ARTIFICIAL WAVE PRODUCER

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

ARTIFICIAL WAVE PRODUCER

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A report submitted
in partial fulfillment of the requirements for the degree of
Bachelor of Mechatronics Engineering with Honours

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

DECLARATION

I declare that this thesis entitled “ARTIFICIAL WAVE PRODUCER 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 : CARREY CHIANG WAI LIONG

Date : 18 - 06 - 2019

APPROVAL

I hereby declare that I have checked this report entitled "title of the project" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Mechatronics Engineering with Honours

Signature :
Supervisor Name : MR. SYED MOHAMAD SHAZALI BIN SYED ABDUL HAMID
Date : 18 - 06 - 2019

DEDICATIONS

To my beloved mother and father

ACKNOWLEDGEMENTS

In preparing this report, I was in contact with many people including staffs and seniors. They have helped me in my understanding and thoughts. In other words, I wish to express my sincere appreciation to my main project supervisor, Mr. Syed Mohamad Shazali bin Syed Abdul Hamid, for encouragement, guidance, critics, advices and motivation. Besides, I would like to thank the panels PM Dr. Chong Shin Horng and Dr. Hyreil Anuar Bin Kasdirin for their feedback and critics on my research for improvements.

Apart from that, I would also like to express my gratitude to lecturers in Electrical Faculty of UTeM (FKE), PM Dr. Ahmad Zaki Bin Shukor, Dr. Fariz Bin Ali, and other lecturers who were involved in guiding for a proper report writing and research study with integrity.

My sincere appreciation also extends to my parents, course mates and others who have provided assistance, views and tips which had helped me in completing this project research.

ABSTRACT

The research was driven by the unavailability of an Artificial Wave Producer in the Underwater Research Lab in Faculty of Electrical Engineering (FKE) in Universiti Teknikal Malaysia Melaka (UTeM) besides with an increasing use of Remotely Operated Vehicle (ROV) in deep sea exploration and underwater tasks. The high cost and large scale of existing wave producer has been a problem as it is pricey and occupies large space in laboratory. The objectives of the research was to develop a low cost and small scale Artificial Wave Producer and to evaluate its performance in terms of generated wave amplitude and wavelength. The method used in this research is by operating an oscillating plunger in a water tank of size 2 m x 1 m of length and width with 0.5m depth of water which is already available in the lab. The concept of producing wave with the Artificial Wave Producer was by using the Scotch Yoke mechanism to convert rotational motion to reciprocating motion and the performance of the Artificial Wave Producer were determined by the result of wave amplitude through changes of submerged plunger depth and result of wavelength from different plunger frequency where the wave amplitude produced by the triangular plunger is smaller than that of the half circular plunger even though with same submerged depth while the wavelength of both plunger shows the same exponential graph pattern against the plunger frequency axis. The comparison of theoretical calculation and experimental results were conducted to determine the error of the Artificial Wave Producer and comparison of theoretical plunger velocity with generated wave velocity were found to be lower in experimental wave velocity which was due to friction loss in the Scotch Yoke mechanism.

ABSTRAK

Penyelidikan ini didorong oleh ketiadaan Pengeluar Gelombang Buatan dalam Makmal Penyelidikan Bawah Air di Fakulti Kejuruteraan Elektrik (FKE) di Universiti Teknikal Malaysia Melaka (UTeM) di samping peningkatan dalam penggunaan kendalian kenderaan jauh (ROV) dalam penerokaan laut dalam dan tugas bawah air. Kos yang tinggi dan skala besar pengeluar gelombang sedia ada telah menjadi masalah kerana harga yang tinggi dan memerlukan ruang simpanan yang besar di makmal. Objektif penyelidikan ini adalah untuk menghasilkan Pengeluar Gelombang Buatan kos rendah dan berskala kecil serta untuk menilai prestasi fungsinya dari segi amplitud dan jarak antara gelombang yang dijana. Kaedah yang digunakan dalam penyelidikan ini adalah dengan mengendalikan pelocok berayun dalam tangki air saiz 2 m panjang dan 1 m lebar bersama dengan kedalaman air sebanyak 0.5m yang sedia ada di makmal. Konsep penjanaan gelombang air adalah berasaskan mekanisma "Scotch Yoke" di mana penukaran dari tenaga putaran ke tenaga linear and prestasi Pengeluar Gelombang Buatan ini ditentukan melalui penjanaan ketinggian amplitud gelombang dengan perubahan kedalaman pelocok ke dalam air yang didapati ketinggian gelombang adalah lebih kecil dengan pelocok segi tiga berbanding pelocok separa bulatan manakala eksperimen mengenai perubahan kepanjangan gelombang melalui perubahan frekuensi pelocok bagi kedua-dua pelocok mempunyai corak graf eksponen. Pengiraan secara teori dibandingkan dengan keputusan ekperiment bagi mengenalpasti peratusan kepincangan Pengeluar Gelombang Buatan ini dengan bandingan halaju gelombang adalah lebih rendah daripada halaju pelocok yang disebabkan kehilangan tenaga daripada geseran mekanisma "Scotch Yoke".

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LIST OF SYMBOLS AND ABBREVIATIONS

f - Frequency
d - Water depth
λ - Wavelength
T - Period
v - Velocity
r - Radius
ω - Angular velocity
DC - Direct current
ROV - Remotely operated vehicle
IEEE - Institute of electrical and electronics engineers
AWAS - Active wave absorption system
PWM - Pulse width modulation
DAS - Data acquisition system
SRDC - Subsea research and development center
PLC - Programmable logic controller
NPS - Naval postgraduate school

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Artificial Wave Producer is a system that generate water waves which resembles natural water waves by means of a wave maker system and it is important for underwater research. The first wave-making model was created by Phil Dexter back in 1966 [1] as shown in Figure 1.1 and a first wave pool was opened by him in Big Surf Waterpark two years later. The operational mechanism reported from TIME Magazine on 10th October 1969 of Dexter's design in Big Surf Waterpark wave pool was by pumping millions of gallons of water into a reservoir made out of concrete using hydraulic pumps. Waves were created from releasing of water from the reservoir underwater gates [2]. The wave size was controlled by the volume of water released hence by releasing more water, larger wave size can be produced.

Figure 1.1 The first wave-making machine [1]

The existence and further development of the first wave-making machine had led to commercial use especially in water theme park. On the other hand, experimental researchers mainly in coastal engineering conduct researches on water waves requires wave maker system and the mechanism varies depending on the system itself. The existence of the wave maker system is vital as it is not only for commercial use but also for the study of different type of water wave characteristics which could help in prediction at offshore such as tsunami warnings.

1.2 Motivation

The need of producing a controlled and small scaled artificial wave is vital for underwater research as it could help to save laboratory space and able to generate a similar to natural wave. The unavailability of a small scale Artificial Wave Producer in FKE Underwater Research Laboratory had driven the conduct of this research project.

1.3 Problem Statement

The current existing wave producer occupies large space and is high in cost which affect the affordability of purchasing and locating an artificial wave producer in the laboratory for research and study purposes.

1.4 Objectives

Upon completion, this project will achieve the following objectives:-

1. To develop a low cost and small scale Artificial Wave Producer
2. To evaluate the performance of the Artificial Wave Producer in terms of wavelength and amplitude with value in between range of 1cm to 1m for wavelength and wave amplitude of below 5cm respectively.

1.5 Scope

A list of focused segment for the project is as follow:-

1. Varying of PWM value of oscillating plunger

    a. From 150 to 250 with an increment of 25 for every reading

2. Varying the depth of water displaced by plunger
    a. From 1.0 cm to 5.0 cm with an increment of 1.0 cm for every reading
3. Plunger wave generator
    a. Half circular plunger
    b. Triangular plunger

CHAPTER 2

LITERATURE REVIEW

2.1 Research Background

Water waves are formed from disturbing force where the wave height is the vertical distance between the wave crest and the adjacent trough and wavelength is the horizontal distance between two successive crests (or troughs) [3] while the wave amplitude is the halved of the wave height. The wave characteristics is shown in Figure 2.1.

