

WAVE ENERGY ELECTRIC GENERATOR

by

NUR AZURA KAMARUZZAMAN

5863

**Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)**

JANUARY 2008



**UNIVERSITI
TEKNOLOGI
PETRONAS**
engineering futures

**UNIVERSITI TEKNOLOGI PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan**

CERTIFICATION OF APPROVAL

WAVE ENERGY ELECTRIC GENERATOR

by

**NUR AZURA BINTI KAMARUZZAMAN
5863**

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

(AP Dr. Abdul Rashid Abdul Aziz)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JANUARY 2008

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NUR AZURA BINTI KAMARUZZAMAN

ABSTRACT

This project reports on how to generate electricity from ocean wave by using permanent magnet linear generator. The objectives of this project are to design and build a small scale linear generator powered by ocean wave energy that able to generate electricity. It is not easy to harness wave energy and convert it into electricity in large amounts. So, the studies for this project include finding information and knowledge related to the topic besides developing skill through enquiry and literature review. In linear generator, electrical power is generated simply by forced relative movement of linear generator to its armature. The linear generator will oscillates with the wave up and down to cut electromagnetic flux inside the armature. The cuts of magnetic flux will result as electricity. To become a successful project, several things need to be reviewed like literature review on linear generator, design and development of the generator, experiment of prototype before gaining result and correct data. As the result, this project has been successfully developed to generate electricity.

ACKNOWLEDGEMENT

First and foremost, all praise to Allah S.W.T for granting me the opportunity to complete this final year project, which has proven to be a very enriching experience.

It is with pleasure that I express my heartfelt thanks to all who have assisted me either directly or indirectly during the course of this project. My gratitude goes to my supervisor, AP Dr. Abdul Rashid Bin Abdul Aziz, who helped me to achieve the project objectives. His contribution on this project is invaluable. I would like to acknowledge that without his guidance, all my efforts would not be profitable.

I would also like to thanks all the technical staffs of Mechanical Engineering Department especially Mr. Mohd Razali Bin Hanipah and who have been very cooperative in helping and supportive throughout the experimental work. He has spent numerous hours helping me from the starting phase till the testing phase of this project. Without his contribution, the completion of this project seems to be impossible.

Here I would also like to thanks to my parents for their support, their encouragement and understanding until the completion of this project.

TABLE OF CONTENTS

CERTIFICATION OF APPROVAL	.	.	.	.	.	.	.	.	i
CERTIFICATION OF ORIGINALITY	.	.	.	.	.	.	.	.	ii
ABSTRACT	.	.	.	.	.	.	.	.	iii
ACKNOWLEDGEMENT	.	.	.	.	.	.	.	.	iv
CHAPTER 1:									
INTRODUCTION	.	.	.	.	.	.	.	.	1
1.1 Background of Study	.	.	.	.	.	.	.	.	1
1.2 Problem Statement.	.	.	.	.	.	.	.	.	7
1.3 Objectives	.	.	.	.	.	.	.	.	7
1.4 Scope of Study	.	.	.	.	.	.	.	.	8
1.5 The Relevancy of the Project	.	.	.	.	.	.	.	.	8
1.6 Feasibility of the Project within Scope and Time	.	.	.	.	.	.	.	.	9
CHAPTER 2:									
LITERATURE REVIEW	.	.	.	.	.	.	.	.	10
2.1 Current Technology	.	.	.	.	.	.	.	.	10
2.2 Offshore Devices for Energy Conversion Method	.	.	.	.	.	.	.	.	13
2.3 Wave Power Activities in the Asia-Pacific Region	.	.	.	.	.	.	.	.	20
2.4 Previous Technology on Linear Generator	.	.	.	.	.	.	.	.	22
2.5 Mathematical Model of the Generator	.	.	.	.	.	.	.	.	25
CHAPTER 3:									
METHODOLOGY	.	.	.	.	.	.	.	.	31
3.1 Research Methodology	.	.	.	.	.	.	.	.	31
3.2 Project Activities	.	.	.	.	.	.	.	.	34
3.3 Gantt Chart	.	.	.	.	.	.	.	.	39
3.4 Tools/Equipment	.	.	.	.	.	.	.	.	39

CHAPTER 4:	RESULTS AND DISCUSSION	.	.	.	.	.	.	.	44
4.1	Experiment Using Wave Energy Tank								45
CHAPTER 5:	CONCLUSION	.	.	.	.	.	.	.	54
REFERENCES	.	.	.	.	.	.	.	.	55
APPENDICES	.	.	.	.	.	.	.	.	56
	Armature Cover Drawing	.	.	.	.	.	.	.	56
	Coil Drawing	.	.	.	.	.	.	.	57
	Coil Cover Drawing	.	.	.	.	.	.	.	58
	Floater Drawing	.	.	.	.	.	.	.	59
	Frame Drawing	.	.	.	.	.	.	.	60
	Linear Generator Drawing	.	.	.	.	.	.	.	61
	Screw Drawing	.	.	.	.	.	.	.	62
	Steel Plate [A] Drawing	.	.	.	.	.	.	.	63
	Steel Plate [B] Drawing	.	.	.	.	.	.	.	64
	Assemble Drawing	.	.	.	.	.	.	.	65
	First Semester of 2-Semester Final Year Project Milestone	.							66
	Second Semester of 2-Semester Final Year Project Milestone								67

LIST OF FIGURES

CHAPTER 1 : INTRODUCTION

Figure 1.1 : Description of A Simple Wave	2
Figure 1.2 : Malaysia's Geographical	8

CHAPTER 2 : LITERATURE REVIEW

Figure 2.1 : Pelamis	10
Figure 2.2 : The Duck	11
Figure 2.3 : How the LIMPET 500 works	12
Figure 2.4 : The McCabe Wave Pump	14
Figure 2.5 : The OPT WEC	15
Figure 2.6 : The Pelamis	16
Figure 2.7 : The Archimedes Wave Swing	17
Figure 2.8 : Permanent Magnet Linear Generator	19
Figure 2.9 : Permanent Magnet Linear Generator Buoy	23
Figure 2.10 : Geometry of The Buoy	29

CHAPTER 3 : METHODOLOGY

Figure 3.1 : Process Flow Chart	31
Figure 3.2 : Steel Plate to Paper Plate	34
Figure 3.3 : Steel Framework	35
Figure 3.4 : Wye Connection	36
Figure 3.5 : Experiment using Wave Energy Tank	37
Figure 3.6 : Schematic Assemble of Linear Generator	38
Figure 3.7 : Wave Energy Tank Dimension	40
Figure 3.8 : Wave Energy Tank	40
Figure 3.9 : Spring	41
Figure 3.10 : Delta and Wye Connection	42

CHAPTER 4 : RESULTS AND DISCUSSION

Figure 4.1 : 30 Hz Voltage Waveform	50
Figure 4.2 : 40 Hz Voltage Waveform	50
Figure 4.3 : 50 Hz Voltage Waveform	50
Figure 4.4 : 60 Hz Voltage Waveform	51
Figure 4.5 : 70 Hz Voltage Waveform	51
Figure 4.6 : 80 Hz Voltage Waveform	51
Figure 4.7 : 90 Hz Voltage Waveform	52

LIST OF TABLES

CHAPTER 1 : INTRODUCTION

Table 1.1 : Recommended Addition to Beaufort Scale	6
Table 1.2 : Comparison between Beaufort and Sea State Code	7

CHAPTER 2 : LITERATURE REVIEW

Table 2.1 : Parametric Dimensions of Generator	23
Table 2.2 : Wave Tank Test Result	24

CHAPTER 4 : RESULTS AND DISCUSSION

Table 4.1 : Wave Increment for Certain Wave Frequency	45
Table 4.2 : Voltage for 1 Phase	46
Table 4.3 : Voltage, Current and Power for 1 Phase	46
Table 4.4 : Total Power Generated by Generator	46

LIST OF GRAPHS

CHAPTER 4 : RESULTS AND DISCUSSION

Graph 4.1 : Wave Increment vs Wave Frequency	47
Graph 4.2 : Voltage vs Wave Frequency for 1 Phase	47
Graph 4.3 : Average Voltage vs Wave Frequency for 1 Phase	48
Graph 4.4 : Current vs Wave Frequency for 1 Phase	48
Graph 4.5 : Power vs Wave Frequency for 1 Phase	49
Graph 4.6 : Total Power vs Wave Frequency	49

CHAPTER 1 : INTRODUCTION

1.1 BACKGROUND

1.1.1 Ocean Waves

Wave energy can be considered as concentrated form of solar energy. Winds are generated by the differential heating of the earth and, as they pass over open bodies of water, they transfer some of their energy to form waves. Energy is stored in waves as both potential energy (in the mass of water displaced from the mean sea level) and kinetic energy (in the motion of the water particles). The amount of energy transferred, and hence the size of the resulting waves, depends on the wind speed, the length of time for which the wind blows and the direction over which it blows (the "fetch"). Power is concentrated at each stage in the transformation process, so that the original average solar power levels of typically $\sim 100 \text{ W/m}^2$ can be transformed into waves with power levels of typically 10 to 50 kW per meter of wave crest length.

Waves lying within or close to the areas where they are generated appear as a complex, irregular "wind sea". These waves will continue to travel in the direction of their formation even after the wind is no longer acting on them. In deep water, waves lose energy only slowly, so they can travel out of the storm areas with minimal loss of energy, becoming progressively regular, smooth waves or "swell". These can persist at great distances (up to ten thousand kilometers or more) from the point of origin. Therefore, coast with exposure to the prevailing wind direction and long fetches tend to have the most energetic wave climates, for instance the west coast of the Americas, Europe and Australia/New Zealand. The global wave power resource in deep water (i.e. $\geq 100 \text{ m}$ water depths) is estimated to be $\sim 10^{12} - 10^{13} \text{ W}$. [6]

1.1.2 Description of Waves

Sea waves can be simply described as sinusoidal wave with the characteristics shown in Figure 1. [6]

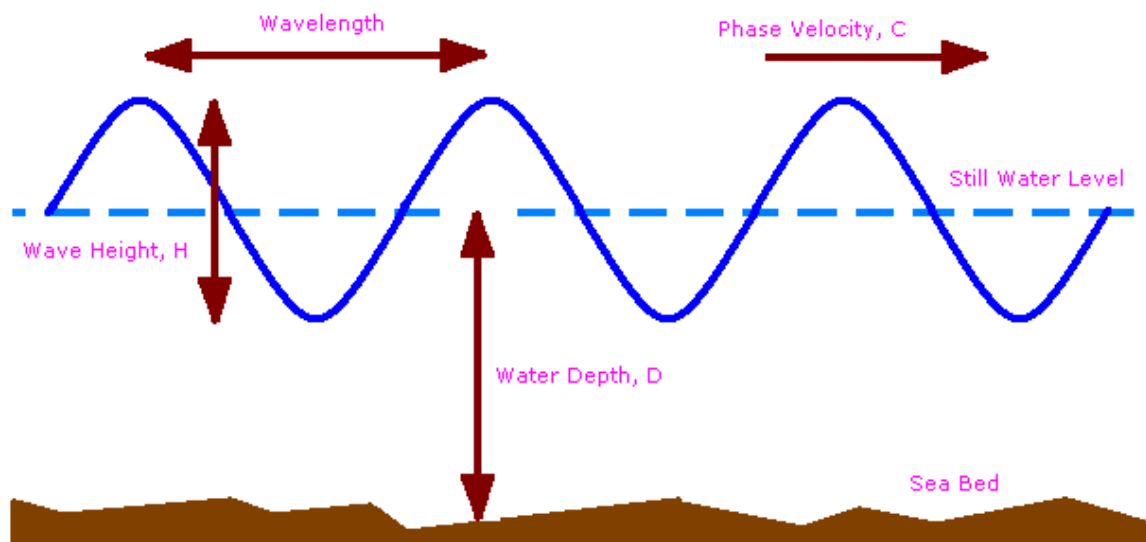
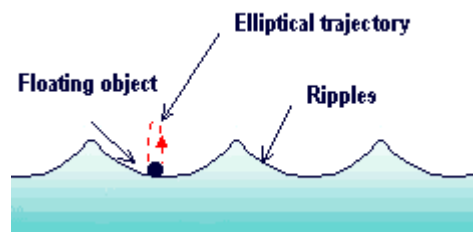


Figure 1.1 : Description of a simple wave

[Source: Page 8, John Brooke - ECOR: "Wave Energy Conversion", Ocean Engineering Series Editors, R. Bhattacharyya & M.E. Mc Cormick, 2003]

1.1.3 Wave Physical Concepts



When an object bobs up and down on a ripple in a pond, it experiences an elliptical trajectory.

In general, large waves are more powerful. Specifically, wave power is determined by wave height, wave speed, wavelength, and water density. Wave size is determined by wind speed and fetch (the distance over which the wind excites the waves) and by the depth and topography of the seafloor (which can focus or disperse the energy of the waves). A given wind speed has a matching practical limit over which time or distance will not produce larger waves. This limit is called a "fully developed sea."

Wave motion is highest at the surface and diminishes exponentially with depth; however, wave energy is also present as pressure waves in deeper water.

The potential energy of a set of waves is proportional to wave height squared times wave period (the time between wave crests). Longer period waves have relatively longer wavelengths and move faster. The potential energy is equal to the kinetic energy (that can be expended). Wave power is expressed in kilowatts per meter (at a location such as a shoreline).

The formula below shows how wave power can be calculated. Excluding waves created by major storms, the largest waves are about 15 meters high and have a period of about 15 seconds. According to the formula, such waves carry about 1700 kilowatts of potential power across each meter of wave front. A good wave power location will have an average flux much less than this: perhaps about 50 kW/m.[1]

Formula: Power, $P = 0.5 H_s^2 T_e$ kW/m

where : H_s is average height of the highest 1/3 waves [in meters]
 T_e is mean wave period [in seconds]

The most usual wave height and period parameters are:

- Significant wave height H_s is defined as the average height of the highest one-third waves. This approximates to the height that a shipboard observer will report from visual inspection of the sea state, since such an observer tends to overlook the smaller, less conspicuous waves.
- Energy period T_e is a mean wave period with respect to the spectral distribution of wave energy transport (wave power level). Peak period T_p is defined as the period corresponding to the peak in the variance density spectrum of sea surface elevation. It thus represents the harmonic frequency component having the greatest amount of energy at a place passed by a random wave train. Some wave energy devices can be "tuned" to this frequency in a manner analogous to the tuning of a radio circuit in an electromagnetic wave field. [6]

From equation:

$$\text{Power, } P = 0.5 H_s^2 T_e \quad \text{kW/m}$$

Power to be generated, $P = 1$ kW

Average height of the highest 1/3 waves, $H_s = 1.5$ m

So,

$$P = 0.5 H_s^2 T_e$$
$$1 \text{ kW} = 0.5 (1.5)^2 T_e$$

$$T_e = 0.88 \text{ s}$$

:: Mean wave period, $T_e = \underline{0.88 \text{ s}}$

1.1.4 Wave Energy Extraction Technologies

The world's first wave energy device patent was registered in 1799 by Girard, in Paris. After more than 200 years' development, there are currently more than 1500 wave energy device patents. Historically, there have been two booms of interest in the research of wave energy, corresponding to the 1970 s oil crisis and pollution concerns as well as concerns regarding natural resource reserves since the mid 1990 s. Depending on the distance between the conversion devices and the shoreline, wave energy systems can be classified as shoreline, near shore and offshore extraction systems. This project will only consider for offshore extraction system.[4]

1.1.4.1 Offshore Devices

Offshore devices, such as the proposed buoy generator, are the farthest out to sea; they extend beyond the breaker lines and utilize the high energy densities and higher power wave profiles available in the deep-water (>40 m) waves and surges. In order to extract the maximum amount of energy from the waves, the devices need to be at or near the surface. This makes it a requirement to have flexible moorings. In addition, for utility grid support applications, submersible electrical cables are needed to transmit the generated power onto land where they can be interconnected to the grid. The devices can be placed in such a way that they have little visible impact (>2 miles offshore) and can actually provide homes for many aquatic creatures, similar to an artificial reef. [4]

1.1.5 Selection of Wave Height

The Sea State Code is scaled from 0 – 9 whereas the Beaufort Wind Code and Wave Height are scaled from 0 – 12. Therefore it is confusing to match the wave height to the sea state code. As we are interested in wind-induced waves, it is appropriate to correspond the wave heights to the Beaufort wind scale, instead of corresponding it to the sea state code. For many applications of wave research, it is necessary to choose a single wave height which characterizes a particular sea state. The one used most is the significant wave height $H_{1/3}$, which is the average height of the highest one third of all waves occurring in a particular time period.

