MINI WAVE ENERGY HARVESTING TEST RIG USING MULTIPLE SOLENOID MAGNETS

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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A thesis is submitted
in fulfillment of the requirement for the degree of
Bachelor of Mechanical Engineering (with Honours)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

JUNE 2020

DECLARATION

I declare that this thesis entitled "Mini wave energy harvesting test rig using multiple solenoid magnets" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :.....

Name : Lee Voon Hui

Date : 26/6/2020

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (with Honours).

Signature :.....

Supervisor Name : Dr. Yusmady Bin Mohamed Arifin

Date :.....

DEDICATION

To my beloved family, friends, and lecturer

ABSTRACT

The usage of a conventional source power plant to generate electricity gives a big impact to environment due to its pollutions. The development of conventional source of power plant is crucial, however the common conventional sources use in Malaysia are gas, steam and hydro power plants. In Malaysia the wave power plant is not widely use, but there is a potential to build the wave power plant in Malaysia. In Malaysia the most suitable area to develop a wave power plant is Terengganu, because the potential energy that can be generated is between 2.8kW/m to 8.6kW/m. In this study, the potential of electric generation system based on wave energy was investigated. The objectives of this project are to improve the previous mini wave harvesting test rig and study different wave pattern effect that obtained from a mini wave simulator in producing electricity for different configuration of multiple solenoid magnets. In this study, wave generator and linear generator were modified and improved. The wave generator that moves in linear motion (reciprocating motion) was used to produce artificial wave. From the fluctuation movement of the artificial wave, the linear generators will convert the kinetic energy to electrical energy through the magnetic flux cutting between copper coil and magnet. The induced current produced will light up the LED as an indicator of electric production. A multimeter was used to measure the voltage and current produced. The experiments were conducted with 3 different wave generator speed and location of linear generator to determine the highest voltage and current produced as preliminary results. The highest voltage and current produced at a distance of 40cm from wave generator with speed no.3. The next experiment for multiple linear generators was conducted with the first linear generator located at 40cm from wave generator and the second linear generator was set at 20cm and 60cm from wave generator. The experiment was repeated as preliminary experiment. Performance of this test rig is determined based on the capability of producing high induced current and voltage. The findings of this study showed direct relationship between number of linear generator and induced current and voltage produced. The number of linear generator increased this lead to more induced current and voltage produced. The motor speed increased this lead to high amplitude of wave. Motor speed is directly proportional water wave amplitude. Wave amplitude also affects the number of magnetic flux cutting on linear generator. The higher the amplitude, the more number of magnetic flux cutting on linear generator, the more induced current and voltage produced. Based on the preliminary experiment the best location to fixed the first linear generator is 40cm from wave generator, which produced the highest electricity. Based on the actual experiment result obtained, the highest value of induced current and voltage produce at a distance of 20 cm and 40cm from the wave generator with speed 3 and time taken 25 minutes are 4.72mA and 6.41V respectively.