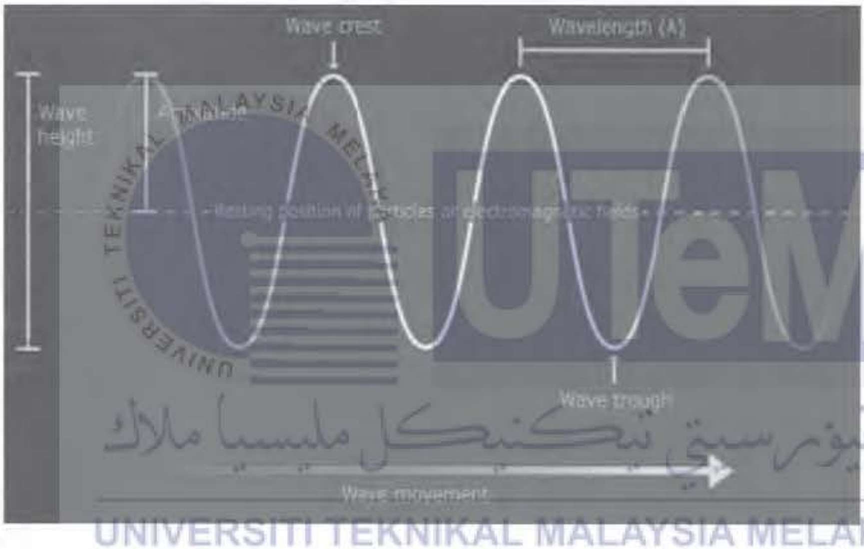


Figure 2.1 Wave characteristics [4]

Water depth of less than 5% of the wavelength is defined as shallow water where the wave behavior is influenced by the waves interact with the bottom and depth between 5% and 50% of wavelength is considered to be intermediate waves while deep water is depth above 50% of water wavelength [5]. (2.1) can be used to determine on wether the condition is deep where the "d" is the water depth and "λ" is the wavelength.

$$\frac{d}{\lambda} > 0.5 \tag{2.1}$$

The wavelength can be calculated using (2.2) if the result from (2.1) is true. The "T" in (2.2) is the wave period.

$$\lambda = 1.56T^2 \tag{2.2}$$

From wave period, the frequency of a wave can also be determined by using (2.3) where "f" is the wave frequency.

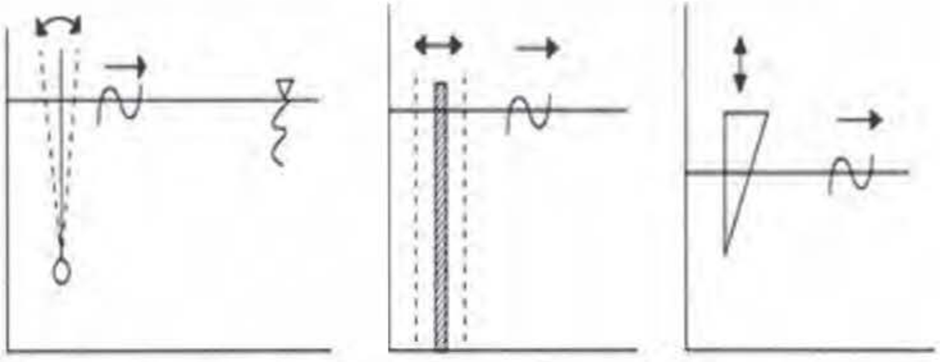
$$f = \frac{1}{T} \tag{2.3}$$

2.2 Type of Waveform

Several type of waves were produced through various wave maker system which include regular, irregular, linear and circular. Progressive wave is the common type of wave generated as it depicts the motion of wave front through the medium. Progressing wave was produced by Horst Punzmann et al. with vertically oscillated plunger and the motion of fluid was observed using buoyant tracer particles that were dispersed all around the fluid surface [6]. A research by David Aknin and Johannes Spinneken involved several wave amplitude set with the alteration of displacement and force using piston type wave maker to generate regular waves [7]. Based on a study by P.C. de Mello et al., generated regular and irregular waves with the flap wave maker automation system that is controlled by PLC for comparison between theoretical and experimental transfer function of wave generation for the automation system performance validation [8].

2.3 Type of Wave Maker

Plunger type was used to produce regular and irregular waves in the research for the surface elevation measurement with and without the activation of absorption by YANG et al. [9] while a study research done by Ishmam et al. in "Construction of a Plunger Type Experimental Wave Tank for Validation Study" uses vertically oscillated plunger for regular and irregular wave generation [9] in the research of wave absorbing beach. The variables of the research were the presence of wave absorbers on the effect of measured continuous waves. Piston, plunger and flap maker are the most general method of producing waves as shown in Figure 2.2. Flap and piston generate waves from bottom to top and are more suitable for deep water while plunger type generates water waves through top to bottom water surface contact.



a) Flap (hinged) type b) Piston type c) Plunger type

Figure 2.2 Type of wave generators [6]

2.4 Measuring Devices

Ultrasonic probes were used by several researchers as a measuring method for wave height from the oscillating wedge according to a research by Leo M Jones [5]. Study [5] involved varying the frequency of oscillation to the wave amplitude and data were collected via MATLAB routine from voltage reading of each probes. The research of [8] to measure the distance between transducer and the water surface using ultrasonic wave height meter that operates via pulse-echo technique. The data from experimental result were almost similar to the theory of wave flap response transfer function for phase and magnitude relation relative to varying frequency.

In the "Determination of a Plunger Type Wave Maker Characteristice in a Towing Tank" by Sayed et al., resistive type of probes with transducer were used as a measuring method for wave height that converts into electrical signal [11]. The research also include the comparison of data acquisition system (DAS) with ruler and camera of 25 fps for characteristic curve of plunger type wave maker of Subsea Research and Development Center (SRDC) and the results of both method was found to be quite closed [11]. Different types of probes for measurement whether through the changes of voltage output or duration for reflected ultrasonic wave receiver helps to obtain a more accurate and reliable result for wave height and frequency but a more conventional way of using ruler and camera could obtain almost similar wave height result.

2.5 Wave Absorbers

In [13], passive nylon beach was used as a wave absorber. The reflected energy must be absorbed by the same wave generator, whose movement is modified to cancel out the reflected waves called Active Wave Absorption System (AWAS) [14] was carried out by Altomare et al., dissipative beach or horizontal sponge wall were used as passive wave absorber. The Active Wave Absorber System (AWAS) was used by absorbing reflected energy by the same wave [14]. In the research of "Evaluation of a Source-Function Wave maker to Accurately Generate Random Directionally Spread Waves" by Suanda et al. had observed monochromatic waves with sponge layers placed at the side to absorb waves [15]. Research [9] uses absorption algorithm to produce an opposite phase of equal amplitude to eliminate the re-reflected wave. Wave absorber is important in the design for a better wave generation for significant disturbance of reflected waves as it helps to absorb remaining wave and prevent reflected wave that will affect the data validity.

2.6 Small Scale Wave Maker System

Research [9] by Ishmam et al. in validation studies on plunger type experimental wave tank uses waveflume design of size 1.75m x 0.25m x 0.3m. The system operates with a plunger wedge controlled via Variable Frequency Drive (VFD). The VFD varies the motor input frequency in order to control the motor speed. Regular and irregular waves are able to be generated with the installed wave maker within a range of time period. The system uses gear to convert rotational motion of motor into a reciprocating motion of the actuator as shown in Figure 2.3. A study in research [6] uses a smaller waveflume of size 1.5m x 0.5m x 0.08m using vertical oscillation of different plunger shape consisting of conical, cylindrical, triangular and square pyramidal. With plunger frame, the vertically oscillating plunger was attached to the electromagnetic shaker on the table. Small scale wave maker system could be concluded to common use of plunger besides able to save laboratory space as it only requires small size of waveflume.

