rising and falling sea levels in a direction perpendicular to the earth's surface which forms a sinusoidal graph, so that ocean waves are transverse. Ocean waves are influenced by three main factors, namely the force of gravity, the intensity of the sea breeze, and the surface tension of seawater. Each region has a different nature of ocean waves, based on wave height, period, and wind speed. An ideal ocean wave has parts on its wave, namely:

- Crest

  The highest point of a wave.

- Troug
  The lowest point of the wave, between the two crests of the wave.
- Wavelength
  The horizontal distance between two wave crests or between two wave troughs.
- Wave height
  The vertical distance between the crest and trough of the wave.
- Wave period
  Waktu time it takes for two successive crests of a wave to pass through a point.

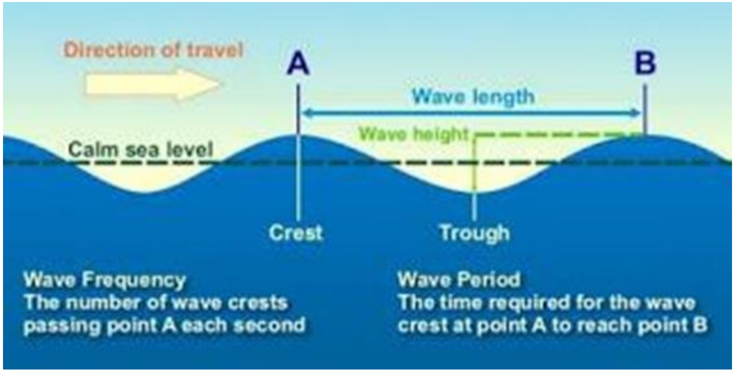


FIGURE 1. Ideal Ocean Wave

II.2. Ocean Wave Linear Theory

The surface of ocean waves is not linear but is random or erratic. For the wave motion to be calculated, simplification is needed, among others, it is assumed that the flow of the wave is 2-dimensional with the wave propagating on the x-axis. The friction with the seabed and the viscosity of seawater are also neglected. So that the equation for the surface elevation of sea waves (ζ) that propagates on the x-axis is obtained as follows:

$$\zeta = a \sin(kx - \omega t) \tag{2.1}$$

With:

ζ = Wave elevation (m)

α = Wave amplitude (m)

k = Wave constant

ω = Angular speed of the wave (rad/s)

The wave constant and the angular velocity of the wave can be calculated using the following 2 equations:

$$\omega = 2\pi f = 2\pi/T \tag{2.2}$$

$$k = 2\pi\lambda \tag{2.3}$$

With:

k = Wave constant

ω = Angular speed of the wave (rad/s)

f = Wave frequency (Hz)

T = Wave period (s)

λ = Wavelength (m)

II.3. Linear Generator

A Linear generator is an electrical machine that functions to convert the mechanical energy of linear motion into electrical energy using the principle of electromagnetic induction. The components of the linear generator are as follows:

- Permanent Magnet
- Conductor winding
- Stators
- Translator
- Prime mover

The stator is a stationary part in which there is a conductor winding. A translator is a part that moves linearly back and forth where there is a permanent magnet. The linear movement of the permanent magnet in the translator relative to the conductor windings in the stator will cause a change in the magnetic flux in the conductor windings so that it will produce an electric current in the stator.

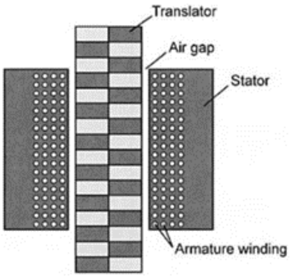


FIGURE 2. Illustration of components in a linear generator side view

II.4. Linear Generator Working Principle

Linear generators work according to the principle of electromagnetic induction. Electromagnetic induction is a symptom of the emergence of an electromotive force (EMF) in a conductor coil when there is a change in the magnetic flux to the conductor or when the conductor moves relative to a magnetic field. A magnetic field is the area around a magnet in which all objects in it experience a magnetic force. The magnitude of the magnetic field can be measured by the intensity of the magnetic field (H) and the density of the magnetic field (B).