As wind speed increases, so $H_{1/3}$ in the fully developed sea increases. The relationship between sea state, $H_{1/3}$ and wind speed is expressed best by the Beaufort scale. The Beaufort scale can be used to estimate wind speed at sea, but is valid only for waves generated within the local weather system, and assumes that there has been sufficient time for a fully developed sea to have become established. The recommended addition to the present Beaufort Wind Scale is shown at Table 1.1. The comparison between Beaufort and Sea State Code is shown in Table 1.2. [5]

Table 1.1 : Recommended Addition to Beaufort Scale

Beaufort Scale	Wave Height (m)
0	0
1	0.1 – 0.3
2	0.3 – 0.5
3	0.6 – 1.0
4	1.5
5	2.0
6	3.5
7	5.0
8	7.5
9	9.5
10	12.0
11	15.0
12	> 15

Source : www.hydro.gov.my

Table 1.2 : Comparison between Beaufort Scale and Sea State Code

Beaufort Scale Code		Sea State Code	
Scale	Wave Height (m)	Scale	Wave Height (m)
0	0	0	0
1	0.1 – 0.3	1	0 – 0.1
2	0.3 – 0.5	2	0.1 – 0.5
3	0.6 – 1.0	3	0.5 – 1.25
4	1.5	4	1.25 – 2.5
5	2.0	5	2.5 – 4
6	3.5	6	4 – 6
7	5.0	7	6 – 9
8	7.5	8	9 – 14
9	9.5	9	> 14
10	12.0		
11	15.0		
12	> 15		

Source : www.hydro.gov.my

1.2 PROBLEM STATEMENT

Ocean wave energy is captured directly from surface waves or from pressure fluctuations below the surface. Waves are caused by the wind blowing over the surface of the ocean. In many areas of the world, the wind blows with enough consistency and force to provide continuous waves. There is tremendous energy in the ocean waves. Wave power devices extract energy directly from the surface motion of ocean waves or from pressure fluctuations below the surface. [2]

The problem is that it's not easy to harness this energy and convert it into electricity in large amounts. Thus, wave power stations are rare. This project attempts to capture the energy from wave and convert it into electricity.

1.3 OBJECTIVES

- To design and build a small scale linear generator powered by ocean wave energy
- To generate electricity using wave energy.

1.4 SCOPE OF STUDY

- Finding information and knowledge related to the topic.
- Take initiative to develop skill and knowledge through enquiry and literature review.
- Clerical and documentation works.
- Attend weekly meeting with supervisor.
- Lab work in assemble component.
- Prepare report to the supervisor.

1.5 THE RELEVANCY OF THE PROJECT

This project is relevance since Malaysia's geographical is surrounding by the ocean. Thus, the source of energy is always available.



Figure 1.2 : Malaysia's Geographical

[Source: www.solarnavigator.net/geography]

1.6 FEASIBILITY OF THE PROJECT WITHIN THE SCOPE AND TIME FRAME

This project is feasible since planning had been done to be suitable within the time given. This project is divided into two parts since the time given is two semester. For first semester, the project only focuses on designing the linear generator and calculation of data to choose suitable components. For the second semester, the project will focuses on the experiment of linear generator using wave tank. Following to what had been planned; this project is expected to be successful.

CHAPTER 2 : LITERATURE REVIEW

2.1 CURRENT TECHNOLOGY

There are three types of wave energy collector. These are:

- Hinged Contour Device
- Buoyant Moored Device
- Oscillating Water Column

2.1.1 Hinged Contour Device

This type of device follows the motion of the waves; it creates power using the motion at the joints. It is commonly moored slackly to hold it in place. One example of this type of device is the Pelamis WEC that is being developed by Ocean Power Delivery.

As the Pelamis moves with the waves, the motion is resisted at the joints by hydraulic rams that pump high-pressure oil through hydraulic motors via smoothing accumulators. These motors are used to drive generators to create power. It has been said that a 750kW device would be 150m long and 3.5m in diameter and comprise five sections.

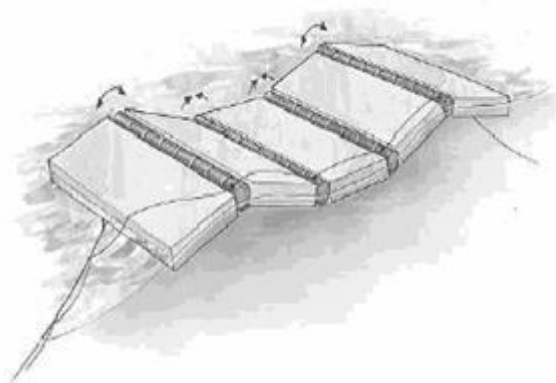


Figure 2.1 : Pelamis

Source : www.esru.strath.ac.uk

2.1.2 Buoyant Moored Device

This type of device floats on the surface of the water or below it. It is moored to the seabed by either a taut or loose mooring system. One example of this type of device will be discussed, the Edinburgh or Salter Duck. The Duck team is led by Professor Salter at Edinburgh University.

The Duck is shown in the figure below. Ducks work by independently rotating about a long linkage; this maintains its stability by out spanning wave crests. The front edge of the duck matches the wave particle motion. In moderate seas, the more cylindrical back portion creates no stern waves but when the weather is bad these parts shed energy through wave making to the rear. The device requires a depth of at least 80 metres and uses a system of weights and floats to give almost constant tension in the mooring cables.

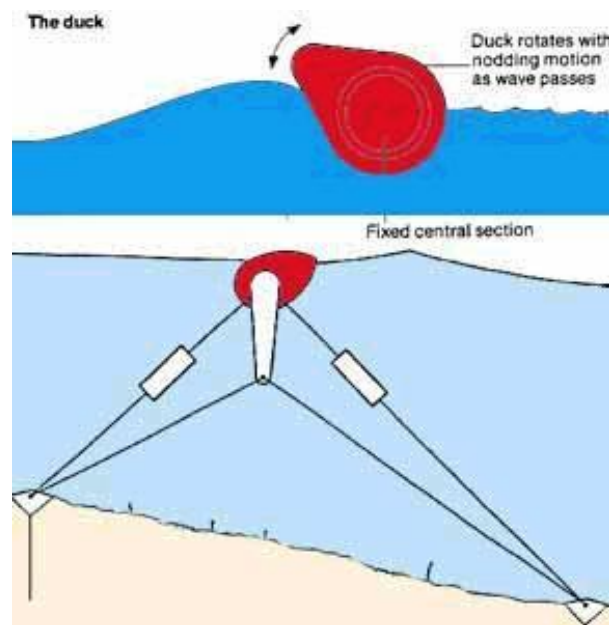


Figure 2.2 : The Duck

Source : www.esru.strath.ac.uk

2.1.3 Oscillating Water Column (OWC)

This method generates power from the tide works by using a column of water as a piston to pump air and drive a turbine to generate power. This type of device can be fixed to the seabed or installed on shore.

In Scotland, the Government awarded three wave energy projects under the Scottish Renewables Obligation. Only one of these projects has been realised and is generating power in Scotland as this pack is being written, this is the LIMPET 500 on the Island of Islay of the west coast, enabling the Island to take a step towards becoming self sufficient in renewable energy. [9]

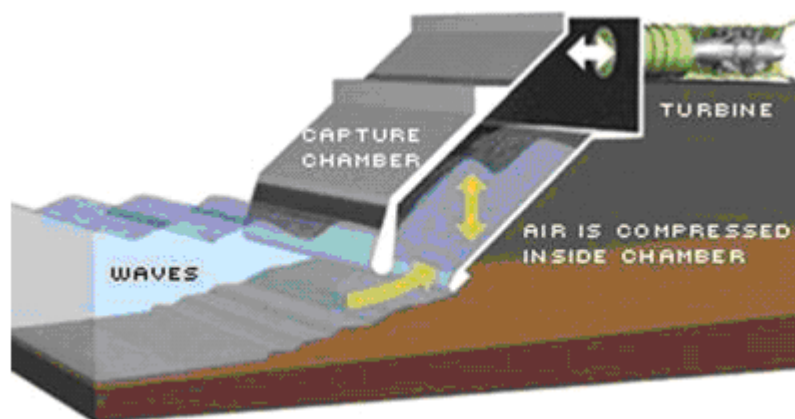


Figure 2.3 : How the LIMPET 500 works

Source : www.esru.strath.ac.uk

2.2 OFFSHORE DEVICES FOR ENERGY CONVERSION METHOD

2.2.1 The McCabe Wave Pump

This device consists of three narrow (4 m wide) rectangular steel pontoons, which are hinged together across their beam. These pontoons are aligned so that their longitudinal direction heads into the incoming waves and they can move relative to each other in the waves. The essential aspect of the scheme is the damper plate attached to the central pontoon; this increases the inertia of the central pontoon (by effectively adding mass), ensuring that it stays relative still. Therefore, the fore and aft pontoons move in relation to the central pontoon by pitching about the hinges. Energy is extracted from the rotation about the hinge points by linear hydraulic rams mounted between the central and two outer pontoons near the hinges. Control of the characteristics of the hydraulic system allows the device to be tuned to the prevailing sea state and so optimise energy capture. This energy can be used in two ways:

- to provide electricity by driving an hydraulic motor attached to a generator, with a rating of ~ 400 kW
- to produce portable water by supplying pressurised sea water to a reverse osmosis plant.

A 40 m long prototype of this device was deployed off the coast of Kilbaha, County Clare, Ireland and a commercial demonstration scheme is currently being built.

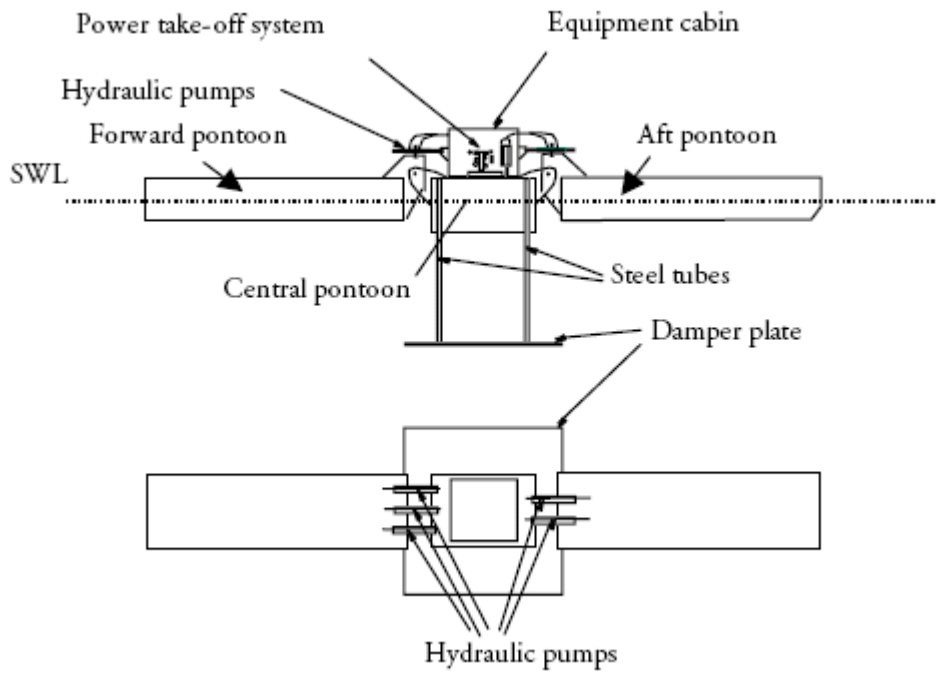


Figure 2.4 : The McCabe Wave Pump

Source : www.wave-energy.net

2.2.2 The OPT WEC

The Wave Energy Converter developed by Ocean Power Technology (OPT WEC) in the USA consists of a simple and ingenious mechanical system to drive the generators using mechanical force developed by the wave energy converter. It has very efficient power conversion electronics to optimize the generated electricity. The generators and electronics are housed in a watertight compartment, in marine proven ocean-going buoys. The system employs standard marine grade power cabling and grid connection hardware and software, and a combination of mooring chains and anchors are used for positioning.

Underwater hubs and electrical power cables are used for interconnection and transmission to the shore. The OPT system has been extensively tested at a large scale in the Eastern Atlantic and the first commercial schemes are about to be built in Australia and in the Pacific, with a number of other schemes in the pipeline.

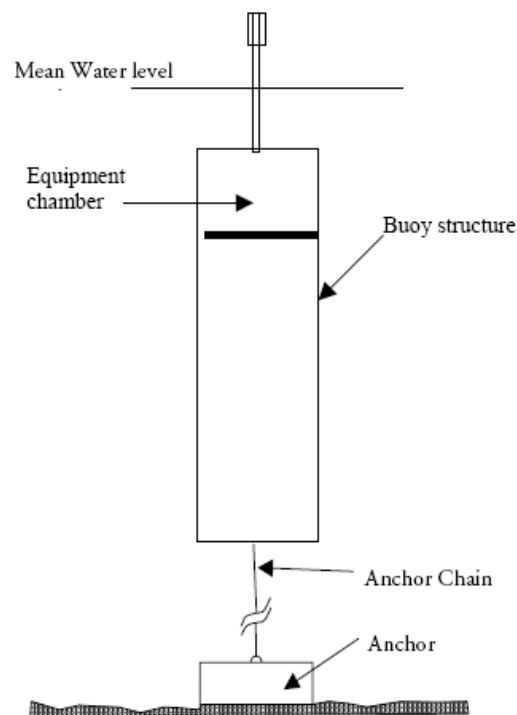


Figure 2.5 : The OPT WEC

Source : www.wave-energy.net

2.2.3 The Pelamis

The Pelamis device is a semi-submerged, articulated structure composed of cylindrical sections linked by hinged joints. The wave induced motion of these joints is resisted by hydraulic rams which pump high pressure oil through hydraulic motors via smoothing accumulators. The hydraulic motors drive electrical generators to produce electricity. A novel joint configuration is used to induce a tunable, cross-coupled resonant response, which greatly increases power capture in small seas and control of the restraint applied to the joints allows tuning to the particular sea state. A device is being developed for SRO3, which is rated at 375kW and is 130 m long and 3.5 m in diameter.