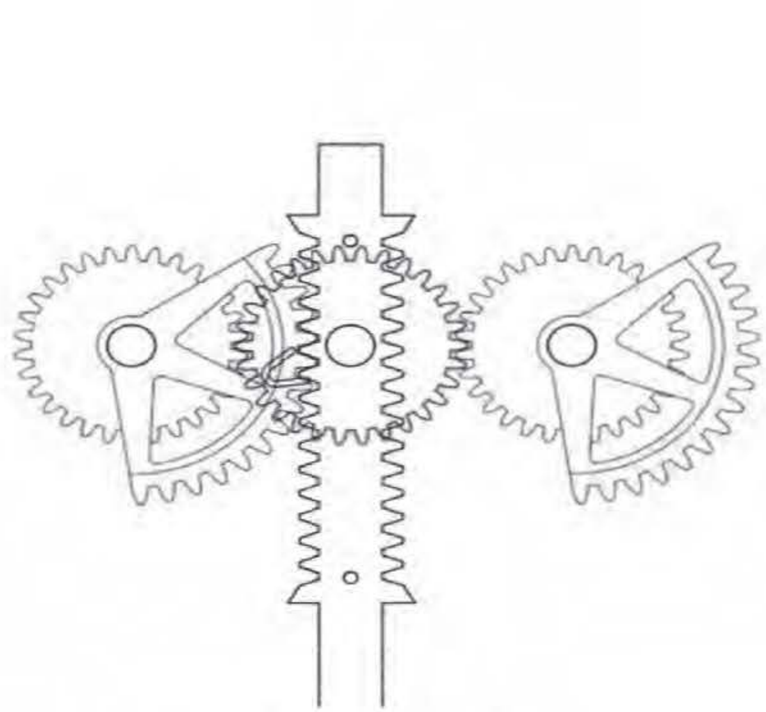


Figure 2.3 Wave maker mechanism [7]

2.7 Large Scale Wave Maker System

It is wideused of large scale wave maker system to produce artificial wave in the laboratory where the significance of the large scale is depicted with the use of large waveflume. The research in [8] by P.C. de Mello et al. uses basin of size 14m x 14m x 4m which uses wave maker system of hinged flap that consist of 148 actuators controlled using PLC as shown in Figure 2.4. The wave maker system consist of transmission system using ball-screw linear system and each hinged flap powered by a 1HP servo-motor as depicted in Figure 2.5. Besides, each immersed flap is as large as 1.21m for regular wave generation and could generate high wave amplitude as the flap is immersed deep into the basin. A 10.9m x 0.9m x 1.2m of waveflume was used in Naval Postgrduate School (NPS) with wave maker system of sized 0.6m in height and 0.9m wide using linear actuator for wedge motion control controlled by Modusystems Pulse/Dir controller as shown in Figure 2.6. From the wave maker system, the maximum stroke of linear actuator is 0.6096m with a maximum thrust of 1779.3N [5]. With large basin, deep immersed flap and long stroke of wave maker, larger water wave amplitude can be produced but requires a bigger space in the laboratory for the system to operate.

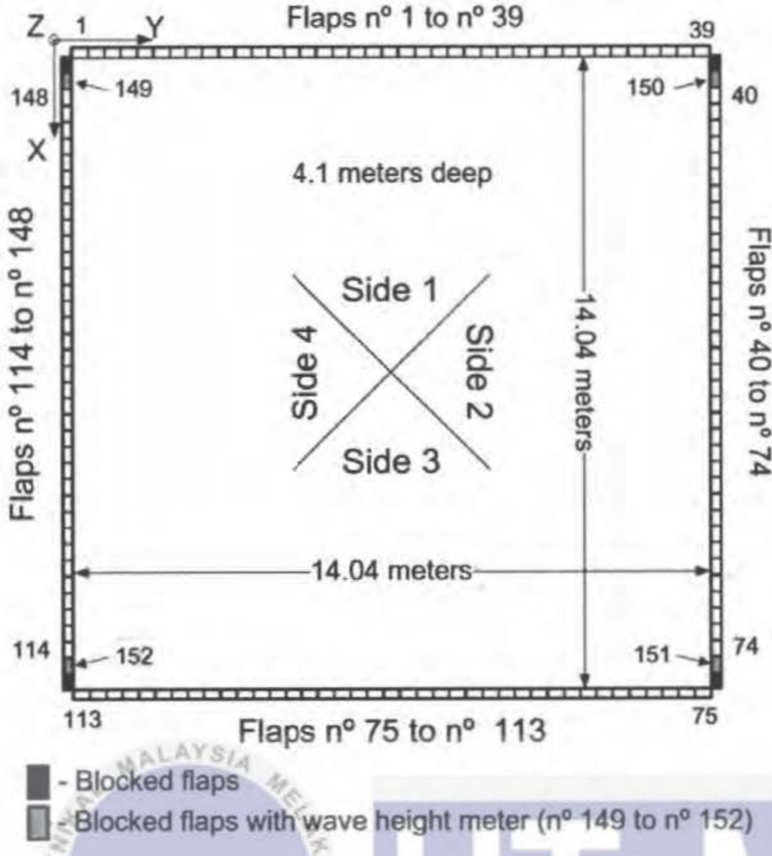


Figure 2.4 Numerical Offshore Tank (TPN) wave basin [8]

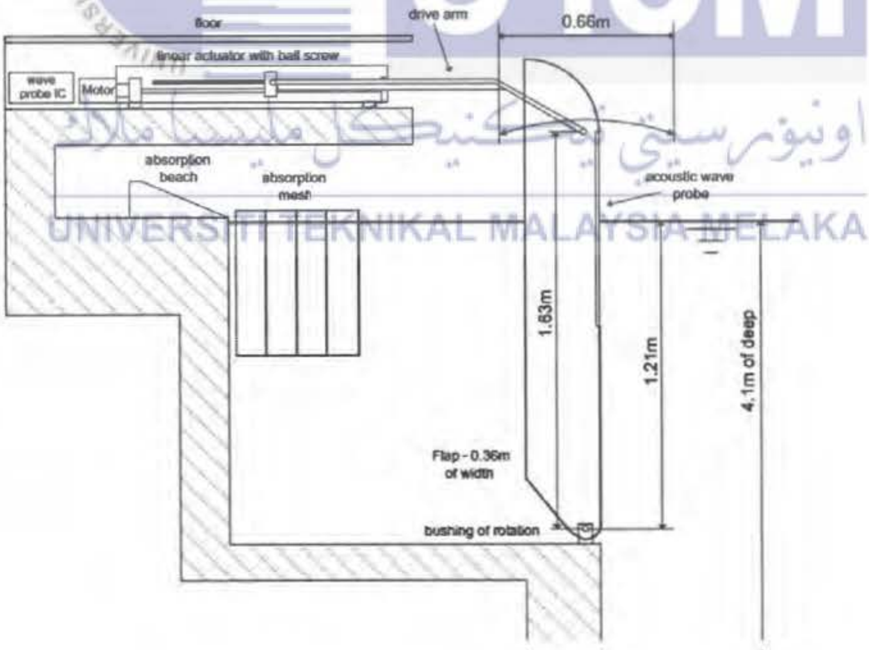


Figure 2.5 Mechanism of hinged flap [8]

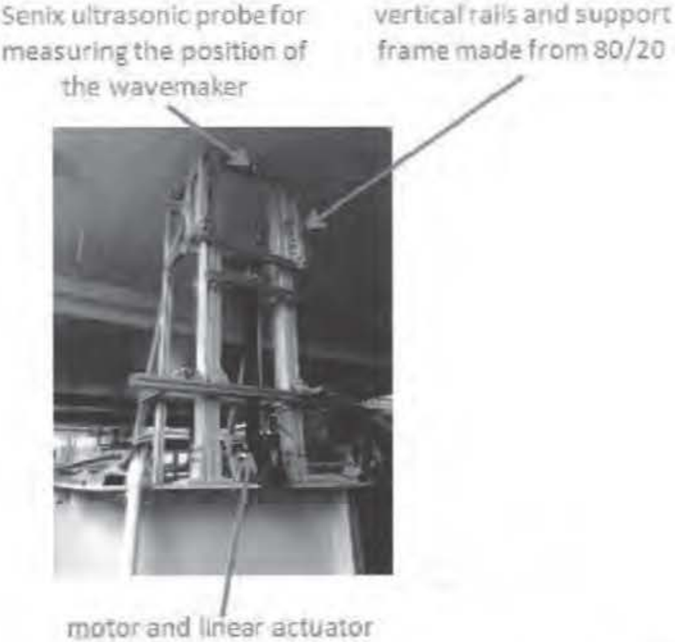


Figure 2.6 80/20 T-slotted wedge made of aluminium [5]

2.8 Summary

As a summary, the Arduino Uno will be selected as it is more suitable for hardware projects besides having a lower purchasing price and easier programming language than other controllers. The plunger to be used were triangular section and half circular wedge as it will produce linear and circular waves respectively and both shapes were the most general shape as it is easily deployed to make amplitude waves. The method of using image capturing was selected to capture the wave amplitude and wavelength of generated wave due to simplicity of retrieving the results through still image and frame by frame. A DC motor was selected controlled by Arduino Uno to drive the actuators. As overall, the Artificial Wave Producer were designed to be a small scaled wave maker system.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter include the overview of the whole research on the method of conducting and obtaining the result in terms of experimental set-up and measuring method. The flow of the Artificial Wave Producer in sense of Block Diagram and flowchart were shown in this chapter.