ABSTRAK

Penggunaan loji tenaga sumber secara konvensional untuk menjana elektrik memberi kesan besar kepada persekitaran kerana pencemarannya. Pembangunan sumber tenaga elektrik konvensional sangat penting, namun sumber konvensional yang biasa digunakan di Malaysia ialah loji tenaga gas, wap dan hidro. Di Malaysia loji tenaga gelombang tidak banyak digunakan, tetapi ada potensi untuk membina loji tenaga gelombang di negara ini. Kawasan yang paling sesuai untuk membangunkan loji tenaga gelombang ialah di Terengganu, ini kerana potensi tenaga yang dapat dihasilkan adalah antara 2.8kW / m hingga 8.6kW / m. Dalam kajian ini, potensi sistem penjanaan elektrik berdasarkan tenaga gelombang dikaji. Objektif projek ini adalah untuk memperbaiki pelantar ujian penghasil gelombang mini dan mengkaji kesan corak gelombang yang berbeza yang diperolehi dari penyelaku gelombang mini dalam menghasilkan elektrik untuk konfigurasi magnet solenoid yang pelbagai. Dalam kajian ini, penjana gelombang dan penjana lelurus diubah dan diperbaiki. Penjana gelombang yang bergerak dalam gerakan lelurus digunakan untuk menghasilkan gelombang buatan. Dari pergerakan turun naik gelombang buatan, penjana lelurus akan menukar tenaga kinetik kepada tenaga elektrik melalui pemotongan fluks magnet antara gegelung tembaga dan magnet. Arus yang dihasilkan akan menyalakan LED sebagai petunjuk pengeluaran elektrik. Multimeter digunakan untuk mengukur voltan dan arus yang dihasilkan. Eksperimen dilakukan dengan 3 kelajuan penjana gelombang yang berbeza dan lokasi penjana lelurus untuk menentukan voltan dan arus tertinggi yang dihasilkan sebagai hasil awal. Voltan dan arus tertinggi yang dihasilkan pada jarak 40cm dari penjana gelombang dengan kelajuan no.3. Eksperimen seterusnya untuk dua penjana lelurus dilakukan dengan penjana lelurus pertama terletak pada jarak 40cm dari penjana gelombang dan penjana lelurus kedua ditetapkan pada 20cm dan 60cm dari penjana gelombang. Eksperimen diulang sebagai eksperimen awal. Prestasi pelantar ujian ini ditentukan berdasarkan keupayaan menghasilkan arus dan voltan aruhan tertinggi. Dapatan kajian ini menunjukkan hubungan langsung antara bilangan penjana lelurus dengan arus dan voltan teraruh yang dihasilkan. Bilangan penjana lelurus meningkatkan menunjukkan bahawa arus dan voltan yang lebih banyak dihasilkan. Kelajuan motor menyebabkan terhasilnya yang meningkat menyebabkan gelombang beramplitud menjadi tinggi. Kelajuan motor adalah amplitud gelombang air. Amplitud gelombang juga mempengaruhi jumlah pemotongan fluks magnetik pada penjana lelurus. Semakin tinggi amplitud, semakin banyak bilangan pemotongan fluks magnetik pada penjana lelurus, semakin banyak arus dan voltan yang dihasilkan. Berdasarkan eksperimen awal, lokasi terbaik untuk menetapkan penjana lelurus pertama adalah 40cm dari penjana gelombang, yang menghasilkan elektrik tertinggi. Berdasarkan hasil eksperimen sebenar yang diperoleh, nilai arus aruhan dan voltan tertinggi dihasilkan pada jarak 20 cm dan 40 cm dari penjana gelombang dengan kelajuan 3 dan masa yang diambil 25 minit masing-masing adalah 4.72mA dan 6.41V.

ACKNOWLEDGEMENTS

Throughout my journey in Universiti Teknikal Malaysia Melaka (UTeM), many people were helping me builds my academic career. It would have been near impossible to complete this journey without the help of these people. Therefore, I am taking this opportunity to address names that supported the completion of this thesis.

First, I would like to whole heartedly thank my supervisor, Dr. Yusmady Bin Mohamed Arifin from the Faculty of Mechanical Engineering UTeM for his guidance, assistive supervision, and invaluable support towards the completion of this research.

Special thanks to my beloved alma mater, UTeM, for providing fluid laboratory and the grant funding which served as the financial support throughout the research.

My special thanks my family members for loving support. Lastly thanks for my beloved friend for their moral support, informative discussions and motivation.

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LIST OF ABBEREVATIONS

WEC	Wave Energy Converter
PTO	Power-Take Off
DC	Direct Current
AC	Alternating Current
AWS	Archimedes Wave Swing
PVC	Polymerizing Vinyl Chloride
emf	Electromotive Force
PMLG	Permanent Magnet Linear Generator
LIA	Linear Induction Accelerator
PWM	Power Window Motor
OWC	Oscillating Water Column
FYP	Final Year Project

LIST OF SYMBOL

E	Total energy	(J)
PE	Potential energy	(J)
KE	Kinetic energy	(J)
g	Acceleration of gravity	(m/s^2)
ρ	Density of water	(kg/m^3)
A	Wave amplitude	(m)
T	Wave period	(s)
λ	Wave length	(m)
H	Height	(m)
I	Current	(A)
V	Voltage	(V)

CHAPTER 1

INTRODUCTION

1.1 Background

Since the industrial revolution, the demand of electricity becomes higher. Nowadays, the energy produce more depend on coal and fossil fuel, which will caused environmental pollution. Now a magnified global awareness has reawakening the important o renewable energy technology [Ramadan et al., 2014]. In order to reduce the uses of coal and fossil fuel the renewable energy being introduces. The types of renewable energy are wind energy, solar energy, hydropower energy, wave energy and etc. The renewable energy used in Malaysia is hydropower energy, solar energy and biomass energy. In Malaysia do not have wave energy power plant, but actually Malaysia is very suitable to install wave energy convertor. Since Malaysia is surrounded by sea, the sea has a lot of sources of motion energy such as tides, wave and etc. In future the renewable wave energy has huge potential in power generation [Polinder et al., 2004].