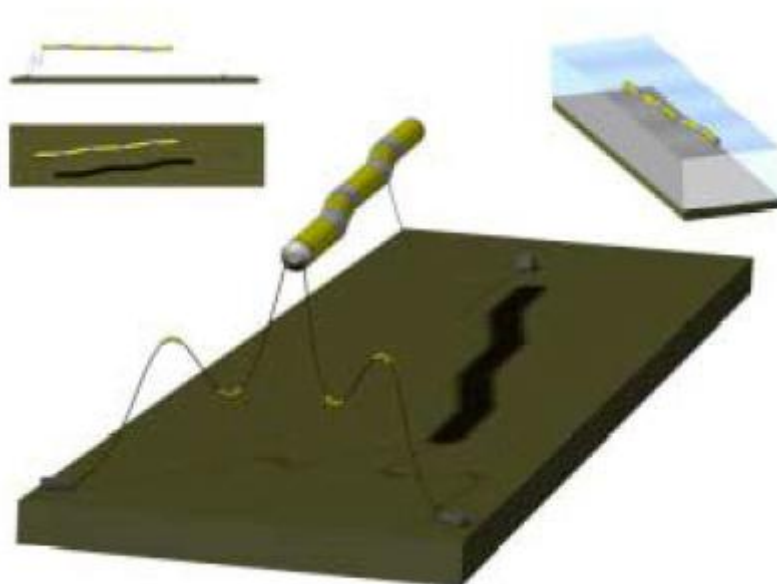


Figure 2.6 : The Pelamis

Source : www.wave-energy.net

2.2.4 The Archimedes Wave Swing

This consists of a cylindrical, air filled chamber (the "Floater"), which can move vertically with respect to the cylindrical "Basement", which is fixed to the sea bed. The air within the 10m – 20m diameter Floater ensures buoyancy. However, a wave passing over the top of the device alternatively pressurizes and depressurizes the air within the Floater, changing this buoyancy. This causes the Floater to move up and down with respect to the Basement and it is this relative motion that is used to produce energy. The design for a 2 MW Pilot scheme is currently being finalized. [7]

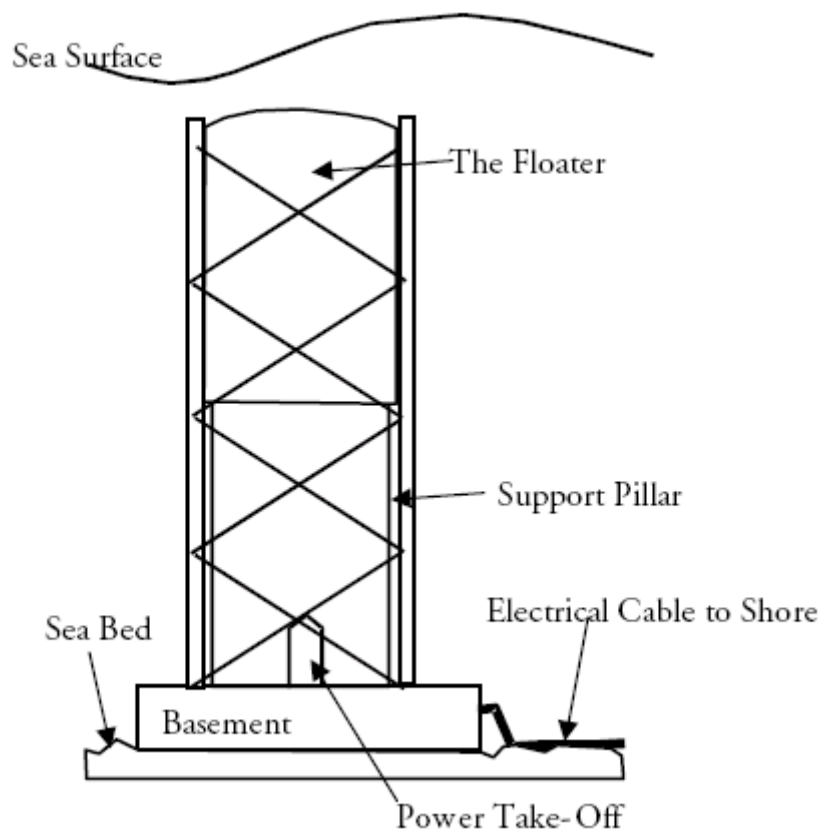


Figure 2.7 : The Archimedes Wave Swing

Source : www.wave-energy.net

2.2.5 Linear Generator

Linear generator has a number of significant advantages over hydraulic cylinders as a means of capturing sea energy. Traditional devices use floatation chambers to drive hydraulic cylinders, which in turn drive hydraulic rotary engines, and in turn, rotary generators. In the case of a linear generator, electrical power is generated simply by the forced relative movement of its generator relative to its armature. Thus, by coupling a linear generator to a sea wave displaced float, wave energy is converted directly to electricity as there is no need for any intermediary mechanism, and there are no internal moving components.

The use of patented linear generator for this purpose has been demonstrated by Direct Thrust Designs Ltd during summer of 1999. The test took place in-shore off the North Devon Coast. A robust test rig was built by the company's engineers for this purpose which comprised a rigid wooden/steel framework placed upon the sea bed. This supported the (fixed) stator of the linear generator, while an annular float, rising and falling with the waves, was used to move the generator vertically up and down the stator of the generator.

In the equipment orientation, the fixed stator of the generator comprises a stainless steel tube, supported by the wooden/steel framework. The tube contains a special series of magnetic components for producing a series of radial magnetic fields along its length. The armature of the generator comprises a cylindrical housing containing the armature coils. The housing is equipped with bearings at each end, for guiding it co-axially along the stator, and is mounted within the centre of the annular float. As is self evident, the force arising from the buoyancy of the float as a wave approaches causes generator assembly to travel up the stator, and so generate electricity. As the wave falls away, gravity causes the combination to fall. Thus electrical power is generated both on the up and down strokes. [7]

Citation:

"In the permanent magnet linear generator, an electric coil surrounds a magnetic shaft, and while coil is secured directly to the buoy. When waves cause the coil to move up and down relative to the fixed magnetic shaft, voltage is induced and electricity is generated. Each linear generator could potentially produce 250 kilowatts of power, and the technology can be scaled up or down to suit a variety of energy needs. A fleet of about 200 such buoys could power the business district of downtown Portland."

(PhysOrg (<http://www.physorg.com>.) [3]

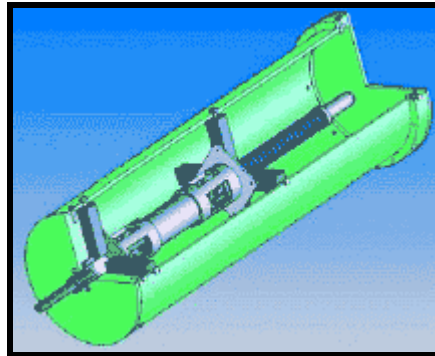


Figure 2.8: Permanent Magnet Linear Generator

[Source: www.physorg.com]

2.3 WAVE POWER ACTIVITIES IN THE ASIA-PACIFIC REGION

The Pacific-facing coastline of Asia has a more modest wave exposure than that of the west coast of Americas, e.g. 10 to 15 kW per metre of wave crest length off the coast Japan. Nevertheless, there is a significant level of wave energy conversion activity, due in part to the large population with many potential customers, including island nations such as Indonesia, Philippines and Sri Lanka.

Japan, a pioneering nation in the wave energy conversion field, has the largest program. Its work dates back to the 1960s with innovative research on navigation buoys, and continues today with several operating plants producing electrical energy. Most recently in Japan, a floating oscillating water column device has been constructed and deployed with the dual purpose of producing electricity and providing shelter. China and India, whose ongoing research programs in the wave energy conversion field started in the 1980s, each have one operational plant. South Korea is involved in several projects, including a combined wave-wind power generation device. Among other countries, Russia has several institutes with research and development programs in the field, Indonesia is involved in research and planning initiatives, and the Philippines has had a survey of its wave energy resource undertaken.

2.2.1 Indonesia

On the basis of operating experience at the Toftestallen, Norway, tapered channel plant, plans were finalized for a commercial 1.1 MW plant at Java, Indonesia (Tjugen 1996). However, preparatory construction work at the site was discontinued after the Indonesian financial crisis of 1997 (Anderssen 1999).

As of 2001, research on an oscillating water column device involving model tests in a wave tank was underway in a joint project between Gajah Mada University, Jogjakarta and the Sepuluh Nopember Institute of Technology, Surabaya (ITS) (Suroso 2001).

Also in Indonesia, the government has designated the Baron coastal area of Jogjakarta as an alternative energy park for various forms of renewable energy, including wind power and wave power. One of the research projects involves a combined wave/wind-powered device.

2.2.2 Philippines

An investigation of the wave energy resource of this country was undertaken in 1996. It was executed by the Norwegian company OCEANOR for the Philippines Department of Energy, with funding from the United Nations Development Program (OCEANOR 2002). The primary objectives of the project were to assess and establish the potential of wave energy for power generation in this country, and to determine the technology viability, economic feasibility and environmental desirability of the utilization of this energy source. [6]

2.4 PREVIOUS TECHNOLOGY ON LINEAR GENERATOR

2.4.1 Oregon State University

The energy from the same ocean waves that push surfers to shore can be harnessed to power light bulbs.

In fact, researchers believe that by harnessing just 0.2 percent of the ocean's power that could be enough to power light bulbs around the world. Engineers at Oregon State University have taken the first steps towards generating power from waves. They have built a buoy system capable of capturing the ocean's power in the form of offshore swells, and converting it into electricity. One system bobs two miles offshore and is called the permanent magnet linear generator buoy.

Inside the buoy, an electric coil wraps around a magnetic shaft, which is attached to the sea floor. The coil is secured to the buoy, and it bobs up and down with the swells while the shaft stays in a fixed place. This movement generates electricity.

Each buoy could potentially produce 250 kilowatts of power, according to researchers, and the technology could be scaled up or down to suit the needs of the people on shore. Researchers estimate it would only take about 200 of these buoys to provide enough electricity to run the business district of downtown Portland.

Wave power is 15 to 20 years behind other clean energies, like wind and solar power. However, it is more predictable, available and energy-dense than wind. [4]

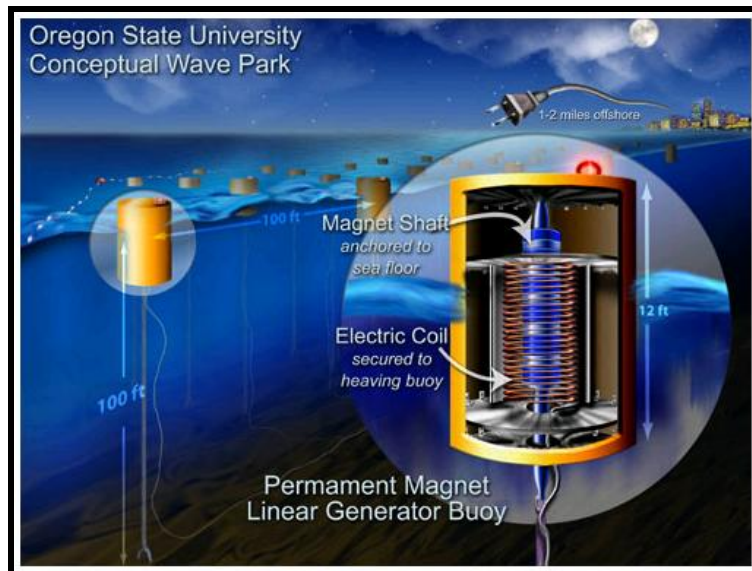


Figure 2.9 : Permanent Magnet Linear Generator Buoy

Source : www.sciencedirect.com

Parametric Dimensions of Generator

Table 2.1 : Parametric Dimensions of Generator

Total thickness of magnet pair	0.02 m
Magnet external diameter	0.045 m
Magnet internal diameter	0.020 m
Steel spacer thickness	0.02 m
Total translator length	0.32 m
Number of stator poles	4
Height of coil section	0.02 m
Radial width of coil section	0.006 m
Air gap clearance	0.0006 m

Electrical Parameters of the Generator

- Rated voltage 25 V
- Rated current 3 A
- Rated power output 50 W
- Number of phases 2

Wave Tank Tests

Table 2.2 : Wave Tank Test Result

Load (ohm)	Wave height (m)	Wave period (s)	Peak voltage (V)	Peak current (A)	Peak power (W)
5	1.37	3	20	1.4	25
2	1.37	3	16	1.6	18
10	1.37	3	19	1.2	12
5	0.98	3	12	0.6	6
5	1.21	3	10	0.5	5
5	0.66	3	9	0.5	5
2	0.98	3	6	0.7	4
5	0.98	2	10	0.5	3.6
2	0.82	6	2.4	0.1	0.2
10	0.98	3	20	0	0
No load	0.98	3	20	0	0

2.5 MATHEMATICAL MODEL OF THE GENERATOR

2.5.1 Basic Equations

To get reasonable computational times, a two-dimensional time-dependent model has been developed. The magnetic field inside the generator is, apart from a negligibly small component, restricted to a plane perpendicular to the direction of the currents in the stator. Coordinates x , y , and z can be introduced in each sector of the generator, with the z coordinate along the current direction. The magnetic field is in the xy plane, with the strongest component along y at the pole surface. This justifies a planar magnetic-field model with

$$\mathbf{B} = \nabla A(x, y, t) \times \hat{\mathbf{z}} \quad (1)$$

in each sector of the generator. The contributions from all sectors should be added to get the total power output.

A noteworthy feature in two dimensions is that the magnetic flux lines are closed, as can be seen from (1).

In a full three-dimensional analysis, the B field lines would not be closed typically.

The magnetic field is described by Maxwell's equations

$$\nabla \times \mathbf{H} = \mathbf{j}_f \quad (2)$$

$$\nabla \times \mathbf{E} = - \frac{\partial \mathbf{B}}{\partial t} \quad (3)$$

The velocity of the permanent magnets at the moving piston gives a time-dependent magnetic field.

A magnetic-dipole moment density \mathbf{M} is related to the B-field by

$$\mathbf{B} = \mu \mathbf{H} = \mu_0 (\mathbf{H} + \mathbf{M}) \quad (4)$$

and

$$\mathbf{J}_m = \nabla \times \mathbf{M}$$

is the magnetization current density. There is a volume distribution of ohmic and nonlinear magnetization currents in the stator steel, and hysteresis effects are included. Surface-magnetization currents model the permanent magnets by the jump condition

$$\mathbf{J}_{m,s} = \{\mathbf{n} \times \mathbf{M}\} \quad (5)$$

at the permanent magnet surfaces.

By substituting Ohm's law, i.e.,

$$\mathbf{j}_f = \sigma \mathbf{E} \quad (6)$$

and

$$\mathbf{E} = -\frac{\partial \mathbf{A}}{\partial t} - \nabla U \quad (7)$$

into the z component of Ampere's law, an equation for the flux function A is obtained

$$\nabla^2 A - \sigma \mu_0 \mu_r \frac{\partial A}{\partial t} = \frac{\nabla \mu \cdot \nabla A}{\mu} + \sigma \mu_0 \mu_r \frac{dU}{dz} \quad (8)$$

where U is the applied potential. The time derivative in (8) corresponds to the skin effect that gives a finite scale length for the diffusive penetration of the electromagnetic field. The local resistive scale length is sensitively dependent on the conductivity of the material,

$$L_{\text{skin}} \approx \sqrt{\frac{T_{\text{wave}}}{N}} \frac{1}{\sigma \mu_0 \mu_r} \quad (9)$$

and the characteristic electromagnetic timescale is, in our case, due to the "electromagnetic gear box," the wave period T_{wave} divided by the number of poles N .

The thermal load is derived from Fick's law and the continuity equation for heat

$$k \nabla^2 T - \frac{\partial T}{\partial t} = -J_{\text{heat}} \quad (10)$$

where k is the diffusivity and J_{heat} is the heat source originating from ohmic currents, magnetic losses, and external cooling. The magnetization curve (the B-H curve) for the specific materials chosen, and the appropriate initial, boundary, and jump conditions should be added to the system of field equations. Water cooling of the generator can be included, but is not required in the sea-wave application, since the surrounding seawater is expected to provide sufficient cooling.

2.5.2 Additional Equations

Models for the electric circuit and the piston motion are added to the electromagnetic- and thermal-field equations. The equations describing the stator (armature) circuit are

$$\begin{aligned}
 i_a + i_b + i_c &= 0 \\
 u_a + R_s \cdot i_a + L_s^{\text{end}} \cdot \frac{\partial i_a}{\partial t} - u_b - R_s \cdot i_b - L_s^{\text{end}} \cdot \frac{\partial i_b}{\partial t} &= V_{ab} \\
 u_c + R_s \cdot i_c + L_s^{\text{end}} \cdot \frac{\partial i_c}{\partial t} - u_b - R_s \cdot i_b - L_s^{\text{end}} \cdot \frac{\partial i_b}{\partial t} &= V_{cb}
 \end{aligned} \tag{11}$$

where u_a, u_b are the phase voltages, i_a, i_b are the phase currents, L_s^{end} is the coil-end reactance (obtained from an separate three-dimensional computation), and V_{ab}, V_{cb} are the line voltages of the external-load circuit. The external load may be determined in more detail by, for instance, including equations for rectifiers, transformers, etc. A resistive load is simulated here.

The internal (phase currents, phase voltages, rotor and stator equations) and the external (outer load) circuit equations are added to the system. Sources are described by circuit equations.