3.2 Artificial Wave Producer Block Diagram

The Artificial Wave Producer block diagram in Figure 3.1 shows the experimental study on generating water waves. A Pulse Width Modulation (PWM) will be set for reference to control the rotational speed of the DC motor as referred to Figure 3.2. The PWM set influenced the frequency of plunger linear oscillation. The higher the microcontroller PWM set, the plunger will oscillate faster. As the plunger oscillates, the camera captures slow motion of wave generated and the feedback enable the user to determine whether the wave was desirably generated.

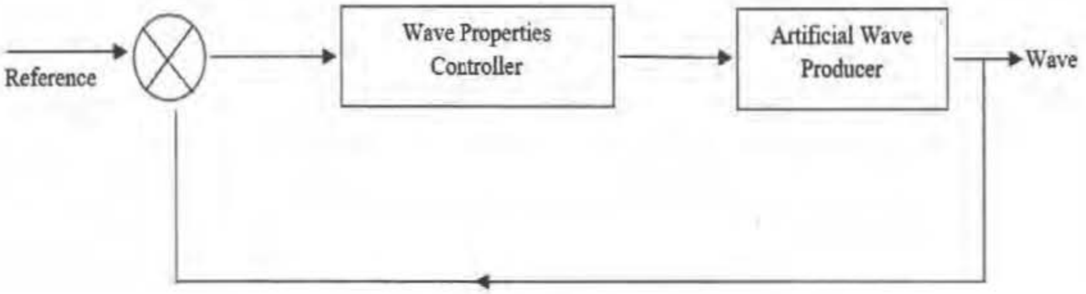


Figure 3.1 Artificial Wave Producer block diagram

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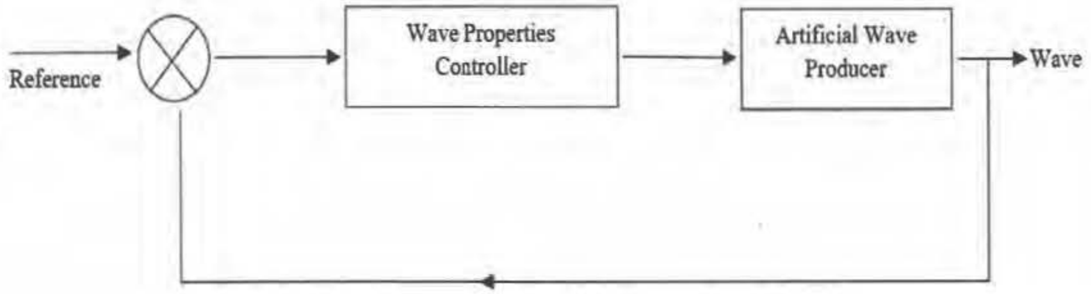

Figure 3.1 Artificial Wave Producer block diagram

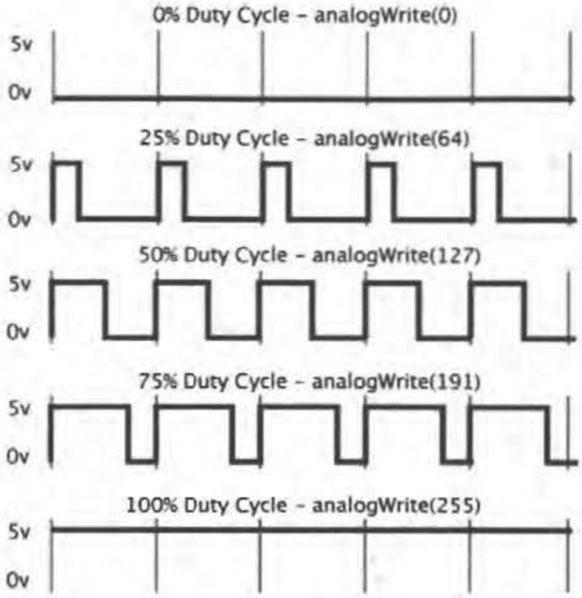

Figure 3.2 Pulse Width Modulation arduino control [16]

3.3 Artificial Wave Producer Schematic Diagram

The flow of Artificial Wave Producer is as depicted in Figure 3.3 for its schematic diagram where the PC is responsible for the wave properties where the input of PWM value were inserted into the Arduino software to send signal to the Artificial Wave Producer. The Artificial Wave Producer consist of the Arduino, motor driver and DC motor. The input from PC controls the speed of the actuator for the wave producer via Scotch Yoke mechanism.

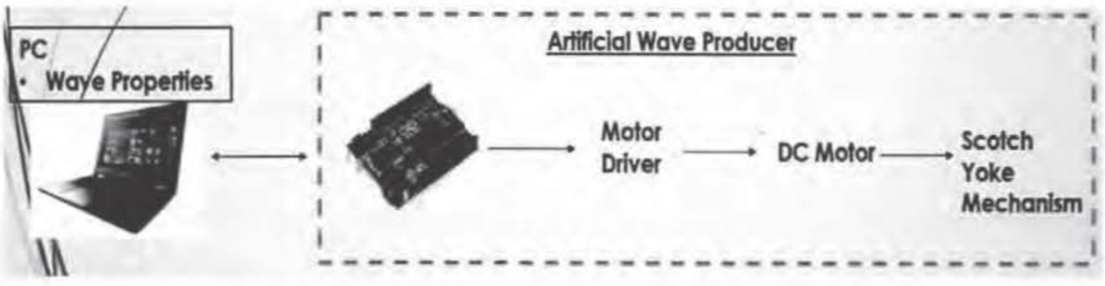

Figure 3.3 Artificial Wave Producer schematic diagram

3.4 Artificial Wave Producer Flowchart

The flowchart for the Artificial Wave Producer is shown in Figure 3.4 and when the power supply is connected, the DC motor will rotate to oscillate the plunger after the initial stage of PWM input is done through the Arduino software. The plunger will continue to oscillate and the system will continue to generate wave until the power supply is removed. The power supply has to be removed first before every new PWM input is inserted.

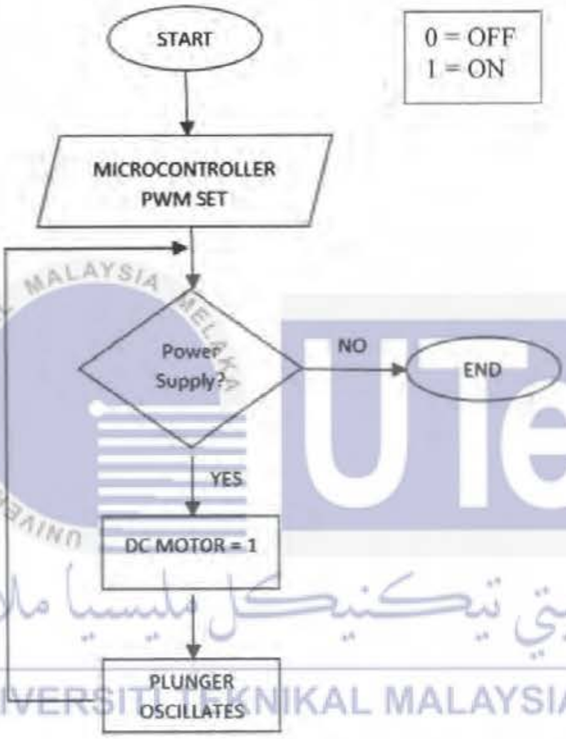

Figure 3.4 Artificial Wave Producer flowchart

3.5 Progress Sequence Flowchart

The sequence flowchart for the whole research from the beginning of title study to the end of collecting data from hardware is as shown in Figure 3.5.