In this Final Year Project (FYP) project a linear generator principle and concept was studied. A wave energy converter (WEC) is a device used to produce electrical energy from wave-induced motion [Nguyen & Tona, 2019]. The WEC uses to convert mechanical energy to electrical energy from wave to oscillating body through the power-take off (PTO) system. In **Figure 1.1** shows the wave oscillates the floater of PTO system to generate electricity. The electricity produced sends to the grid.

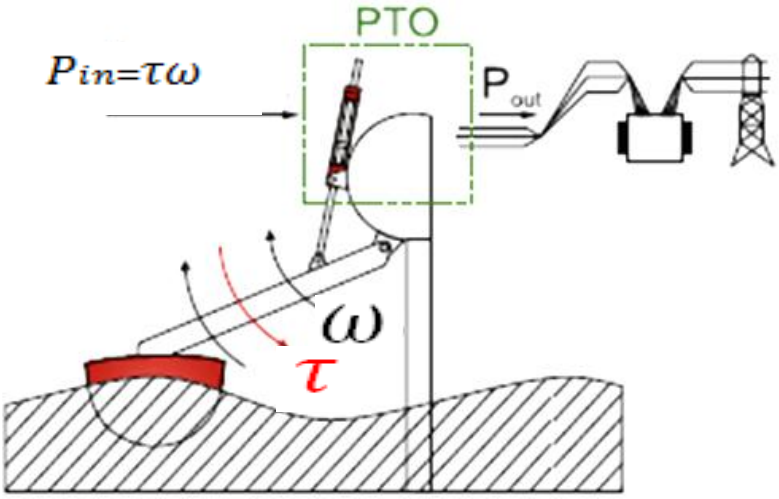

Figure 1.1: Schematic diagram of wave energy converter [Pedersen et al., 2016]

There are four types of wave energy conservation systems which are oscillating water columns, overtopping devices, hinged contour devices and buoyant moored devices [Polinder et al., 2007]. The different types of wave energy conversion system also require PTO system. The oscillating water columns mostly have air turbines that drive rotating generator and the overtopping devices mostly have hydro turbines that drive rotating generator. Hydraulic PTO systems usually use by hinged contour devices. The fourth type oscillating body often have linear generator [Polinder et al., 2007].

The Archimedes Wave Swing is using a linear generator to provide power for offshore application. The wave pass through the linear generator converts the resulting motion to electricity. This FYP project focuses on oscillating body such as the Archimedes Wave Swing (AWS) which uses the linear generator. The linear generator has higher efficient than the others. The linear generator is extracted and converted the wave energy into an oscillatory motion to create mechanical energy [Rao et al., 2017].

The permanent magnet linear generator (PMLG) can produces electricity by the translator with permanent magnets (PM) and the stator with winding coils, the axial-directional magnetic flux which links through the stator winding generate an induced electromotive force (emf) [Rao et al., 2017]. **Figure 1.2** shows the tubular type of PLMG.

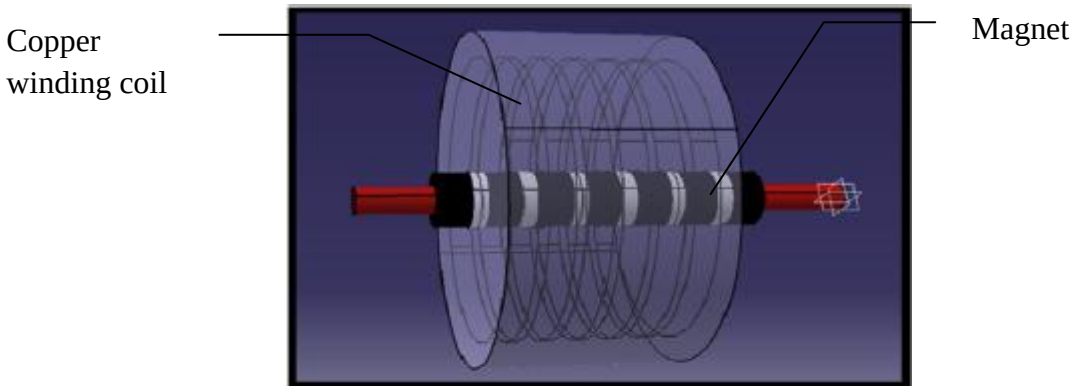

Figure 1.2: Tubular type PLMG [Rao et al., 2017]

The induced emf generated through the magnetic flux changing in the stator and the translator. The size of the stator diameter provides a constraint to the inner radius of the PM. The PM in show the LIA in Figure 1.3 within the induction cell for beam transport and provide magnetic field across the accelerating gap shows in **Figure 1.3** [Burris-Mog et al., 2017].