A symmetric three-phase winding of the stator is modeled. The phases are mutually separated by $2\pi/3$ electrical radians. The main advantage of a symmetric three-phase system is that the output power is only slowly varying with time, provided a proper design is made for the generator.

2.5.3 Piston Motion

For a propagation harmonic wave on deep water, half of the energy in the wave is gravitational potential energy, and the other half is kinetic. The transported time-averaged gravitational wave power P_g per unit width L of the sinusoidal wave front is

$$\frac{dP_g}{dL} = k T_{\text{wave}} h^2, \quad k = 976 \text{ W} \cdot \text{m}^{-3} \cdot \text{s}^{-1} \tag{12}$$

where $1/T_{\text{wave}}$ is the frequency, and the height h of the wave is twice the amplitude

$$h = 2 \cdot w_a. \tag{13}$$

The coefficient for more realistic ocean waves is $k = 500 \text{ W m}^{-3} \text{ s}^{-1}$.

In deep water

$$D > \frac{L_{\text{wave}}}{2} \quad (14)$$

where D is the water depth, and the wavelength and the wave period are related by

$$L_{\text{wave}} = \frac{gT_{\text{wave}}^2}{2\pi}. \quad (15)$$

The gravitational potential energy gives a lift force to the buoy. If the buoy is small compared to the wave dimensions, it can be modeled as a point source with respect to its influence on the surrounding water. A finite dimension of the buoy is required to get a force corresponding to the Archimedes lift force. The buoy force drives a piston in the linear generator. The piston motion is modeled by the equation of motion

$$m \frac{d^2x}{dt^2} = F_{\text{buoy}} + F_{\text{em}} + F_{\text{spring}} + F_{\text{stop}} + F_{\text{g}} \quad (16)$$

where x is the vertical position of the moving piston. The force equation only involves the vertical direction. The horizontal forces can influence the buoy motion and the tension in the rope if the generator is placed at large depths, which may lead to appreciable corrections, but these effects are not included in the present model. The force is a sum of the Archimedes lift force on the buoy, the inductive response of the generator, the mechanical-spring force, the end-stop force, and the gravity force. The mechanical-spring force is given by

$$F_{\text{spring}} = -F_0 + k_{\text{sp}} \cdot x \quad (17)$$

where k_{sp} is the material spring constant and F_0 is the static spring force. For simplicity, as a first approximation, the buoy force is modeled by the Archimedes lift force corresponding to the gravitational force of the water displaced by the buoy.

The model for the buoy force needs to be refined in future studies. For the sake of completeness, we here give details of the force equations used in this paper. The buoy is represented as a point absorber in the calculations. The force from the buoy is determined by the volume of displaced water from the equilibrium position of the buoy

$$\Delta V = (w - x)S_{\text{buoy}} \quad (18a)$$

where S_{buoy} is the area of the buoy, w is the wave height at the position of the buoy, x is the displacement of the piston from the equilibrium position, and $w - x$ is the relative vertical displacement of the wave surface and the piston.

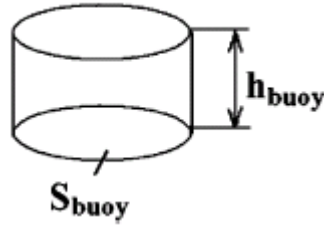


Figure 2.10 : Geometry of The Buoy

Equation (18a) is valid provided that part, and not all, of the buoy is under water. If the buoy is completely covered by water, the displaced water reaches the maximum value

$$\Delta V = \Delta V_{\max} = h_{\text{buoy}} S_{\text{buoy}} - \frac{m_b}{\rho_{\text{water}}} \quad (18b)$$

where m_b is mass of the buoy and ρ_{water} is the density of the displaced water. As is well known, the Archimedes lift force is equal to the gravitational force of the water displaced by the buoy. The buoy force does not operate on the piston with a slack rope, i.e., $w - x < 0$, and thus, the Archimedes force gives

$$F_{\text{buoy}} = \begin{cases} \rho_{\text{water}} g \Delta V, & w > x \\ 0, & w \leq x \end{cases} \quad (18c)$$

where g is gravitational acceleration. Finally, by summing the equations of motion for both the piston and the buoy, we note that the effective mass in the piston equation of motion is

$$m = \begin{cases} m_p + m_b, & F_{\text{buoy}} > 0 \\ m_p, & F_{\text{buoy}} < 0 \end{cases} \quad (18d)$$

where m_p is the piston mass. The buoy and piston masses should be added in the piston equation of motion if $F_{\text{buoy}} > 0$, since the accelerations of the buoy and the piston are the same in that case.

The end-stop force only operates if $|x|$ is sufficiently large

$$F_{\text{stop}} = k_{\text{stop}} R(x) \quad (19)$$

where k_{stop} is a strong end-stop spring constant, and $R(x)$ is active when the piston approaches the upper and lower ends of the stator. The end-stop force is added to protect the generator from damage at stormy weather.

The gravity force is expressed in a common way

$$F_g = -mg. \quad (20)$$

The electromagnetic force (EMF) can be calculated from the magnetic-field energy by

$$F_{em} \equiv \frac{d}{dx} \int \frac{\mathbf{B} \cdot \mathbf{H}}{2} dV \approx \frac{d}{dx} \int_{\text{airgap}} \frac{B^2}{2\mu_0} dV \quad (21)$$

where the last integration is over the air-gap volume. The force contributions from all sectors of the generator should be added. This EMF vanishes at the upper and lower turning points for the piston bouncing motion. As estimation, the EMF is proportional to the piston velocity v , since the induced voltage

$$U \sim \frac{d\Phi}{dt} \quad (22)$$

is proportional to the velocity, and

$$F_{em} = \frac{P}{v} \approx \frac{1}{v} \frac{U^2}{R} \sim Kv. \quad (23)$$

There is greater flexibility in adapting the EMF than mechanical spring forces to various wave conditions. As an example, the generator could be short-circuited when the piston reaches certain positions, and thereby, the generator can be protected at extreme weather conditions. [10]

CHAPTER 3 : METHODOLOGY

3.1 RESEARCH METHODOLOGY

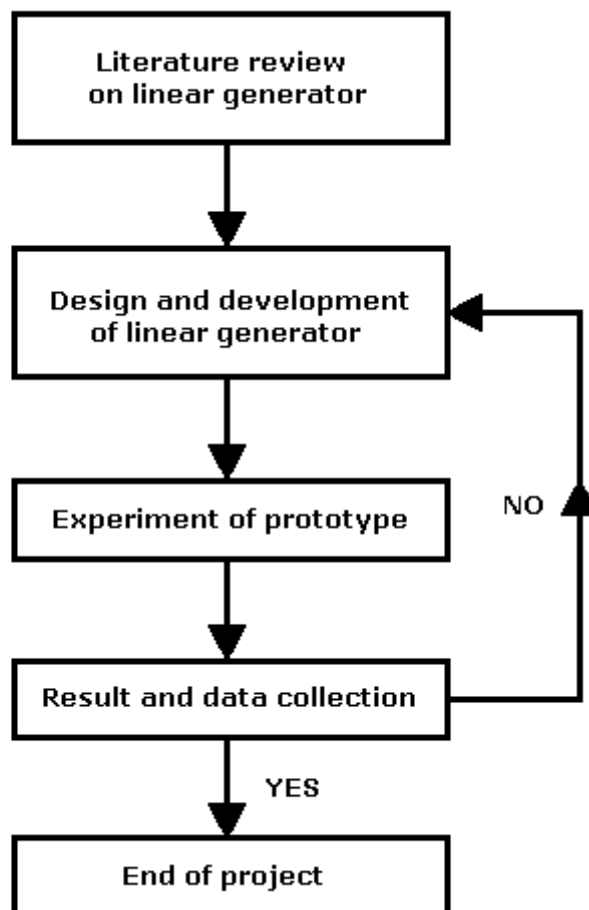


Figure 3.1 : Process Flow Chart

3.1.1 Literature review on linear generator.

A literature review is a body of text that aims to review the critical points of current knowledge on a particular topic.

Most often associated with science-oriented literature, such as a thesis, the literature review usually precedes a research proposal, methodology and results section. Its ultimate goal is to bring the reader up to date with current literature on a topic and forms the basis for another goal, such as the justification for future research in the area.

For this project, after the title selection was done, literature review process was conducted. Literature review is very essential in doing this project since all relevant information regarding this project was gathered and studied during this period. The internet is the biggest and easiest source of information. Nevertheless, some literatures were also gathered from books that can be found in the library.

3.1.2 Design and development of ocean wave linear generator.

The device consists of a linear generator with its armature, a floater and a spring. A steel framework is use to support the linear generator during the experiment. A spring is use as connection between the linear generator and the framework which functions to support the oscillating movement. Below the linear generator is a floater functions as a base to capture the movement of wave. As the linear generator oscillates up and down, it will cut the magnetic flux in the armature and generates electricity. The generated electricity was calculated by using voltmeter.

3.1.3 Experiment of prototype.

After the designing and development of prototype was done, it was tested in a wave energy tank. Several experiments had been conducted to ensure a good result. At this time, some modification had been done to get the expected result.

3.1.4 Result and data collection.

The results from all experiment was recorded and compared. The best result was chosen as the result of the project.

3.2 PROJECT ACTIVITIES

3.2.1 Change steel plate with paper

Description :

The magnet pack usually stuck at the steel plate in the stator when travelling up and down motion. To solve this problem, the steel plate in the stator is replaced with paper. After the changes, the magnet pack move up and down smoothly.

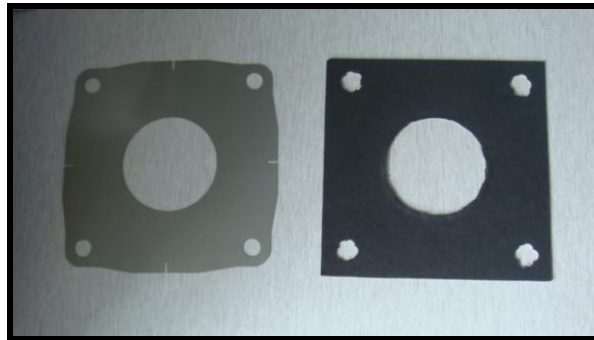


Figure 3.2 : Steel Plate --→ Paper Plate

3.2.2 Spring selection

Description :

To have a good up and down motion, a proper spring should be choose depend on its displacement and ability to sustain weight of the linear generator. For this project, several springs had been tested and only the best spring that give the best motion was selected for the experiment.

3.2.3 Preparation of steel framework

Description :

Steel framework functions as stand to hold the linear generator during the operation. The height of the framework is designed high enough to apply motion of the generator without reaching the water. Apart from that the steel framework must be stable and static.

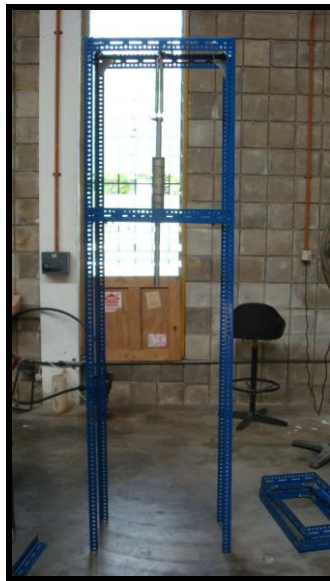


Figure 3.3 : Steel Framework

3.2.4 Research on wave energy tank

Description :

Wave energy tank is a tank that use wave generator to create waves for the experiment of linear generator. There is various frequency of wave that can be generated from the wave tank. So, the experiment is done with all the frequency to see the different of power generated.

3.2.5 Selection of generator electrical configuration

Description :

There are two possible configurations available for three phase connection which is delta and wye. The configuration used for this generator is wye connection. In wye connection, one of the leads of each winding is connected, and the remaining three leads are connected to an external load.

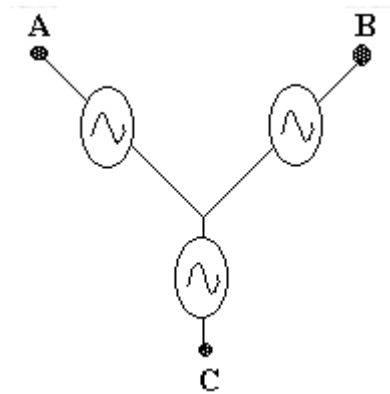


Figure 3.4 : Wye Connection

3.2.6 Experiment using Wave Energy Tank

Description :

An experiment had been conducted to test the generator. The experiment was done by using wave tank. Certain amount of wave frequency had been selected to see the output from the generator. Below are the pictures of the experiment :



Figure 3.5 : Experiment using Wave Energy Tank

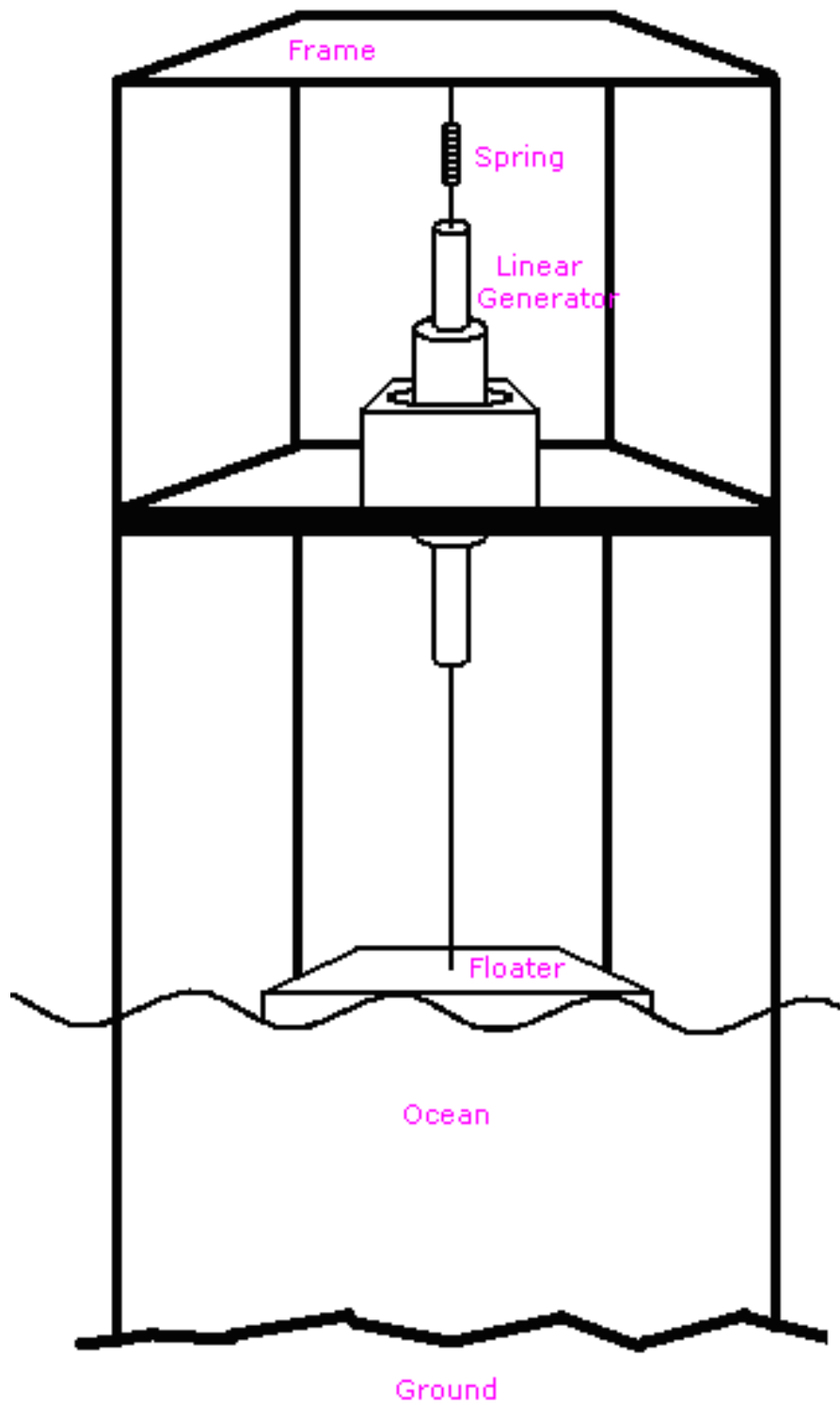


Figure 3.6: Schematic Assemble of Linear Generator

3.3 GANTT CHART

As included in the appendices [page 46-47]

3.4 TOOLS/EQUIPMENT

Tools/equipment required:

- i. Magnet pack and stator coil (armature)
- ii. Steel framework
- iii. Floater or wave energy device
- iv. Spring
- v. Wave energy tank
- vi. Transmission cable
- vii. Multimeter

3.4.1 Wave Energy Tank

Wave energy tank is a tank that used wave generator to create waves of various types. This accessory unit is used to help obtain information on the behaviour of waves in the offshore area as well as in coastal protection.