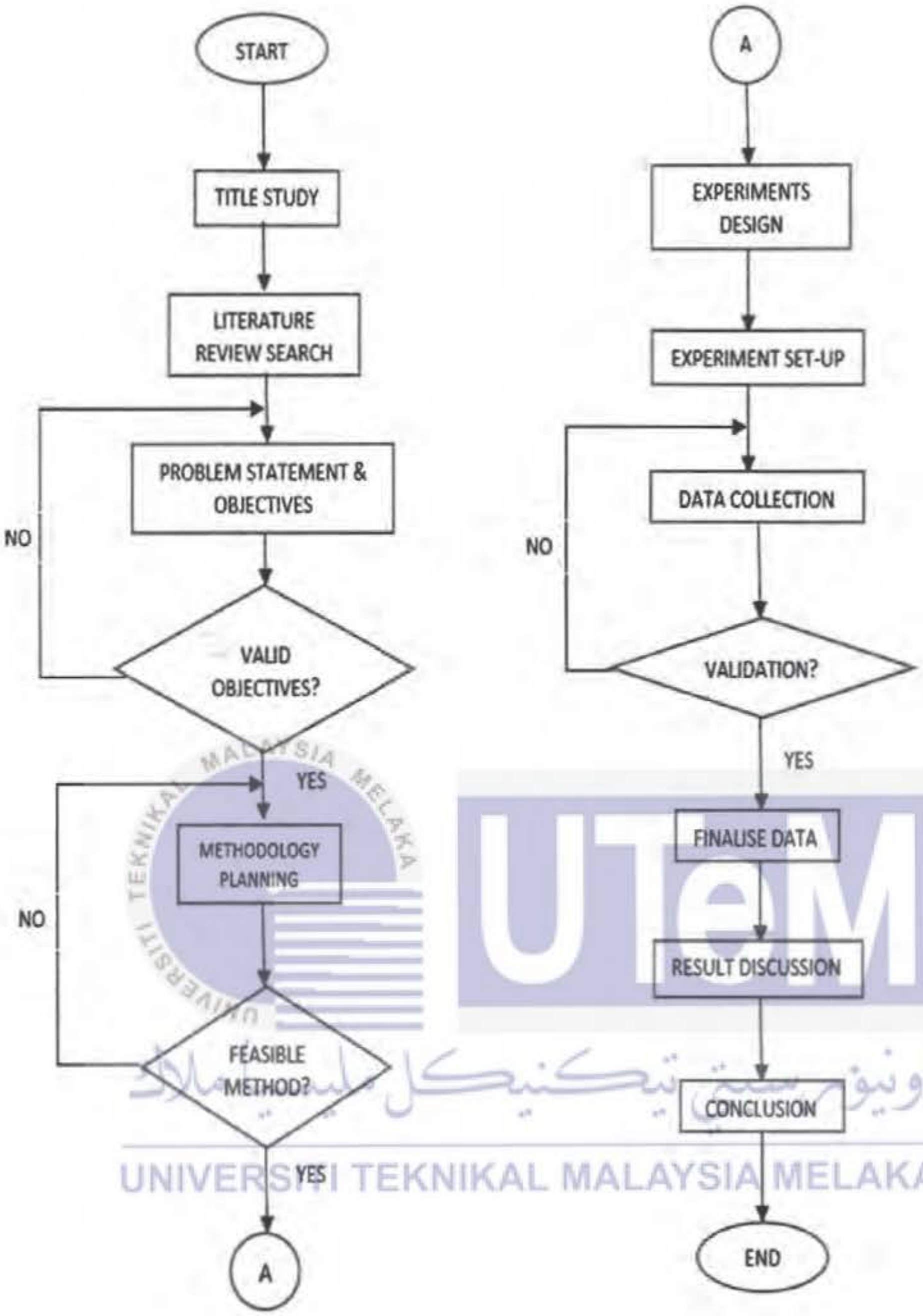

Figure 3.5 Progress sequence flowchart

3.5.1 Title Study and Literature Review

Based on Figure 3.5, a title study was the first step to get a general idea on the title given from books and websites followed by the literature review research to search for information for the method approach of similar title and concept.

3.5.2 Problem Statement and Objectives

After literature review, the problem statement & objectives were identified because it is important to set the objectives of the research based on the problem for the existing system and also the availability of the system in FKE Underwater research lab. The scope of research were narrowed to the study of water wave amplitude and wavelength of generated wave.

3.5.3 Methodology Planning and Feasibility

Methodology planning stage was crucial to conduct plan for the whole research method for a proper procedure. The method planned were based on the formula for wavelength as in (2.2) and (2.3) by changing the PWM value of the oscillating plunger. On the other hand, the amplitude of water waves were to be generated from a constant PWM value of 200 for both linear and circular waves. The depth of submerged plunger were altered by reducing the water in the tank until the desired depth by referring to the marked measurement on the tank. The retraction of actuators were to be made sure that it does not rest on the water due to the buoyancy force that prevent the plunger from being an upright position and hence, every reciprocation of the system should be in contact with water during extension and above of water level during retraction of the actuators.

3.5.4 Experimental Design

The experiment was designed using Solidwork for the plunger which consist of two shapes which are half circular and triangular wedge shape as shown in Figure 3.6 and Figure 3.7. The plunger were printed using 3D printing as the material will be lighter and have more water resistance compared to other materials such as wood that will slightly absorb water.

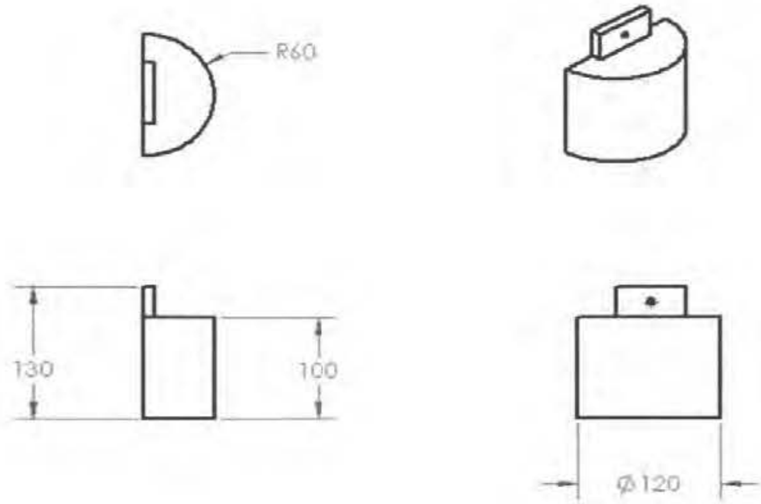

Figure 3.6 Half circular plunger

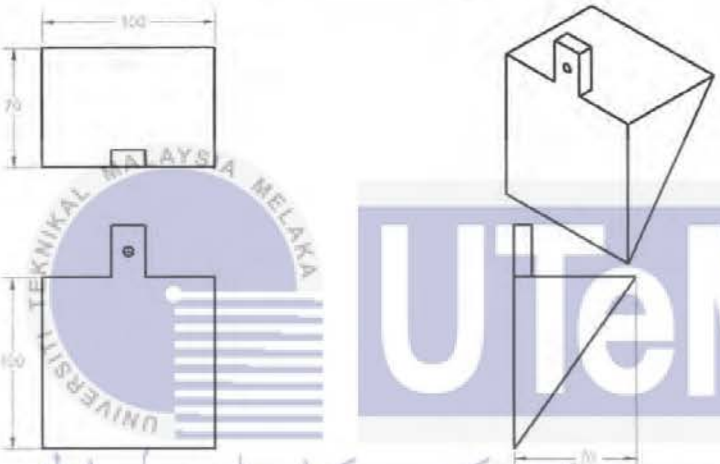

Figure 3.7 Triangular plunger

The individual parts for Scotch Yoke mechanism were designed as shown in Figure 3.8, Figure 3.9 and Figure 3.10.