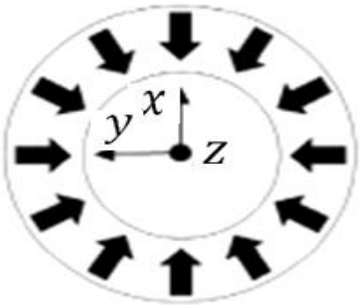

Figure1.3: Illustration of radially magnetized PM ring [Burris-Mug et al., 2017]

The magnetic fields work in PM will either constructively or destructively depend on the number of turning coils on the stator. The magnetic fields are more concentrated in the center compare to outside so more loops will create stronger fields. According Faraday's Law states induced emf may generated by a changing magnetic field when the solenoid magnet crossed the coil on the stator. When the polarity of the induced emf produced a current whose magnetic field opposes the change of it produced.

In conclusion, the introduction briefly explains the types and uses of WEC, how PLMG produced current and how magnetic field formed. This can relate to the project by oscillating body type of WEC more suitable for this FYP project because it use linear generator to convert energy. The PLMG principal and concept are relates to this project in term of how to make a high efficiency linear generator. The magnetic field is important in this project because it affected the amount of current produced in the experiment.

1.2 Problem Statement

The existing power plants in Malaysia usually use coal and fossil fuel as primary source. The fossil fuel is cost highly and cannot be reusable. Not only that, the process to change the fossil fuel to energy will emit hazardous gases which are harmful to environment and human. However the use of use renewable energy such as wind energy, solar energy and wave energy the source are free of charge and able to eliminate carbon dioxide and sulfur dioxide gases. The process to convert renewable energy to electricity will not pollute the environment. Malaysia is surrounded by sea so the wave power plant is very suitable renewable energy to use. However in Malaysia there is no WEC power plant but Malaysia geographic is very suitable for this power plant. Thus, this project is to investigate the potential of wave energy in produces electricity by using multiple linear generators.

1.3 Objective

The objectives of the project are as follows:

i. Identify the problems and improve the previous mini wave harvesting test rig by using multiple linear generators.
ii. To investigate different wave pattern produced by the wave generator after improvement.
iii. To investigate the amount of electricity produce from artificial wave for different configuration of multiple solenoids.

1.4 Scope of Project

The scopes of this project are:

i. Identify and find solutions to problems involve with the previous wave generator, linear generator and its circuits in order to make improvement and modifications.

ii. Record and study the wave pattern that produce by modified wave generator for 3 different motor speeds 1, 2 and 3.

iii. Measure the current and voltage produced by using a multimeter for two linear generators at different gap distance of 20 cm, 40 cm, 60 cm and motor speeds 1, 2 and 3.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter summarizes the literature review on the evaluation methods related to linear generator and wave energy converter. Thus in this chapter there are two main topic discussed, which are linear generator and wave energy converter. For linear generator, there are subtopics involved with solenoid magnet, electromagnetic force and generator design and performance are explained. However for wave energy converter, wave characteristic, wave height and simulation are discussed.

2.2 Linear generator

The literature review under linear generator will discuss more on the topic involve with power-take-off (PTO) system. The PTO system of linear generator is more efficient and robust. **Figure 2.1** shows the PTO system concept [Elwood et al., 2010]. The PTO system is involved with conversion linear motion of spar and buoy to electricity through linear generator. The magnet pass through copper wires, current induced due to changing magnetic field. The PTO cable is attached to spar for transferring electricity [Burris-Mog et al., 2017]. The linear generator needs high peak force, low speed and irregular motion in wave energy conversion system (WEC) [Polinder et al., 2007].

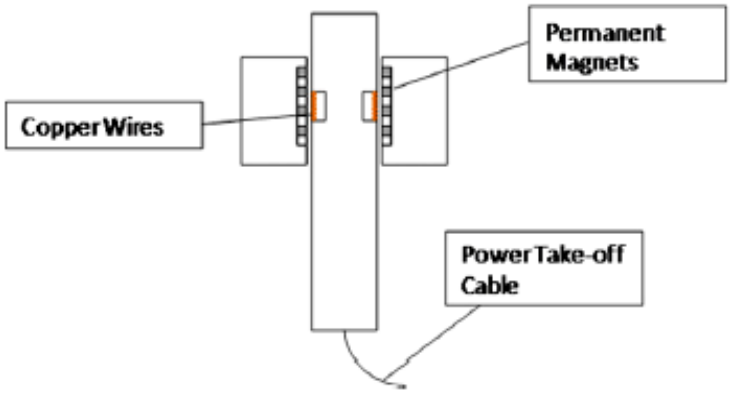

Figure 2.1: PTO concept [Elwood et al., 2010]

Figure 2.2 shows the whole process for electricity generating, first the buoy convert the energy of wave into mechanical energy. Then the linear generator converts the mechanical energy to Alternating Current (AC). The rectifiers connected in series to provide total output and added a capacitor to provide consistent rectified voltage and send to grid [Rhinefrank et al., 2006].