The rotational speed of the drive motor can be steplessly varied, corresponding to wave frequency. Furthermore, the stroke also can be steplessly adjusted, causing a change in the wave height (amplitude). So, the waves can be changed in frequency and amplitude. [8]

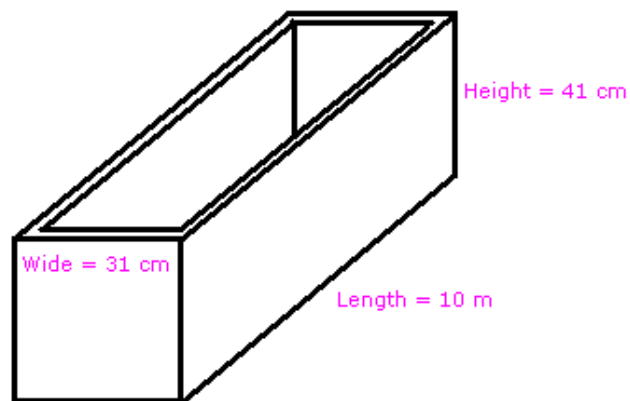


Figure 3.7 : Wave Energy Tank Dimension



Figure 3.8 : Wave Energy Tank

3.4.2 Spring

A spring is a flexible elastic object used to store mechanical energy. Springs are usually made out of hardened steel. In classical physics, a spring can be seen as a device that stores potential energy by straining the bonds between the atoms of an elastic material.

Hooke's law of elasticity states that the extension of an elastic rod (its distended length minus its relaxed length) is linearly proportional to its tension, the force used to stretch it. Similarly, the contraction (negative extension) is proportional to the compression (negative tension). These apply the equation:

$$F = kx$$

where x is the distance the spring is elongated by,
 F is the restoring force exerted by the spring, and
 k is the spring constant or force constant of the spring. [1]

From the data collected:

- Mass of magnet = 6 kg
- Length of spring before stretch = 28.5 cm
- Length of spring after stretch = 33 cm
- Force = mass x gravitational acceleration
= 6 kg (9.81 ms⁻²) = 58.86 N
- Spring displacement, $x = 4.5 \text{ cm} = 0.045 \text{ m}$
- Spring constant, $k = F/x = 58.86/0.045$
= 1308 kgs⁻²



Figure 3.9 : Spring

3.4.3 Generator Electrical Configuration

3.4.3.1 Three-Phase Connections

The winding for each phase has two output leads (for a total of six in a three-phase system). If we examine an actual three phase machine, we will see only three leads coming out. This is because they are connected inside the generator. The two possible configurations are delta and wye.

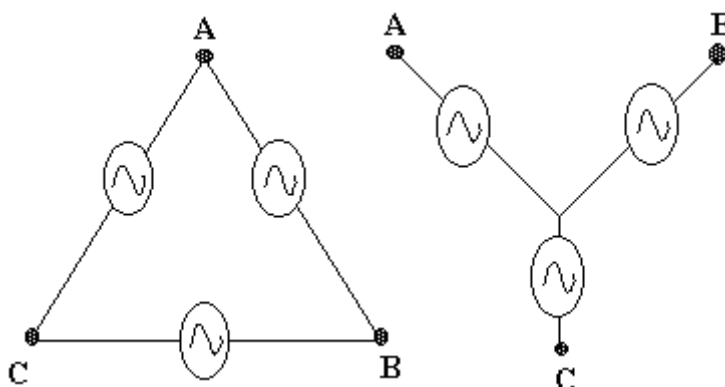


Figure 3.10 : Delta and Wye Connection

System nomenclature:

- Phase Voltage (E_{phase}) :
The induced potential across any single phase; measured inside the machine casing.
- Phase Current (I_{phase}) :
The current passing through any single phase; measured inside the machine casing.
- Line Voltage (E_{line}) :
The potential across any pair of wires (A-B, B-C, C-A); measured outside the machine casing.
- Line Current (I_{line}) :
The current passing through any one of the three output cables (A, B, or C); measured outside the machine casing.

For this project, we are using wye connection. The equations are:

$$E_{line} = E_{phase} \times \sqrt{3}$$
$$I_{line} = I_{phase}$$

3.4.3.2 Power in Three Phase System

$$AP = \sqrt{3} \times E_{line} \times I_{line}$$
$$TP = AP \times pf$$

where:

AP : Apparent Power

TP : Reactive Power

pf : Power Factor

[11]

CHAPTER 4 : RESULT AND DISCUSSION

This linear generator model is designed to generate at least 1 kW of electricity from ocean waves. Ocean wave has various characteristics but the power of it is obtained from equation:

$$\text{Formula: Power, } P = 0.5 H_s^2 T_e \quad \text{kW/m}$$

where : H_s expressed in meters
 T_e in seconds.

To build this model, various aspects need to be counted such as the spring selection for the linear generator to move up and down and linear generator components itself. In spring selection, the displacement of the spring must be obtained correctly in order to have constant movement while generating the electricity. So, the forced exerted by the linear generator should be counted correctly in order to select the best value of spring stiffness constant.

For the linear generator itself, the steel plate in the armature of the generator need to be change into paper plate. This is because the magnet pack usually stuck at the steel plate in the armature when travelling up and down motion. To solve this problem, the steel plate in the armature is replaced with paper but this changing is afraid may cause some reduce in efficiency of the power produce.

Furthermore, to obtain smooth movement of linear generator, the height of the framework must be adjust suitable to the length of the linear generator. Steel framework functions as stand to hold the linear generator during the operation. The height of the framework must be designed high enough to apply motion of the generator without reaching the water.

For generator circuit connections, there are two possible configurations to obtain three phase connection which are delta and wye. For this generator, we use wye connection because for a given amount of line voltage and line current, the wye generator has a larger current while a delta connected machine has a smaller phase current. Unfortunately, because of this more power is lost inside the generator in the form of heat for wye connection than delta connection. Beside that manufacturing and rewinding of a wye connected machine is easier due to the less complex connections of the windings. If one phase of a wye connected machine opens up, two of the three output voltages will go to zero volts. This occurrence does not allow a selection of which loads to remove. Two thirds of the loads on that generator will lose power.

After completed all of the requirements, the experiment of the project can be done in wave energy tank. Wave energy tank is a tank that use wave generator to create waves for the experiment of linear generator. Through this we will get the amount of power generated by the system.

4.1 Experiment using Wave Energy Tank

An experiment had been conducted to test the generator. Certain amount of wave frequency had been selected to see the output from the generator. The wave increment also had been measured for each wave frequency. Below is the results of the experiment :

Table 4.1 : Wave Increment for certain Wave Frequency

Wave Frequency [hz]	Wave Increment [cm]
0	0.0
10	2.5
20	4.0
30	7.0
40	12.0
50	13.5
60	15.0
70	9.0
80	7.0
90	5.5

Table 4.2 : Voltage for 1 Phase

Wave Frequency [hz]	Voltage [mV]		
	Minimum	Maximum	Average
30	9.73	27.50	13.20
40	9.66	44.19	14.73
50	11.92	36.07	21.12
60	11.90	54.16	27.20
70	15.5	33.8	21.66
80	10.69	18.78	13.20
90	10.00	18.78	11.63

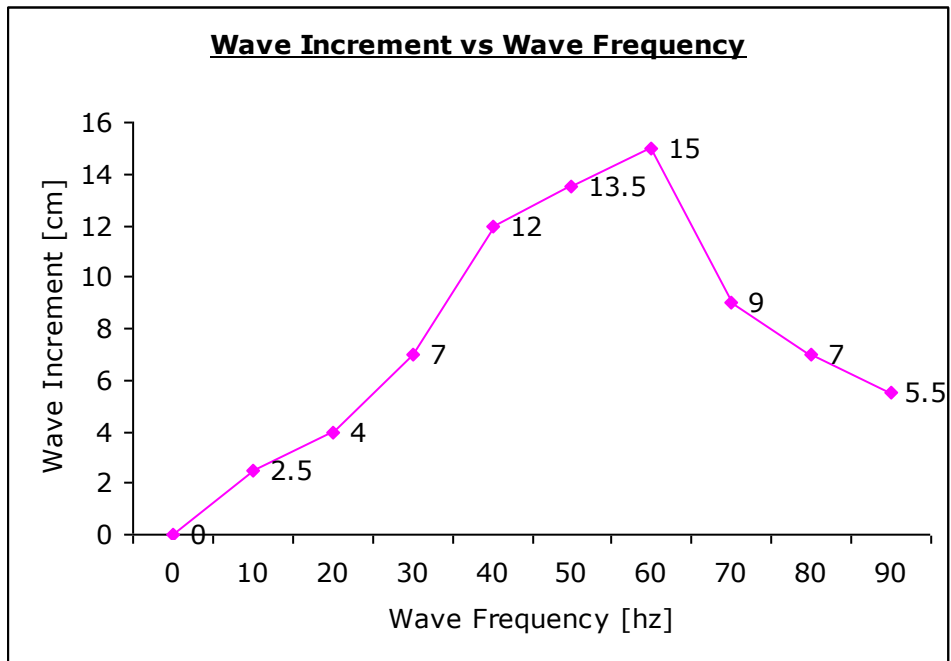
Table 4.3 : Voltage, Current and Power for 1 Phase

Wave Frequency [hz]	Average Voltage [mV]	Current [mA]	Power [10^{-6} W]
30	13.20	1.111	14.67
40	14.73	1.113	16.39
50	21.12	1.116	23.57
60	27.20	1.118	30.41
70	21.66	1.114	24.13
80	13.20	1.111	14.67
90	11.63	1.110	12.91

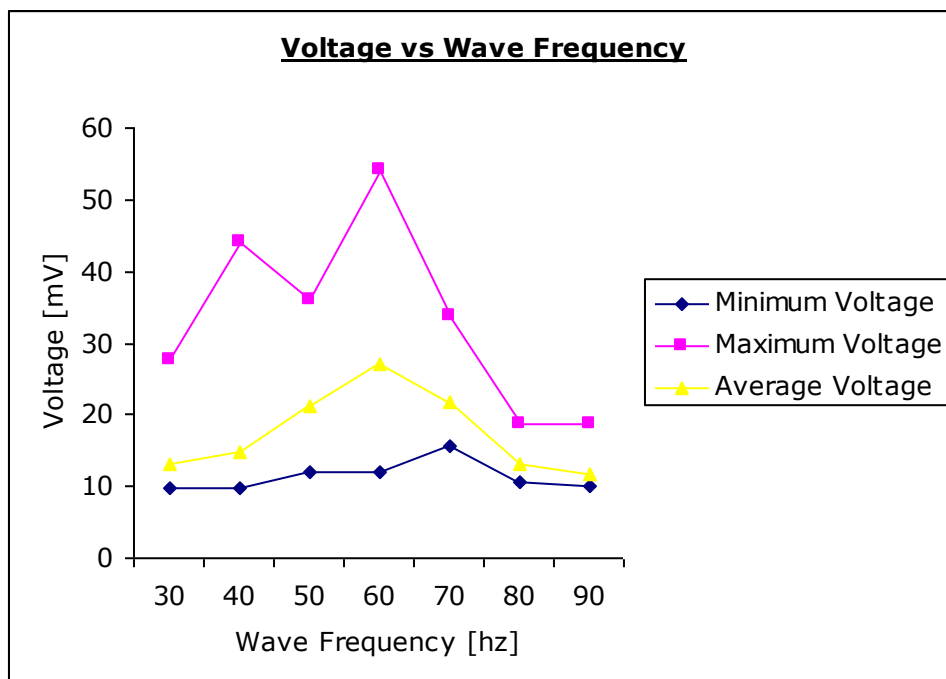
Table 4.4 : Total Power Generated by Generator

Wave Frequency [hz]	Total Power, $P_1+P_2+P_3$ [10^{-6} W]
30	44.01
40	49.17
50	70.71
60	91.23
70	72.39
80	44.01
90	38.73

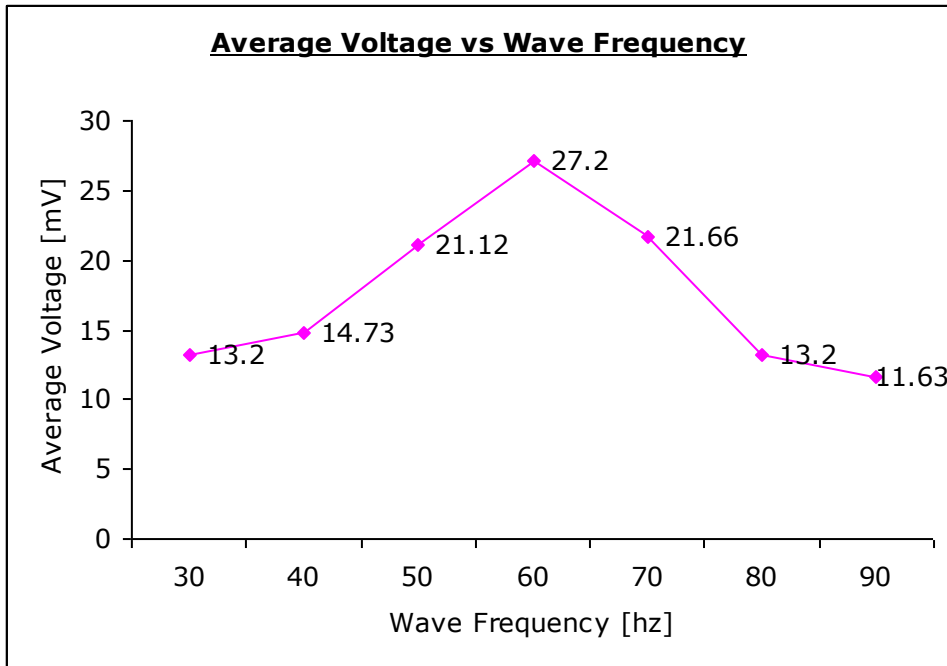
4.1.1 Graphs of the experiment



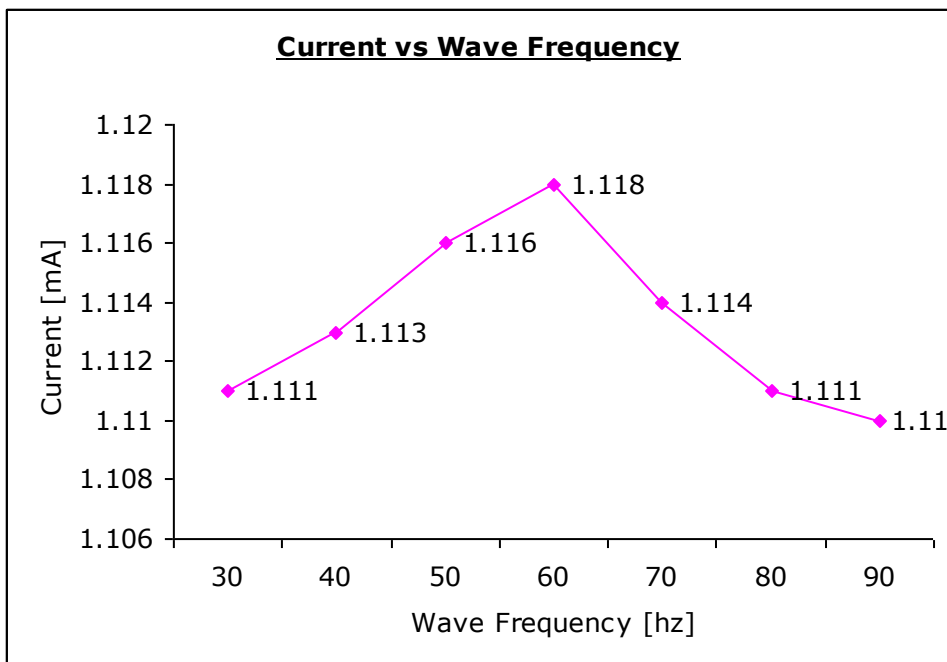
Graph 4.1 : Wave Increment vs Wave Frequency