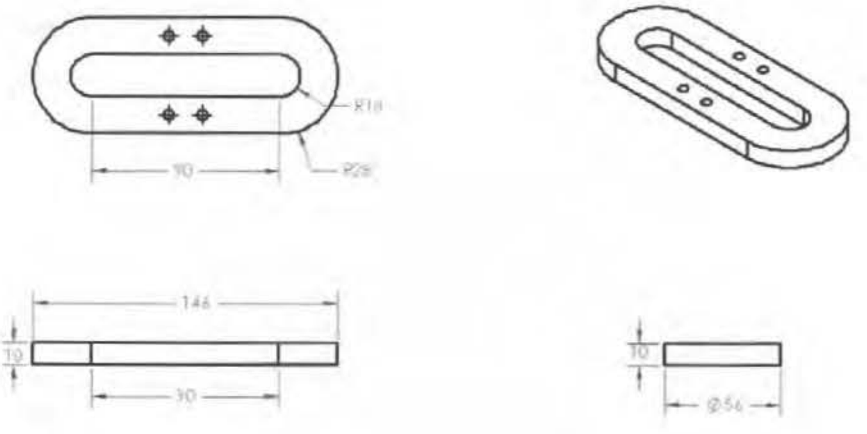

Figure 3.8 Elliptical block

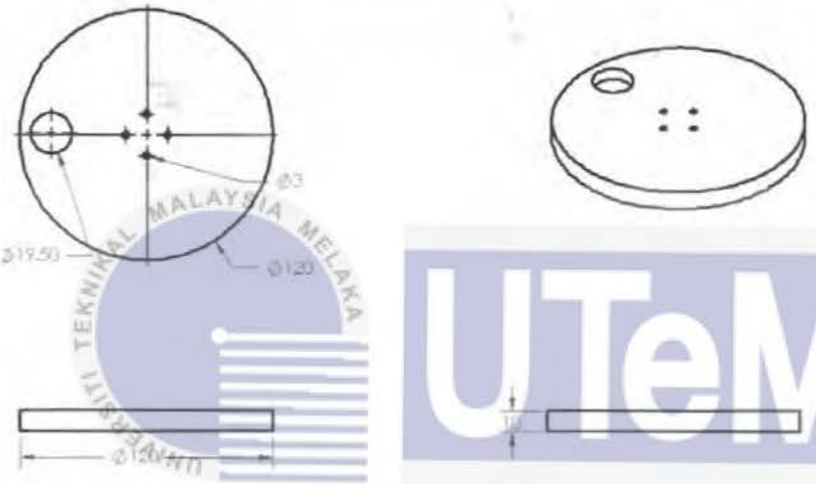

Figure 3.9 Circular disc

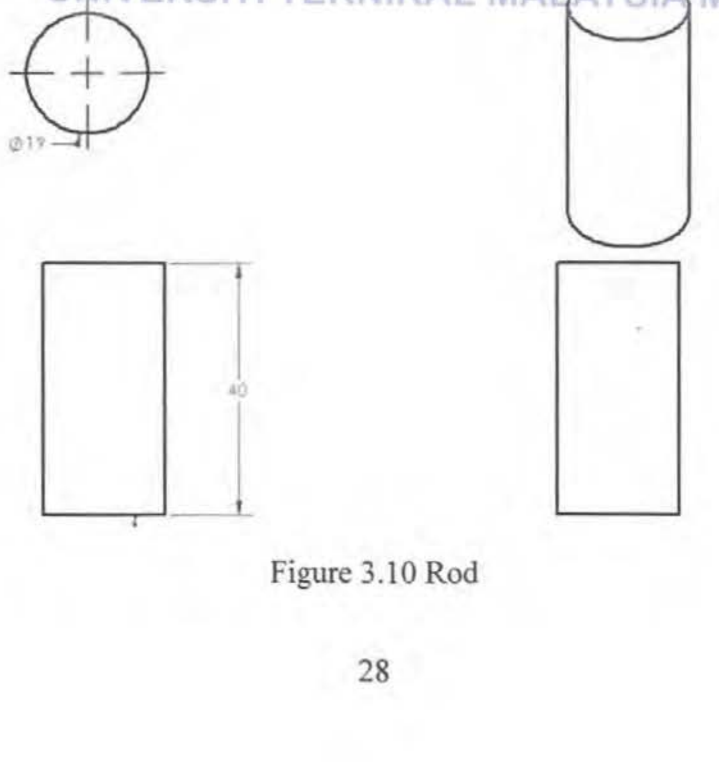

Figure 3.10 Rod

A Scotch Yoke mechanism was designed consisting of 3 parts which include of a circular disc, elliptical block and a rod where all parts were 3D-printed as shown in Figure 3.11. The circular disc was fixed onto the DC motor shaft which will rotate the disc and pushes the rod as it rotates that will then produce a reciprocating motion.

Figure 3.11 Scotch Yoke mechanism design

3.5.5 Experimental Set-up

The set-up of the research was based on the survey on the water tank to be used which was already available at the FKE Underwater Research Lab. The water tank available in the lab has a size of length x width x depth is 2.1m x 1m x 1m while the water depth was filled at 0.5m deep.

Table 3.1 shows the list of components used in the experimental setup of the Artificial Wave Producer.

Table 3-1 List of experimental setup components and its specifications

Components	Specification	
Sealed Lead Acid Battery	Model	: GPP 1212
	Voltage	: 12V
	Current	: 1.2AH
Alkaline battery	Model	: Energizer
	Voltage	: 9V
	Current	: 450mAH
DC Motor	Model	: Cytron SPG30HP-30K
	Voltage	: 12V
	Rated Load Torque	: 1.4kgf.cm
	RPM	: 380
Motor Driver	Model	: L298N
	Drive Voltage	: 5V – 35V
Microcontroller	Model	: Arduino UNO

Figure 3.12 shows the 2D front view of the tank with a transparent side in the middle while Figure 3.13 shows the experimental setup for the plunger. In Figure 3.13, the guided slot circled in red were added at the top and bottom to keep the linear wooden actuator to reciprocate and prevent it from sliding sideways. Figure 3.14 shows the position of the components which consist of a motor driver, Arduino and power supply of a 12V sealed lead acid battery and 9V alkaline battery.

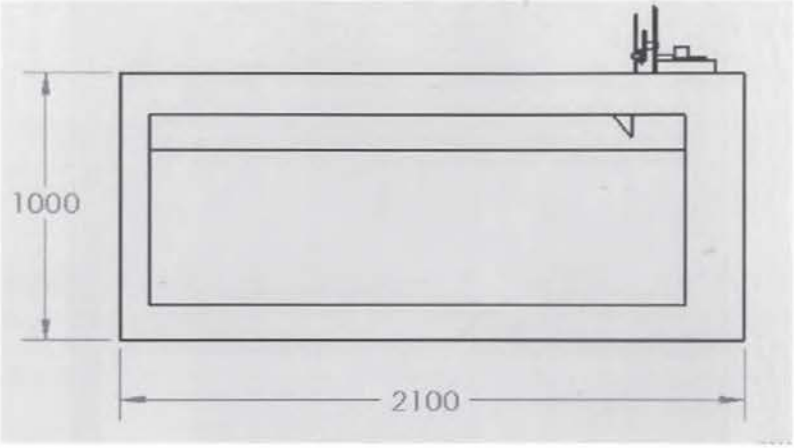

Figure 3.12 Experiment 2D front view

Figure 3.13 Experiment set-up

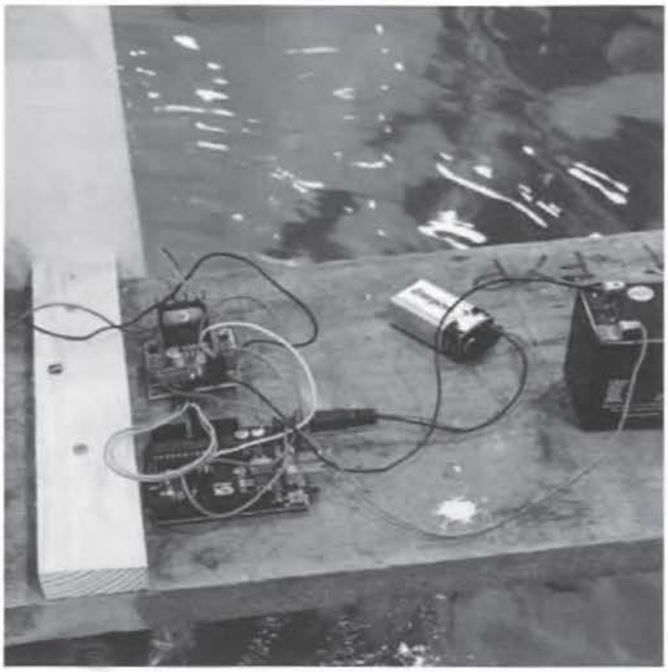

Figure 3.14 Component position

The marking of measurement is shown in Figure 3.15 where two vertical lines were made with 20cm apart as a location guide for the wedge to be placed. The vertical line would be a guide for the measurement of wave to be taken when it reaches beyond the 20cm set distance from the wedge. The horizontal lines were individually marked with 0.5cm difference as a guide for the wave amplitude measurement.