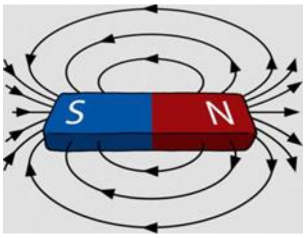


FIGURE 3. Illustration of magnetic field direction

Magnetic flux (symbolized by $\boldsymbol{\phi}$) is a measure or amount of magnetic field density (B) passing through a certain cross-sectional area. The magnetic flux through a given field is proportional to the amount of the magnetic field passing through that field. If the magnetic field is uniform through the plane perpendicularly, the value of the magnetic flux is obtained from the dot product between the magnetic field density vector (**B**) and the cross-sectional area of the plane through which it passes (A). Using the following equation:

$$\Phi = B \cdot A \qquad (2.4)$$

With the elaboration of the dot product vector it becomes the following equation:

$$\Phi = B\,A\cos\theta \qquad (2.5)$$

Where:

$\boldsymbol{\phi}$ = Magnetic flux (Wb)

B = Magnetic field density (T)

A = Cross-sectional area (m^2)

θ = The angle between the magnetic lines of force and the cross-section

If there is a change in magnetic flux with time through a coil of conducting wire, it will cause an induced electromotive force which can be expressed by the following equation:

$$\varepsilon = -N \cdot d\boldsymbol{\phi} / dt \qquad (2.6)$$

The flux used in a linear generator is a flux that changes with time and is sinusoidal with time, so the flux equation can be described as follows:

$$\Phi = \Phi\, m \cos \omega t \qquad (2.7)$$

$$\omega = 2\,\pi \cdot f \qquad (2.8)$$

Where f is the frequency of the linear motion of the rotor of the linear generator. So Faraday's law can be described as follows:

$$\varepsilon = -N \cdot d / d\boldsymbol{\phi}\,(\boldsymbol{\phi}m \cos\ \omega t) \qquad (2.9)$$

$$\varepsilon = \ N \cdot \omega\ \boldsymbol{\phi}m\ \sin \omega t \qquad (2.10)$$

With:

ε = Induction electromotive force (V)

$\boldsymbol{\phi}$ = Magnetic Flux (Wb)

t = Time (s)

N = Number of turns of conductor

$\boldsymbol{\phi}$m = Maximum flux (Wb)

ω = The angular velocity (rad/s)

The effective value of the voltage generated by the linear generator is as follows:

$$\varepsilon_{eff} = (2 \pi f N \boldsymbol{\phi}) / \sqrt{2} \quad (2.11)$$

$$\varepsilon_{eff} = 4{,}44 f N \boldsymbol{\phi} \quad (2.13)$$

In this way it will be possible to calculate the value of the output power of a linear generator with the following equation:

$$P = \varepsilon \cdot I \quad (2.14)$$

$$P = \varepsilon^{2} \cdot R \quad (2.15)$$

With:

P = Linear generator output power (W)

ε = Linear generator voltage (V)

R = Resistance (Ohm)

II.5. Ocean Wave Power Plant

Wave energy converter (WEC) technology has been developed with a variety of different methods. From the variety of existing concepts and designs, in general, WEC technology can be classified into 3 main types, namely as follows:

- Attenuator

This type of tool is placed on the sea surface parallel to the direction of the ocean waves and follows the wave shape. An example of a PLTGL tool which is a type of attenuator is the Pelamis developed by the Ocean Power Delivery Ltd. company.

- Point Absorber

The point absorber type tool has a small dimension to the wavelength of the ocean so that the wave energy used is in the form of linear motion. The structure of this tool is in the form of a buoy that floats on the sea surface and moves up and down following the movement of ocean waves. An example of a point absorber type device is a permanent magnet linear buoy system.

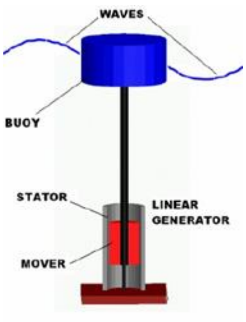


FIGURE 4. Permanent magnet linear buoy system

- Terminator

Terminator-type tools are placed on land or the beach in a position perpendicular to the direction of the incoming wave. So that it will block the ocean waves that lead to the beach.

Examples of this type of device are the oscillating water column system and the canal system (Tapered channel).