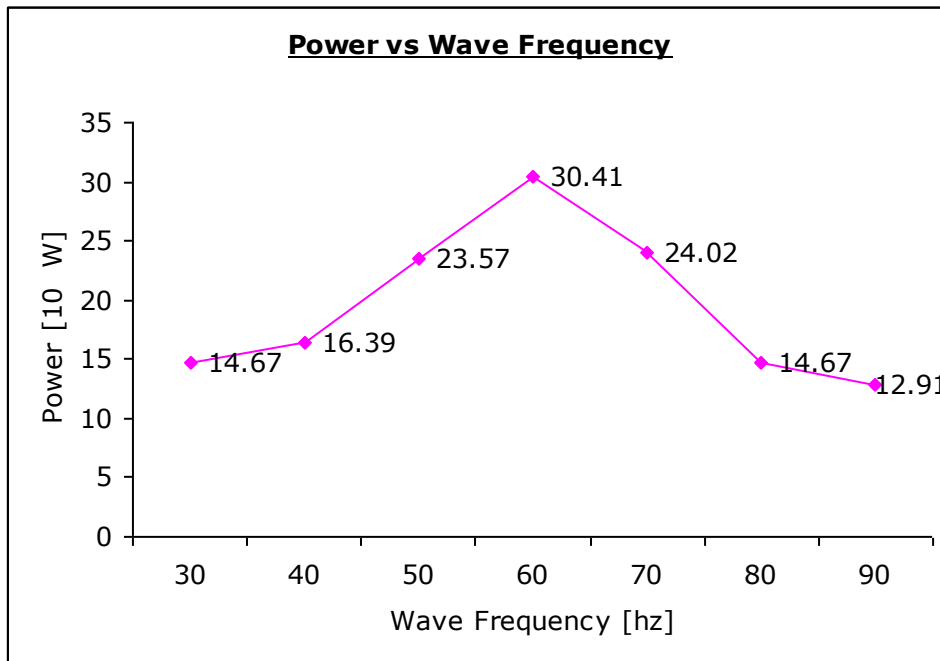
Graph 4.2 : Voltage vs Wave Frequency for 1 Phase



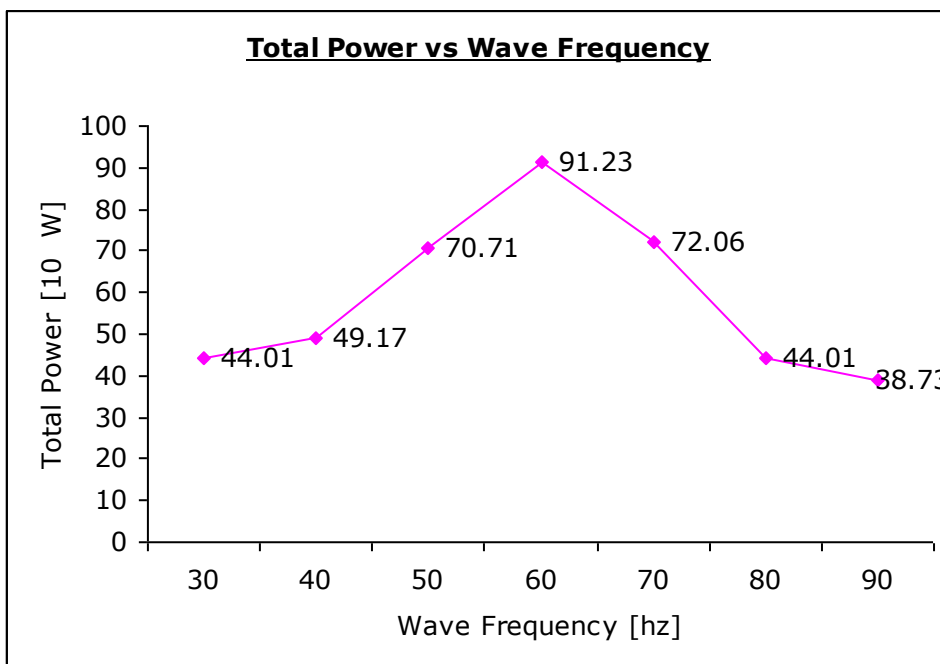
Graph 4.3 : Average Voltage vs Wave Frequency for 1 Phase



Graph 4.4 : Current vs Wave Frequency for 1 Phase



Graph 4.5 : Power vs Wave Frequency for 1 Phase



Graph 4.6 : Total Power vs Wave Frequency

4.1.2 Voltage Waveform

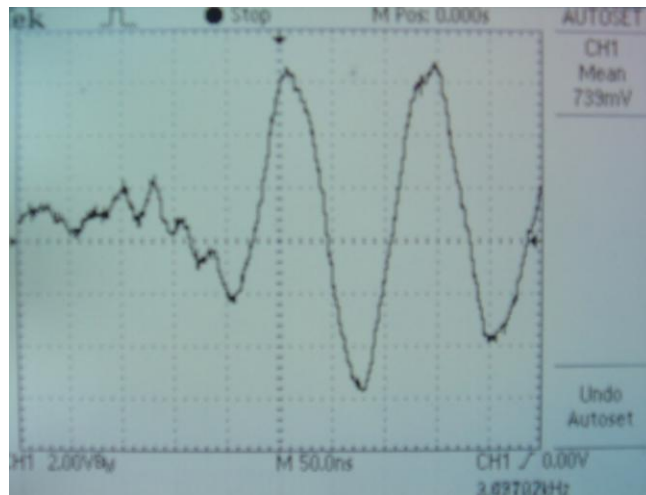


Figure 4.1 : 30 Hz Wave Frequency

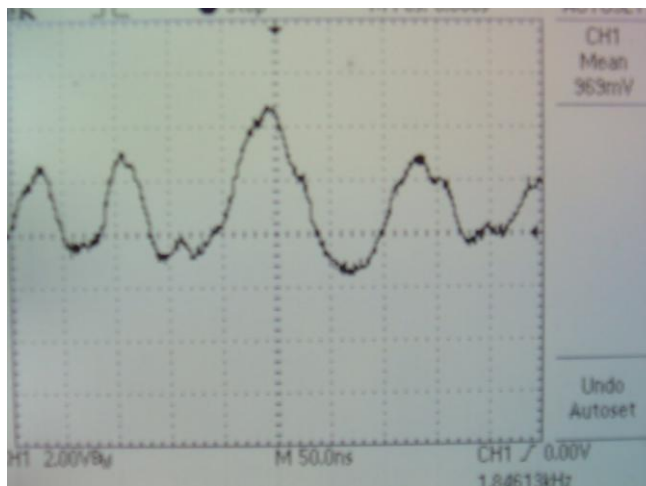


Figure 4.2 : 40 Hz Wave Frequency

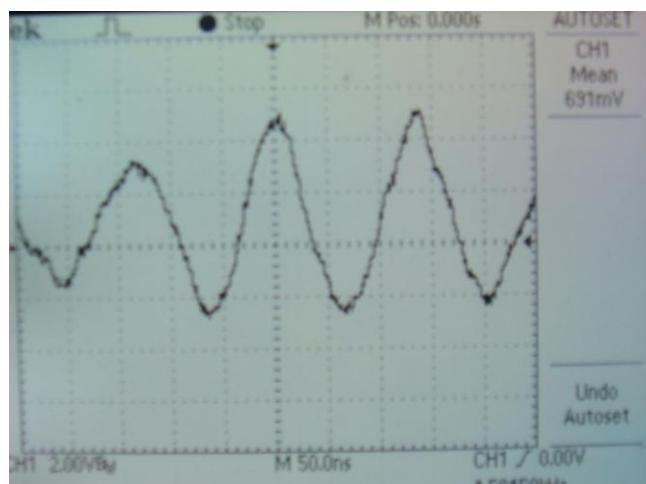


Figure 4.3 : 50 Hz Wave Frequency

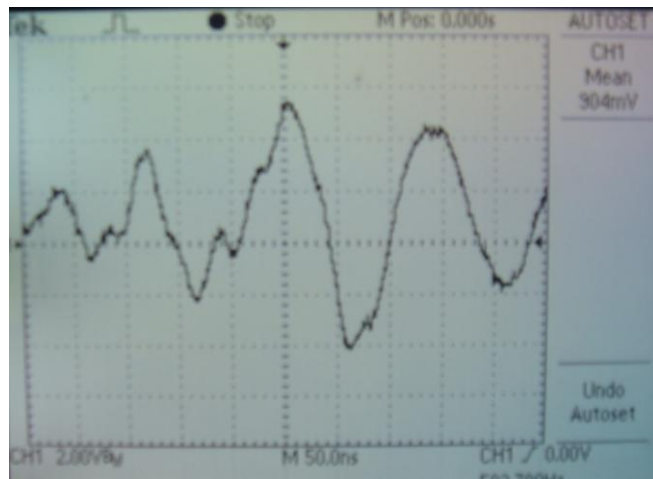


Figure 4.4 : 60 Hz Wave Frequency

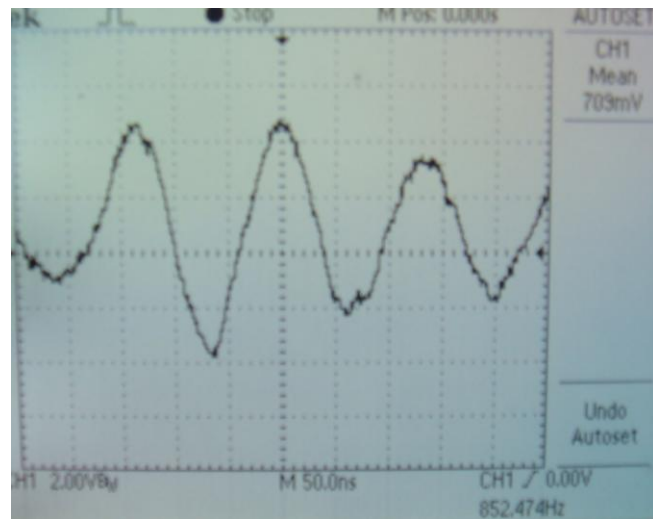


Figure 4.5 : 70 Hz Wave Frequency

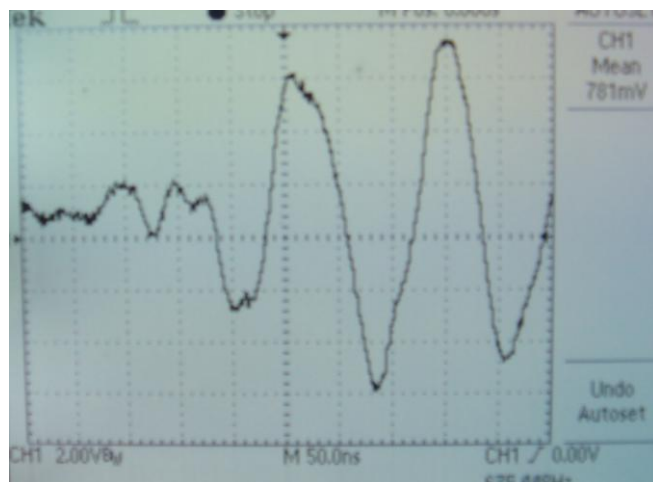


Figure 4.6 : 80 Hz Wave Frequency

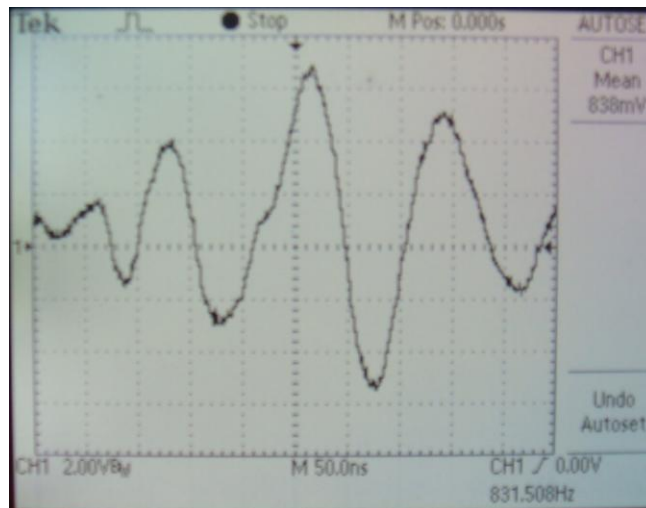


Figure 4.7 : 90 Hz Wave Frequency

From equation above,

$$\text{Power of wave, } P = 0.5 H_s^2 T_e$$

since frequency, $f = 1/ T_e$:

$$\text{Power of wave, } P = [0.5 H_s^2] / f$$

so small the frequency, f will result larger wave power.

From Table 4.1, the increments of wave from 10 Hz to 60 Hz were increasing. Following the theory, the increments should be decreasing as the frequency become larger. These errors occur because of the limited length of wave tank that limit the space for wave to be fully generated. From 60 Hz to 90 Hz, the wave was decrease proportionally to the higher frequency.

For Table 4.2, the output voltage was directly proportional to the increment of the wave height. The larger the wave height, the higher the voltage produced. Since the wave height for 60 to 10 Hz was decreasing, it also cause the output voltage became smaller.

For Table 4.3, we can see that the current generated are directly proportional to the voltage. From the equation :

$$\text{Voltage} = \text{Current} \times \text{Resistance}$$

so higher current will result higher voltage.

The power produced for this experiment is small because of certain errors that occur during the experiment such as limited wave height, improper movement of the floater, permanent magnet condition is not so good and the changes of steel plate in the generator to the paper plate that result lower efficiency of the generator. So, the results can be improved if we minimised the errors.

CHAPTER 5 : CONCLUSION

As the conclusion, we can generate electricity from renewable sources of energy like ocean wave. Ocean wave energy is captured directly from surface waves or from pressure fluctuations below the surface. One of the ways to generate electricity from it is by using linear generator. Linear generator is a generator that uses motion up and down to cut the magnetic flux in the armature and results in generating electricity. So the device is very suitable for this project since it follows the vertical motion of the wave. This application can only be done for offshore project. Apart from that, we should also consider types of wave available because wave power is determined by wave height, wave speed, wavelength, and water density. Wave power is important for buoy/floater movement which will relate to linear generator movement. Some works had been done to calculate correct data to be used for this project. The generator connection circuit for this project is wye connection. The experiment had been done in the wave energy tank. The power output can be scaled up by either increasing the number of modules built or increasing the number of magnet/coil packs.