Figure 3.15 Measurement marking with thread

Figure 3.16 shows the hardware of Scotch Yoke mechanism for the Artificial Wave Producer. The block circled in red was added to the system to reduce the vibration of the circular disc that caused the whole system to vibrate during reciprocation which affects the smoothness of the reciprocating motion and plunger frequency.

Figure 3.16 Scotch Yoke mechanism

The experiment were carried out by varying the PWM value from 150 to 250 with 25 increment for every reading to obtain the wavelength while the depth of water displaced by plunger will also be varied from 1.0 cm to 5.0 cm with increment of 1.0 cm for every reading to obtain the wave amplitude by a constant set PWM value of 200. The experiment were repeated twice using a triangular wedge and a half circular shaped plunger for linear and circular waves.

3.5.6 Data Collection and Validation

The wavelength and amplitude will be the main data to be collected in the data collection stage. In validation stage, the wave amplitude were measured using still image from slow motion feature of the IPhone SE camera of 120fps similar to research [11] that used 30fps while the wavelength will be calculated from the period of wave obtained through the slow motion video as similar to research [11] as well.

The wave period can be calculated from determining the number of frames between 2 wave crests and divided by 120 which is the camera frame per second setting which is also the same method of calculating wave period in research [11]. The wavelength is then calculated using (2.2) and the value is valid if (2.1) is true.

The plunger frequency were also calculated from the slow motion video by dividing the number of strokes of plunger in 10 seconds. The plunger frequency will be plotted as the variable axis in wavelength versus plunger frequency graph.

From the experimental results of plotted graph, linear equations were determined to identify the percentage error of theoretical value with experimental value for the wave amplitude experiment. The percentage error were calculated using (3.1).

$$\left[\frac{\text{Experimental} - \text{Theoretical}}{\text{Theoretical}}\right] \text{x } 100\% \qquad (3.1)$$

On the other hand, the reciprocating plunger velocity were calculated theoretically after the Scotch Yoke design to be compared with the generated wave velocity to determine whether the generated wave velocity does not exceed the speed of reciprocating plunger so that the wavelength results would be valid. In (3.2), "x" is the vertical displacement from the center of disc to the rod in the Scotch Yoke while "r" is the radius of the rod to the center of disc followed by "ω" as the angular velocity and "t" as the time.

$$x = r \sin \omega t \qquad (3.2)$$

The theoretical calculation of plunger speed were done from displacement of (3.2) and whereby differentiating (3.2) to get the velocity (3.3) for the plunger.

$$v = r\omega \cos \omega t \tag{3.3}$$

Since ωt is also equals to θ and θ is obtained using trigonometry from the Solidwork measurement and hence, (3.3) can be written as;

$$v = r\omega \cos \theta \tag{3.4}$$

$$v = f\lambda \tag{3.5}$$

The velocity was calculated based on the measurement from Solidwork as shown in Figure 3.17 to be compared with the wave velocity calculated using (3.5). The calculated plunger velocity were attached in Chapter 4.

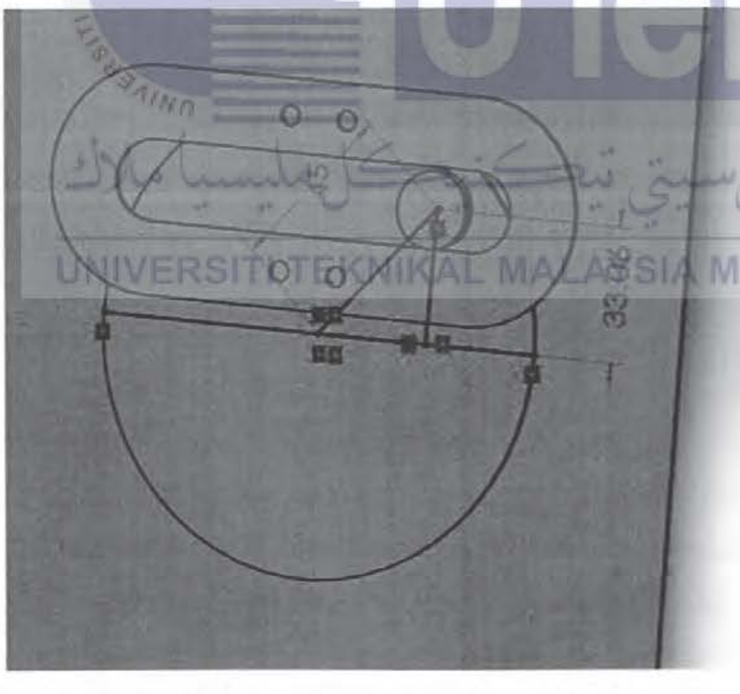

Figure 3.17 Measurement through Solidwork design

3.5.7 Discussion and Conclusion

The data from the graph were analysed for its graph pattern and the percentage error of the experimental with theoretical value were compared in the result analysis stage while the conclusion stage would conclude whether the objectives were achieved besides summing up the relation between wavelength with plunger frequency value and wave amplitude with depth of water displaced by plunger. The results were divided into two sections of which wavelength and wave amplitude as the responding axis with plunger frequency and depth of submerged plunger as manipulated axis respectively.

3.5.8 Research Variables

The size of half circular and triangular plunger wedge are fixed for the research. In determining the wave amplitude generated by the Artificial Wave Producer, the PWM value will be the controlled variable while the manipulated variable will be the depth of water displaced by plunger followed by the wave amplitude as the responding variable.

On the other hand, in determining the wavelength, the PWM value of linear motor were manipulated to obtain the wavelength of wave produced from different PWM values. Hence, in this research, the wavelength and wave amplitude will be the responding variables with manipulated variable of PWM values and depth of water displaced by plunger respectively.

3.6 Performance Indicator

There are two main performance indicator in this research which are the wave amplitude and wavelength of the water wave generated. The amplitude of wave is an indicator on whether the depth of water displaced has strong relationship with the wave amplitude in this Artificial Wave Producer model. Besides, the wavelength is also a performance indicator as to determine on whether the wavelength and plunger frequency has strong relationship in this Artificial Wave Producer model.

3.7 Measuring Method

Measuring component was selected after reviewing several past researches on measuring wave amplitude and wavelength. An Iphone SE camera had been tested for its functionality to capture a moving water wave with slow motion setting of 120 fps with resolution of 1080p. The camera was placed perpendicularly to the transparent side with measurement markings of the tank as shown in Figure 3.18. The wave amplitude were determined from the extracted photo by still image from the slow motion video. The use of camera as a measuring tool was also used in research [11] for its comparison between Data Acquisition (DAS) of wave probes and camera.

Figure 3.18 Camera placement

3.8 Experimental Precautions

Several precautions were taken into account in conducting the measurement which include errors from position of camera which is not perpendicularly facing the marked measurement and inaccurate measurement marking on the transparent side of the tank which lead to repetitive data collection to reduce the result error.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Wave Pattern by Half Circular and Triangular Plunger

Figure 4.1 shows wave pattern similar to linear waves by triangular plunger with slight curves due to the reflected wave from the side of the tank while Figure 4.2 shows the wave pattern of circular waves produced by half circular plunger. The linear waves from the triangular plunger were in slight curved wave pattern were also due to the spreading of linear wave because the tank width was much wider than that of the triangular plunger.

Figure 4.1 Wave pattern from triangular plunger

Figure 4.2 Wave pattern from half circular plunger

4.2 Wave Amplitude on Different Depth of Submerged Plunger

The data for triangular plunger was collected and shown in Table 4.1 with the highest wave amplitude of 0.8cm at 5.0cm submerged depth while the lowest wave amplitude of 0.5cm at 1.0cm submerged depth. The wave amplitude at 1.0cm and 2.0cm submerged depth has the same wave amplitude of 0.5cm because the volume of water displaced were low which was 3.5cm^3 and 14cm^3 respectively compared to 31.5cm^3 of plunger submerged for 3.0cm submerged depth. The volume of water displaced were calculated from the submerged volume of the half circular plunger and triangular plunger. Besides, the marking of measurement has smallest scale of division of 0.5cm and the wave amplitude produced at 1.0cm depth was slightly lower than 0.5cm marking. Hence, the closest value to the wave amplitude which was 0.5cm was selected as the data as shown in Figure 4.3.