LINEAR GENERATOR SYSTEM DESIGN WITH VERTICAL CONFIGURATION

III.1. Research methodology

FIGURE 5 is a flow chart that shows the stages of research carried out from searching for literature studies to obtaining research results so that conclusions can be drawn from the research conducted.

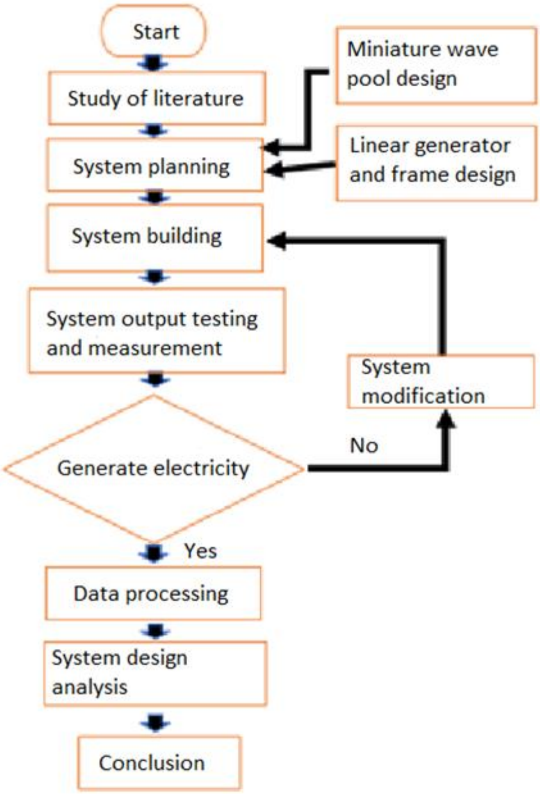


FIGURE 5. Research methodology flowchart

III.2. Ocean Wave Miniature Pool

Miniature ocean wave pools are used to carry out tool testing. The pool building material uses wooden planks arranged into rectangular blocks with an open top. To connect the wooden planks used nails and a glue gun. The inside of the pool is sanded and caulked and then coated with waterproof paint to prevent leakage

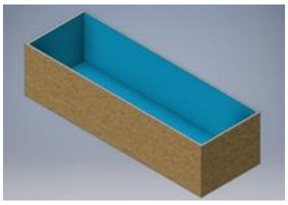


FIGURE 6. The three-dimensional design of a miniature ocean wave pool

Explanation:

Length : 180 cm

Width : 60 cm

Heigth : 45 cm

Wood Thickness : 1,5 cm

III.3. Ocean Wave Miniature Mechanical Parts

III.3.1. Lever Rod

The lever rod is a moving component that conducts the energy received from the ocean waves which produces an impulse so that it moves the linear generator up and down.

FIGURE 7. Logs

a. <u>Logs</u>

Explaination:

Material : Wood

Length : 82 cm

Width : 4 cm

Height : 2 cm

Diameter : 1,6 cm dan 0,5 cm

FIGURE 8. Cylinder rod

b. Cylinder rod

Explaination:

Material : Aluminium

Length : 92 cm

Outer Diameter : 1,6 cm

Inner Diameter : 1,5 cm

FIGURE 9. Wooden cylinder

c. Wooden cylinder

Explanation:

Material : Wood

Length : 18 cm

Outer Diameter : 1,6 cm

III.3.2.The Float

The float is used so that the tool can float on the surface of the water and so that the tool moves according to the wave motion. The PVC pipe used as the floating body is 4".

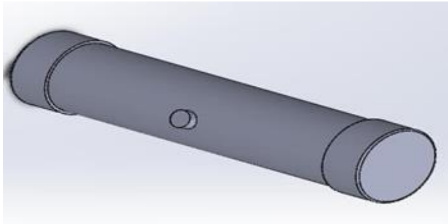


FIGURE 10. Float design

III.3.3. Stator Support Pole

Is the part that is connected to the miniature pool and is also connected to the stator. This section serves to support the stator so that the stator remains in position even when the tool is running.

FIGURE 11. Stator support pole design

III.4. Ocean Wave Miniature Electrical Parts

The linear generator used is in the form of a coil of wire as a stator which will be passed by a permanent magnet with a linear motion back and forth as a rotor.

III.4.1. Copper wire

Using copper wire with a diameter of 0.25mm. The copper wire is wound as much as 2000 turns.