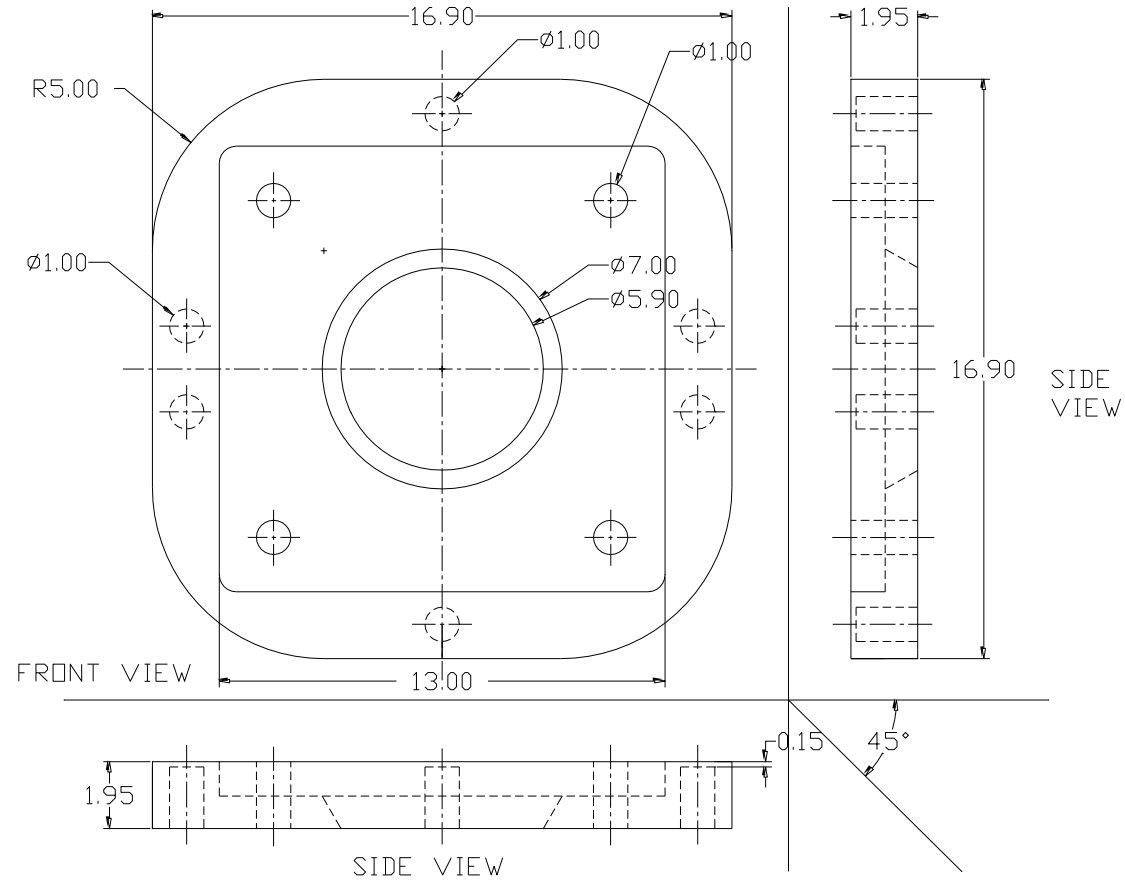
REFERENCES

The references are:

1. <http://wikipedia.org>
2. <http://ocsenergy.anl.gov>
3. <http://www.physorg.com>
4. <http://www.sciencedirect.com>
5. <http://www.hydro.gov.my>
6. John Brooke - ECOR: "Wave Energy Conversion", Ocean Engineering Series Editors, R. Bhattacharyya & M.E. Mc Cormick, 2003.
7. IMechE Seminar Publication: "Wave Power: Moving Towards Commercial Viability", The Department of Trade and Industry, 2000.
8. Instruction Manual, Wave Generator Flap-Type, Equipment for Engineering Education, Gunt Hamburg, Germany.
9. <http://www.esru.strath.ac.uk>
10. <http://www.ieeexplore.ieee.org>
11. <http://www.wrc.navair-rdte.navy.mil>

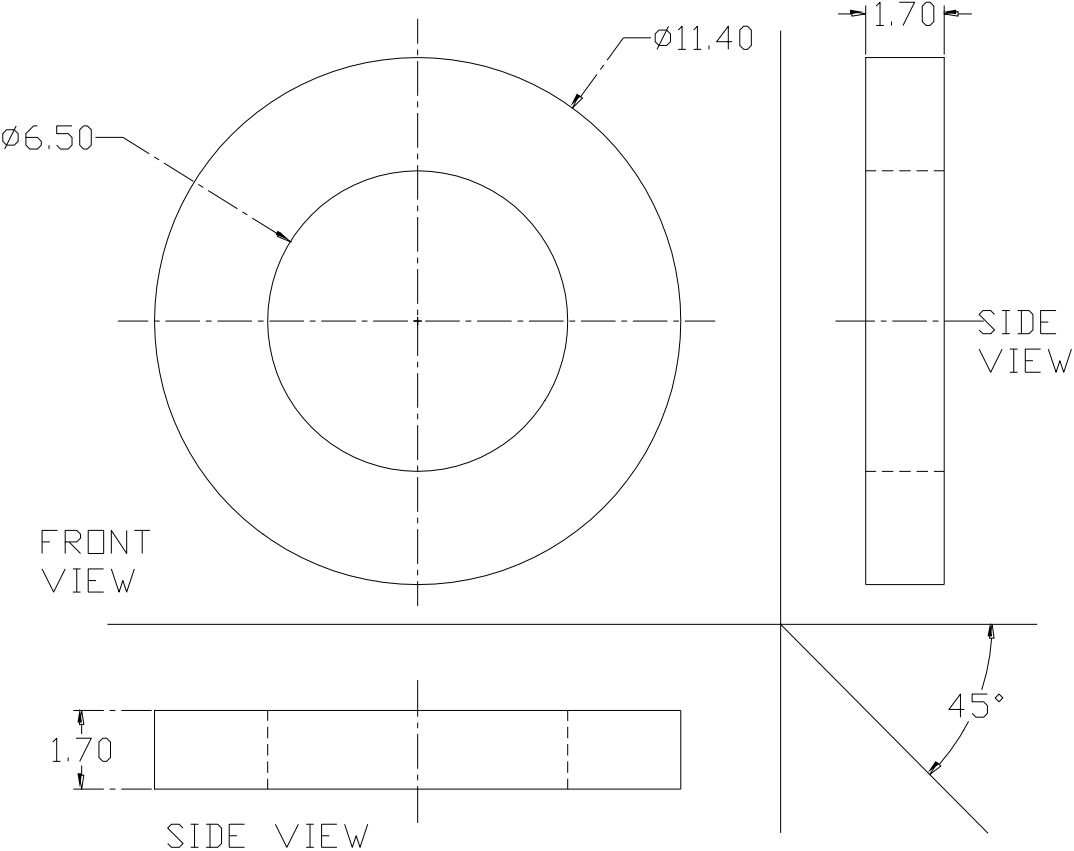
APPENDICES

ARMATURE COVER DRAWING



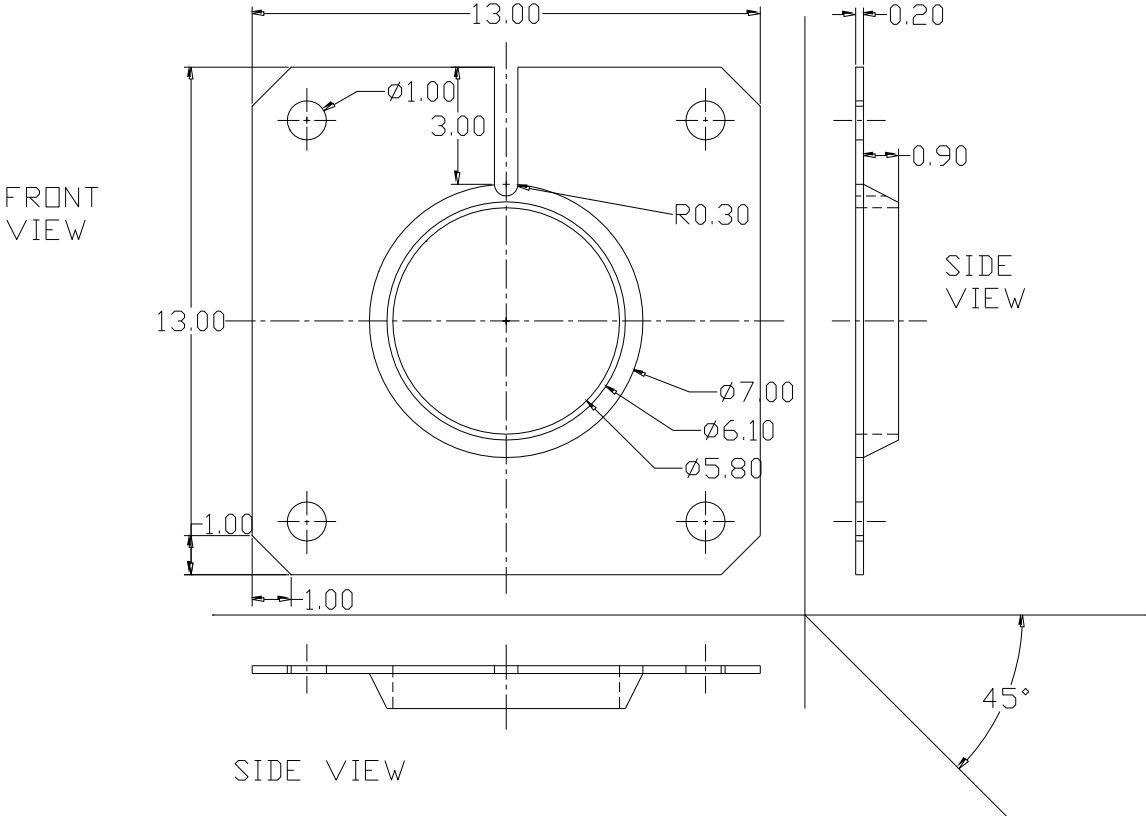
TITLE : ARMATURE COVER				
UNIT : CENTIMETER				
SIZE :	FSCM NO. :	DWG NO. :	REV :	
SCALE : 1:1			SHEET :	

COIL DRAWING



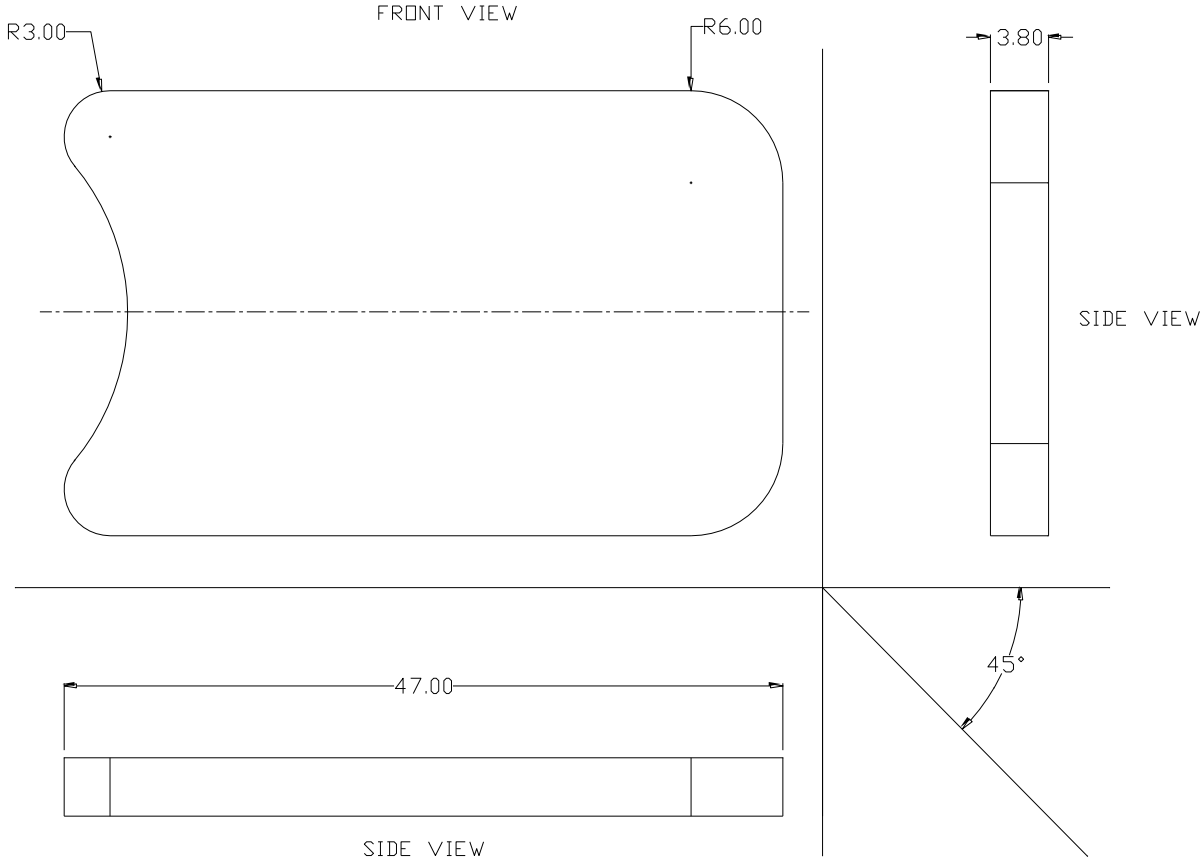
TITLE : COIL				
UNIT : CENTIMETER	SIZE :	FSCM NO. :	DWG NO. :	REV :
	SCALE : 1:1		SHEET :	

COIL COVER DRAWING



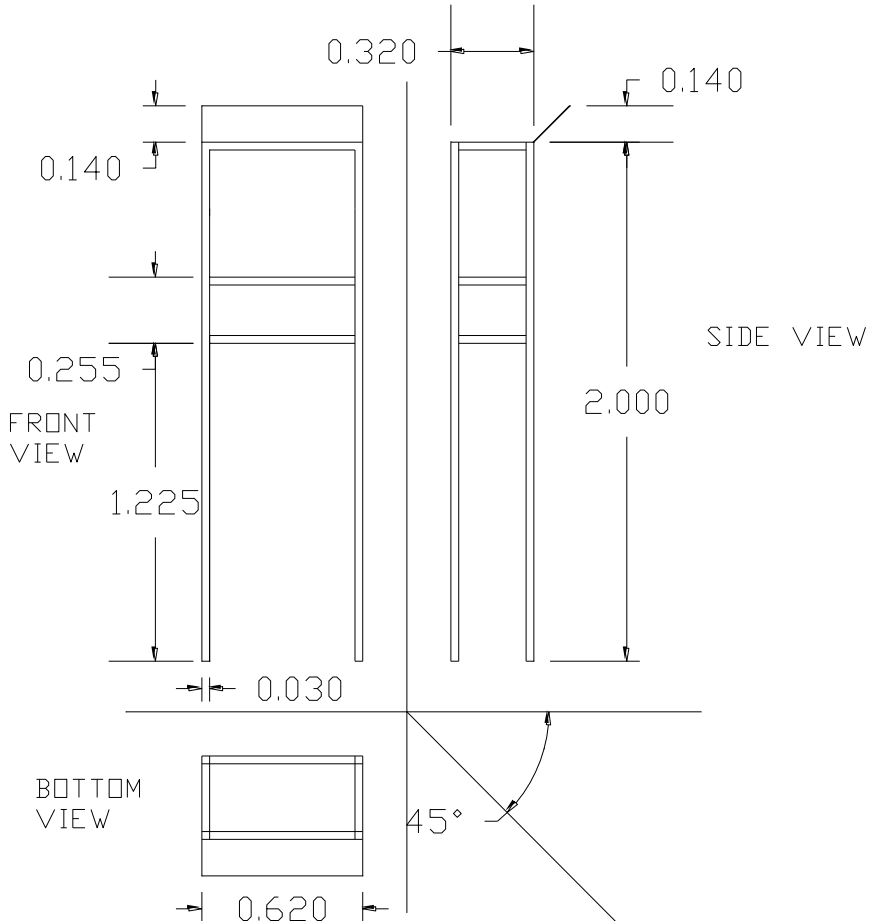
TITLE : COIL COVER				
UNIT : CENTIMETER				
SIZE :	FSCM NO. :	DWG NO. :	REV :	
SCALE : 1:1		SHEET :		