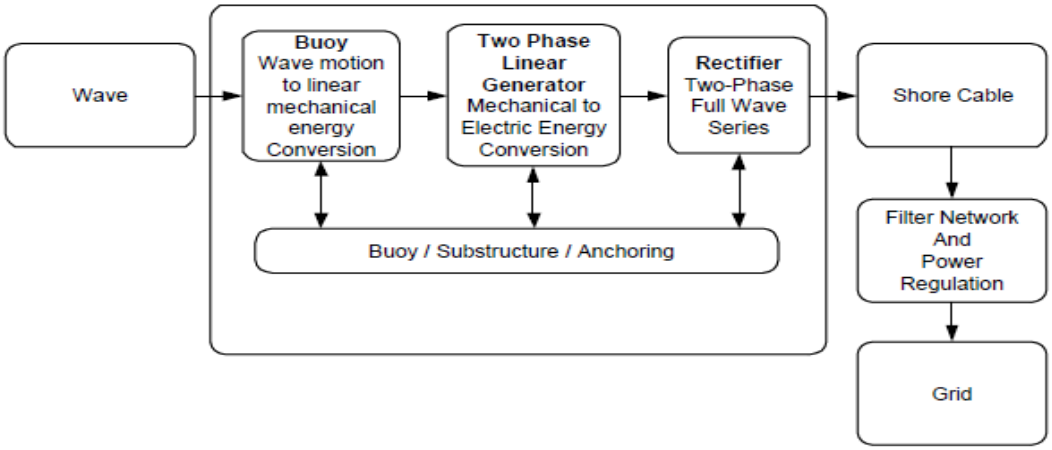

Figure 2.2: System block diagram [Rhinefrank et al., 2006]

The linear generator is uses to convert mechanical absorbed power to electrical power output. The linear generator translator of magnet attached to the floater and the stator of copper winding coil is installed in inner cylinder by a tensioned mooring cable. It produces electrical energy by magnetic flux cutting between magnet and copper coil when the floater oscillated with the wave motion [Son & Yeung, 2017].

2.2.1 Solenoid magnet

Solenoid magnet is magnetically permeable cylindrical core with electrically conductive wire warped and in axial alignment [Brent, 1996]. Magnetic force produced when permanent magnet passes through the coil causes the magnetic flux cutting [Franco et al., 2001]. **Figure 2.3** showed a solenoid magnet that consists of two coils and a permanent magnet plunger to generate magnetic force. The magnetic plumber used because it can generate higher actuation forces compared to ferromagnetic core.

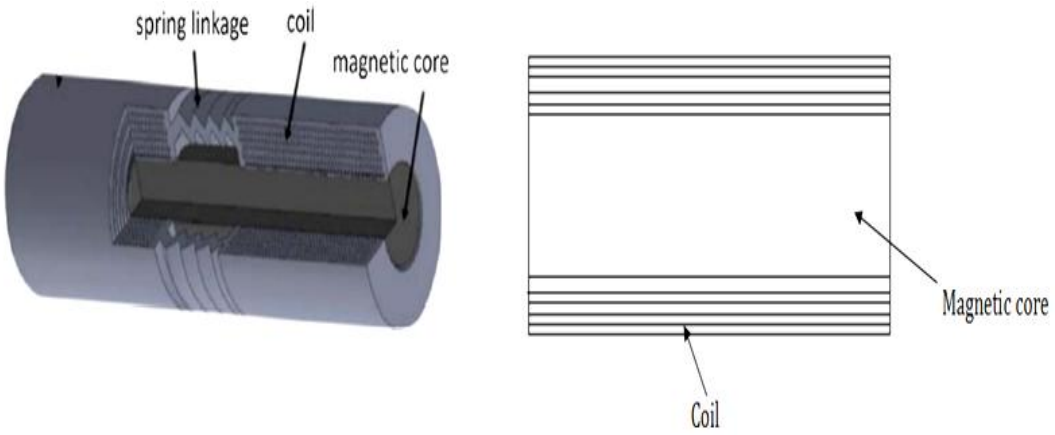

Figure 2.3: Schematic of solenoid magnet [Ebrahimi et al., 2018]

The solenoid magnet is a theory to decrease the dependence that linear induction accelerator have big direct current power supplies. The inner radius of solenoid magnet