III.4.2. Neodymium Magnet

Using a neodymium permanent magnet in the form of an N52 type coin with a diameter of 30mm and a thickness of 5mm which is in 3 dimensions shown in Figure 12.

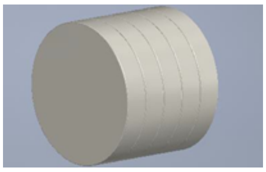


FIGURE 12. Neodymium magnet design

Explaination :

Diameter	: 30 mm
Thickness	: 5 mm
Numbers	: 5 keping
Magnet field density	: 3966,3 Gauss = 0,39663 T[8]

III.4.3. Diode

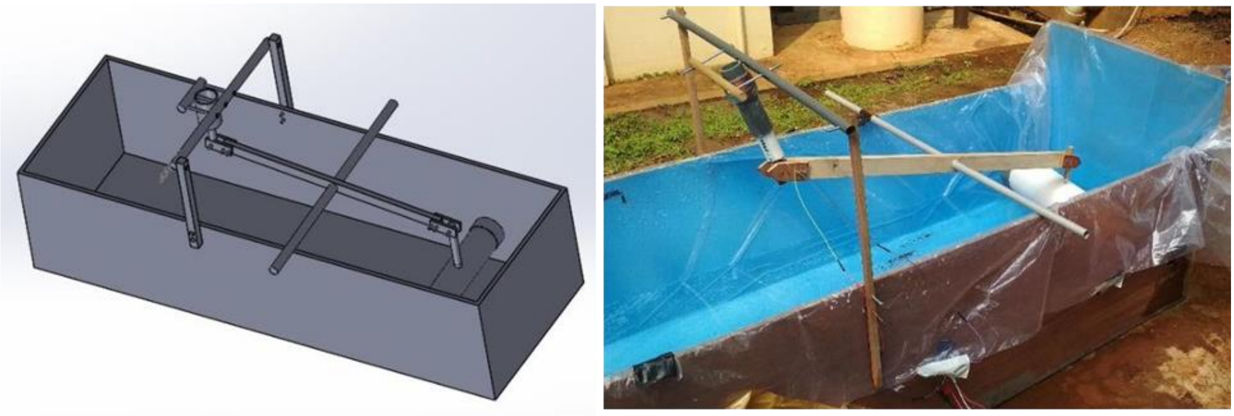
Using 4 pieces of IN4007 type diode as a rectifier circuit with a full-wave rectifier type.

III.4.4. BreadBoard

Used as a place to put a series of rectifiers, loads, and cables needed in the testing process.

III.5. Overall Design

Basically, this tool is divided into 2 main parts, namely the stationary part of the stator where the wire winding is located and the moving part of the rotor where there is a permanent magnet. The following is an illustration of each part as well as the tool as a whole:



(a) (b)

FIGURE 13. (a) Overall design (b) Original look of linear generator system with vertical configuration

RESULT AND DISCUSSION

ANALYSIS OF LINEAR GENERATOR SYSTEM WITH VERTICAL CONFIGURATION

IV.1. System Performance Analyst

IV.1.1. Output Voltage At Open Circuit

In the first test, the instrument was tested in an open circuit, then tested using 2 variations of wave period and 3 variations of wave amplitude. The parameter measured is the output voltage in an open circuit. This is done to determine the characteristics of the output voltage against variations in the period and amplitude of the wave. FIGURE 14 is a graph of the alternating current output voltage measured in volts at each data collection for 3 variations of wave amplitude in 1.5 seconds.

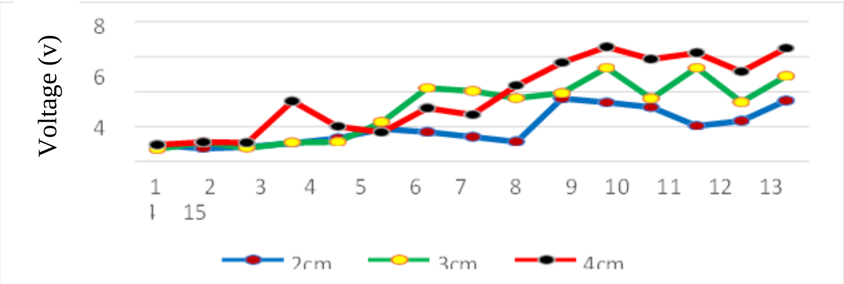


FIGURE 14. AC output voltage in 1.5 seconds with 3 variations of wave amplitude

FIGURE 15 shows a graph of the alternating current output voltage in volts with a wave period of 2 seconds.