FLOATER DRAWING



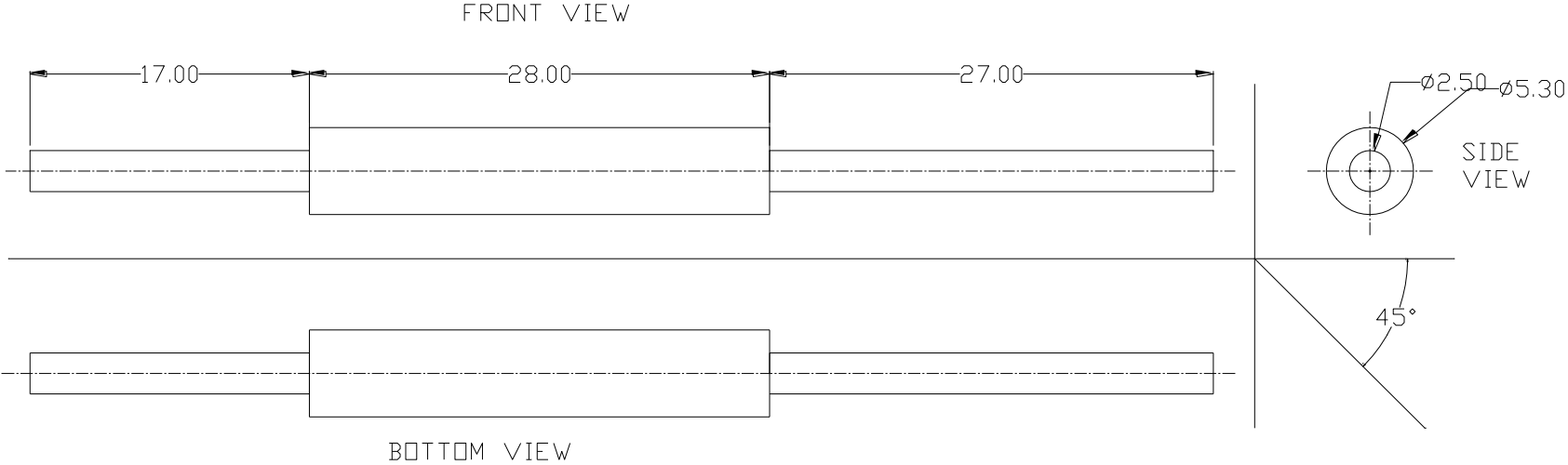
TITLE : FLOATER				
UNIT : CENTIMETER	SIZE :	FSCM NO. :	DWG NO. :	REV :
	SCALE : 1:1	SHEET :		

FRAME DRAWING



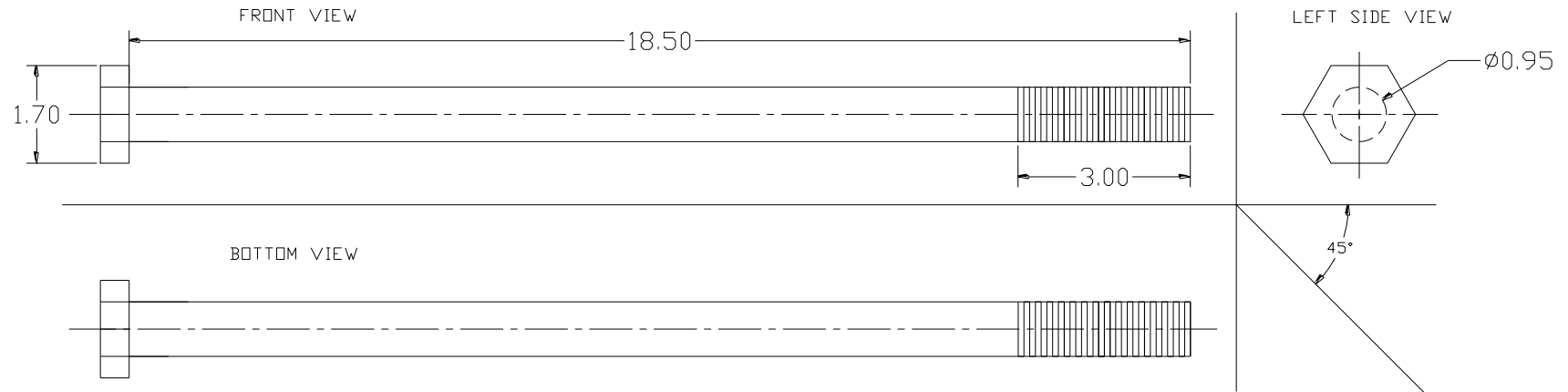
TITLE : FRAME				
UNIT : METER	SIZE :	FSCM NO. :	DWG NO. :	REV :
	SCALE : 1:1		SHEET :	

LINEAR GENERATOR DRAWING



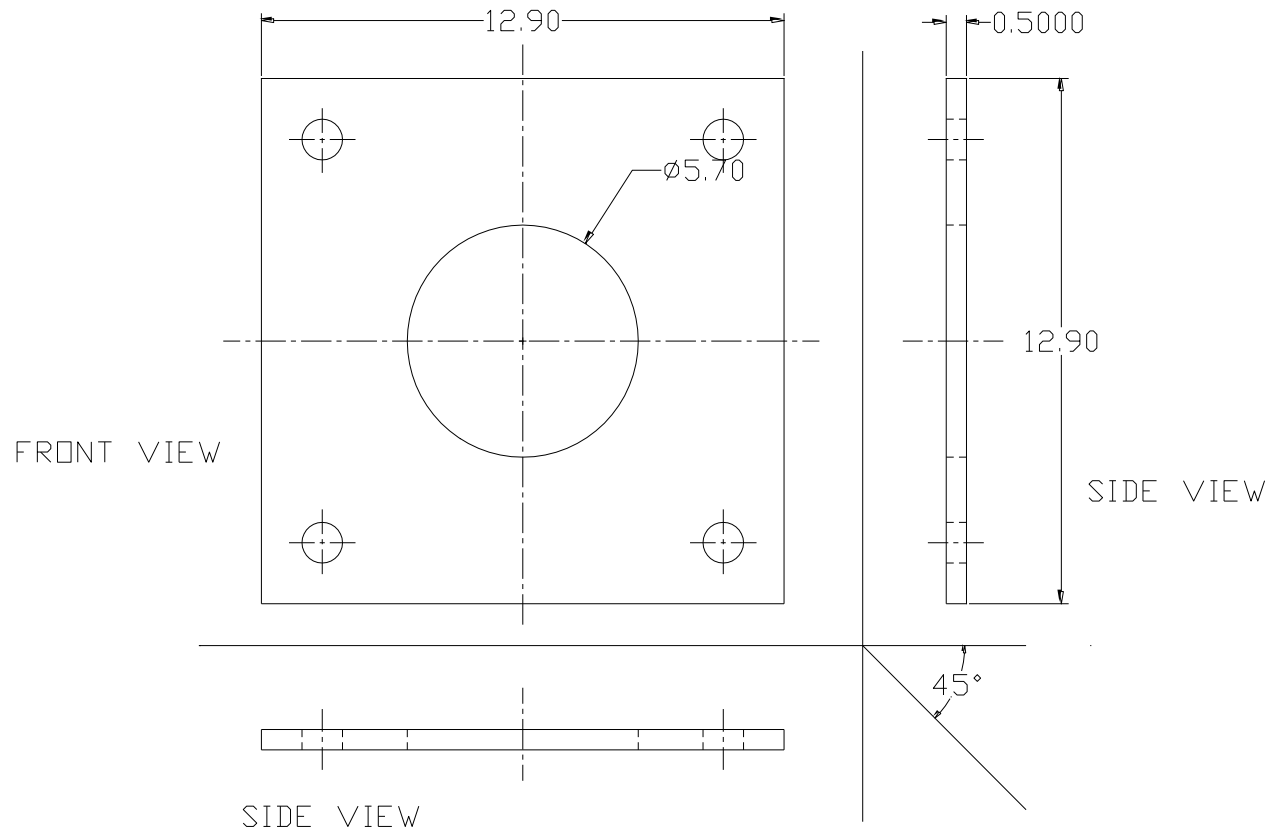
TITLE : LINEAR GENERATOR				
UNIT : CENTIMETER	SIZE :	FSCM NO. :	DWG NO. :	REV :
	SCALE : 1:1		SHEET :	

SCREW DRAWING



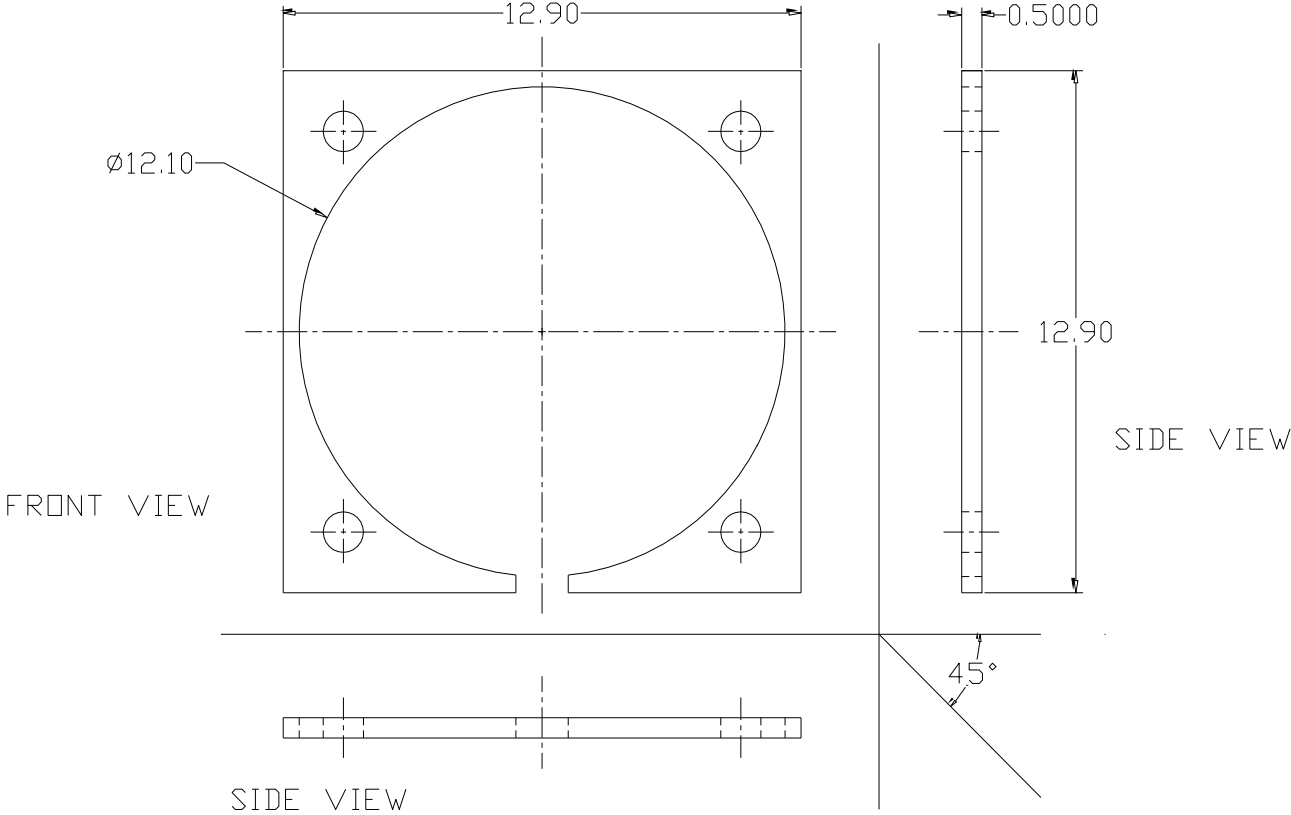
TITLE : SCREW				
UNIT : CENTIMETER	SIZE :	FSCM NO. :	DWG NO. :	REV :
	SCALE : 1:1		SHEET :	

PAPER PLATE [A] DRAWING



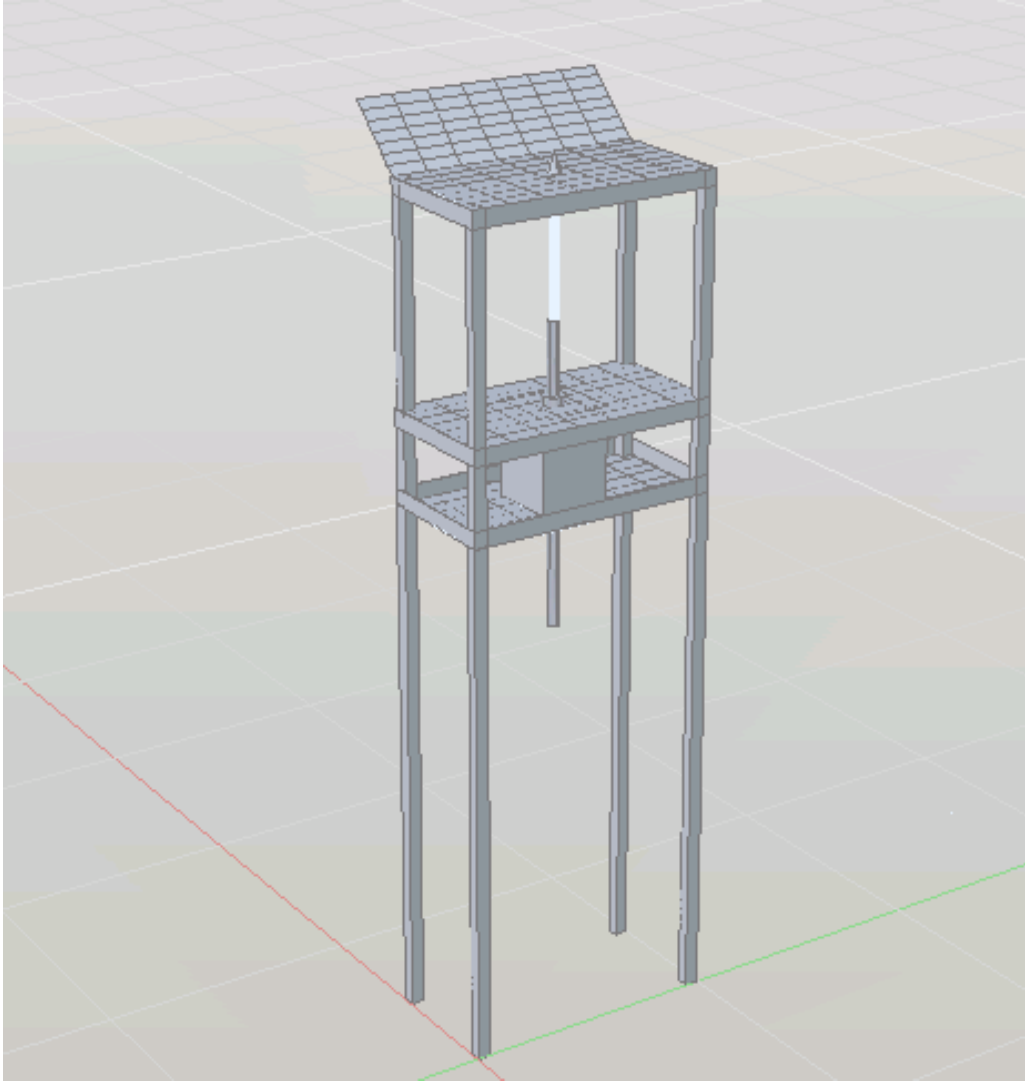
TITLE : STEEL PLATE [A]				
UNIT : CENTIMETER	SIZE :	FSCM NO. :	DWG NO. :	REV :
	SCALE : 1:1		SHEET :	

PAPER PLATE [B] DRAWING





TITLE : STEEL PLATE [B]				
UNIT : CENTIMETER				
SIZE :	FSCM NO. :	DWG NO. :	REV :	
SCALE : 1:1		SHEET :		

ASSEMBLE DRAWING





Suggested Milestone for the First Semester of 2-Semester Final Year Project

No	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic	■	■													
2	Preliminary Research Work		■	■	■											
3	Submission of Preliminary Report															
4	Seminar 1 (optional)					■	■	■								
5	Project Work					■	■	■								
6	Submission of Progress Report															
7	Seminar 2 (compulsory)										■	■	■	■		
8	Project work continues									■	■	■	■			
9	Submission of Interim Report Final Draft															
10	Oral Presentation															

 Suggested milestone
 Process

Suggested Milestone for the Second Semester of 2-Semester Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Work Continue	█	█	█											
2	Submission of Progress Report 1														
3	Project Work Continue				█	█	█	█							
4	Submission of Progress Report 2														
5	Seminar (compulsory)									█	█	█			
5	Project work continue							█	█	█	█	█			
6	Poster Exhibition														
7	Submission of Dissertation(soft bound)														
8	Oral Presentation														
9	Submission of Project Dissertation														

 Suggested milestone
 Process