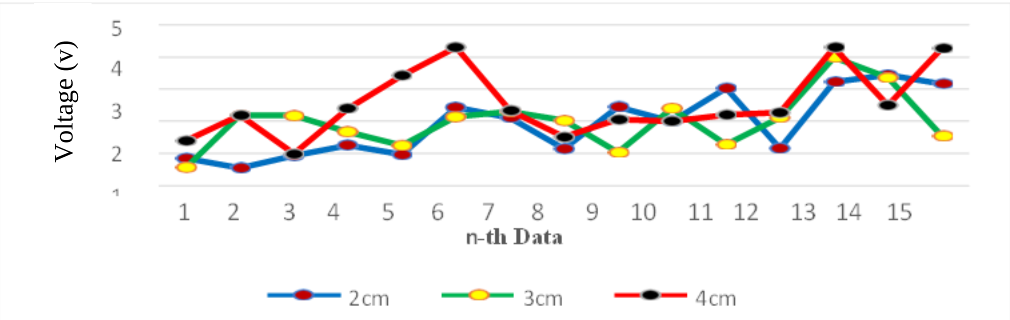


FIGURE 15. AC output voltage in 2 seconds with 3 variations of wave amplitude

TABLE 4.1 Alternating current average output voltage

No	Periode	Amplitudo (cm)	Voltage (V)
1	1,5 second	2	1,95
2		3	3,05
3		4	3,77
4	2 second	2	1,92
5		3	2
6		4	2,55

In general, the greater the wave amplitude, the greater the output voltage, this applies to both variations of the wave period. The faster the wave period, the greater the voltage generated. It can be seen in the data for the same amplitude but different periods, for example at an amplitude of 4 cm during 1.5 seconds the output voltage is 3.77V while during 2 seconds the output voltage is only 2.55V. In the 1.5 periods with an amplitude of 4cm, the output voltage produced is the largest compared to other amplitudes and periods. So it can be concluded that the faster the wave period and the higher the wave amplitude, the greater the output voltage.

The maximum output voltage can be increased by increasing the number of turns of the wire, using a magnet with a higher magnetic field density, increasing the frequency of movement of the linear generator, and smoothing the inner surface of the winding to reduce friction between the permanent magnet and the inner side of the winding.

IV.1.2. Output Power at Loaded State

The test is carried out using a 10 resistor as a load connected to the output of the rectifier circuit. Furthermore, measurements of the output voltage and output current are carried out to determine the electrical power output from the linear generator. The following in FIGURE 15 is a graph of the output electrical power during a wave period of 1.5 seconds with 3 variations of wave amplitude:

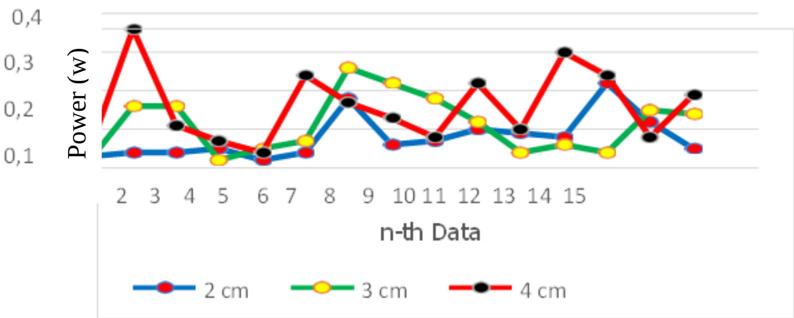


FIGURE 16. Output power in 1.5 seconds with 3 variations of wave amplitude

The following in FIGURE 16 is a graph of the output electrical power for a wave period of 2 seconds with 3 variations of wave amplitude.

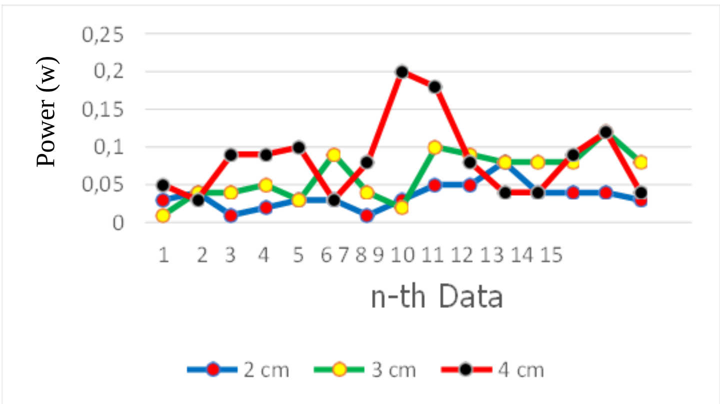


FIGURE 17. Output power in 2 seconds with 3 variations of wave amplitude

TABLE 4.2 Average output power

No.	Periode	Amplitude	Voltage (V)	Current (A)	Power (W)
1	1,5 second	2 cm	0,80	0,10	0,08
2		3 cm	0,76	0,14	0,11
3		4 cm	0,94	0,16	0,16
4	2 second	2 cm	0,48	0,07	0,03
5		3 cm	0,74	0,08	0,06
6		4 cm	0,77	0,11	0,08

In the data from TABLE 4.2, it can be seen that the greater the amplitude of the wave, the greater the output electrical power, this applies for 1.5 seconds or 2 seconds. Electrical power is directly proportional to its value with voltage and current, so to increase the output electrical power it is necessary to increase the output voltage of a linear generator.

IV.2. Generator Output Power Efficiency

The efficiency of the linear generator output power can be calculated by dividing the test output power by the maximum output power. The maximum output power is obtained from the calculation results with the assumption using a 10-ohm load resistor, where there is no reflected wave and the influence of the outside environment. With an effective output voltage of 4.54 V for 1.5 seconds and an effective output voltage of 3.39 V for 2 seconds, the calculation power is 2.06 W for 1.5 seconds and 1.15 W for 1.5 seconds. period of 2 seconds.

The output power efficiency can be calculated using the following equation:

$$\eta = (Puji \;\; / \;\; P\,max) \; x \; 100\% \quad (4.1)$$

With:

η = Output power efficiency

$Puji$ = Test result output power

$Pmax$ = Maximum output power

The following is TABLE 4.3 of the output power efficiency calculation data for each test variable:

TABLE 4.3. Output Power Eficiency

No	**Periode**	**Amplitudo**	**Testing Power (w)**	**Maximum Power (w)**	**Efficiency %**
1	1,5 second	2 cm	0,08	2,06	3,88
2		3 cm	0,11	2,06	5,34
3		4 cm	0,16	2,06	7,77
4	2 second	2 cm	0,03	1,15	2,6
5		3 cm	0,06	1,15	5,21
6		4 cm	0,08	1,15	6,96

The faster the wave period, the greater the maximum output power. So it can be concluded that the maximum output power is inversely proportional to the wave period. The power of the test results is directly proportional to the amplitude of the wave and inversely proportional to the period of the wave.

The maximum efficiency of 7.77% occurs when the wave period is 1.5 seconds and the wave amplitude is 4 cm. This shows that the tool design is still not optimal because there are still quite a lot of mechanical losses that occur in the tool, for example, the frictional force that occurs between the magnet and the inside of the winding and the losses in the rectifier circuit used and the possibility of a reflected wave in the test.

CONCLUSION

From the test results, it can be seen that:

1. The open-circuit voltage is directly proportional to the wave amplitude and inversely proportional to the wave period.
2. The average maximum open-circuit voltage is 3.77 Volts with a wave amplitude of 4cm and a wave period of 1.5 seconds.
3. The implementation for this system has a maximum output power of 0.16W with a load resistor of 10Ohm.
4. The maximum output power efficiency is 7.77% when the wave amplitude is 4cm and the wave period is 1.5 seconds.
5. To increase the output voltage of the system, it is necessary to increase the number of turns of the wire, use a magnet that has a higher magnetic field density, use a faster wave period, and smooth the inner surface of the winding to reduce friction between the magnet and the inner side of the winding.

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