Table 4-1 Wave amplitude on different depth of submerged triangular plunger

Depth of Submerged Plunger (cm)	Wave Amplitude (cm)					
	Data 1	Data 2	Data 3	Data 4	Data 5	Average
5.0	0.5	0.5	1.0	1.0	1.0	0.8
4.0	0.5	0.5	0.5	1.0	1.0	0.7
3.0	0.5	0.5	0.5	0.5	1.0	0.6
2.0	0.5	0.5	0.5	0.5	0.5	0.5
1.0	0.5	0.5	0.5	0.5	0.5	0.5

Figure 4.3 Camera capture of close to 0.5cm wave amplitude

Table 4.2 shows the wave amplitude for half circular plunger with highest amplitude of 2.0cm at 5.0cm submerged depth and lowest of 1.3cm wave amplitude at 1.0cm submerged depth. The wave amplitude for half circular plunger were higher than that of triangular plunger because of higher submerged volume of the half circular plunger. The wave amplitude at 1.0cm depth of half circular plunger was almost 3 times than that of the amplitude of triangular plunger at 2.0cm depth which were 1.3cm wave amplitude compared to 0.5cm wave amplitude. The displaced volume was also approximately 3 times which were 56.55cm^3 compared to 14cm^3 respectively. The difference of wave amplitude for 1.0cm submerged depth of half circular and triangular plunger were shown in Figure 4.4 and Figure 4.5.

Table 4-2 Wave amplitude on different depth of submerged half circular plunger

Depth of Submerged Plunger (cm)	Wave Amplitude (cm)					
	Data 1	Data 2	Data 3	Data 4	Data 5	Average
5.0	2.0	2.0	2.0	2.0	2.0	2.0
4.0	1.5	2.0	2.0	2.0	2.0	1.9
3.0	1.5	1.5	2.0	2.0	2.0	1.8
2.0	1.0	1.5	1.5	1.5	1.5	1.4
1.0	1.0	1.0	1.5	1.5	1.5	1.3

Figure 4.4 Wave amplitude of half circular plunger at 1.0cm submerged depth

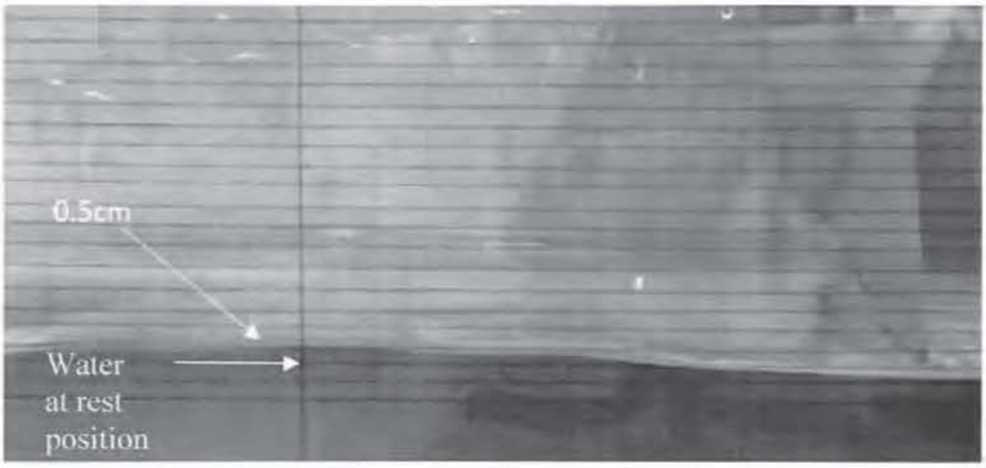

Figure 4.5 Wave amplitude of triangular plunger at 1.0cm submerged depth

The data in Table 4.1 and Table 4.2 were plotted and a best fit line were drawn as shown in Figure 4.6. The linear line equation for both triangular and half circular plunger were determined to test the error with another experimental result by comparing the wave amplitude calculated from the equation. The equation for half circular plunger was determined to be as shown in (4.1) while for triangular plunger was shown in (4.2).

$$y = 0.19x + 1.11 \quad (4.1)$$

$$y = 0.08x + 0.38 \quad (4.2)$$

The R-squared value was determined as well where the half circular R-squared value was 0.9304 and triangular R-squared value was 0.9412. Both R-squared values were close to 1 shows that the depth of submerged plunger has strong relation with the wave amplitude. As an overall view of the graph, the pattern of wave amplitude increases with the increase of depth of submerged plunger for both half circular and triangular plunger due to the increase of submerged volume of the plunger.

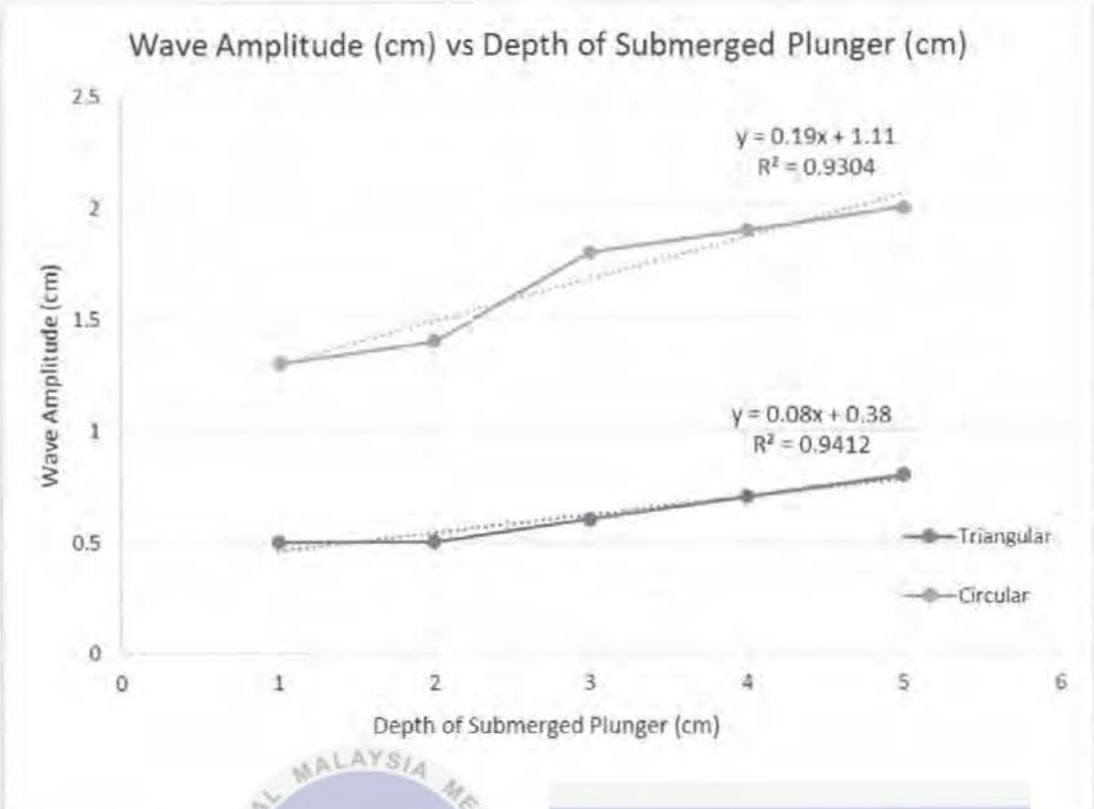

Figure 4.6 Relationship between depth of submerged plunger with wave amplitude

4.3 Comparison of Experimental and Theoretical Value for Wave Amplitude

Table 4.3 shows the experimental data with the theoretical value calculated from the linear equation for triangular plunger of (4.2) that was obtained from the experimental graph in Figure 4.6. The percentage error was highest at 1.5cm depth which shows 20.00% error due to the smallest scale of division for the measurement marking is insufficiently small and the wave produced is small where even small difference of experimental with theoretical value would result in big error difference. The percentage error exceeded 10% for 2.5cm and 1.5cm submerged depth was also due to the hardware design where the angle of submerged plunger were not taken into consideration whereby different angles will result in either no wave or wave amplitude that is too low to be measured by the marking measurement especially when the displaced plunger volume is very low. Besides, the volume of plunger displaced was too low as well which causes little to no wave amplitude produced. The flaw of the design also include on the actuators that were not stable due to vibration during reciprocation that also contribute into different submerged angles. An acceptable range for produced wave amplitude would be an error of less than 10% whereby it is above 3.5cm submerged plunger depth to be within the acceptable percentage error as the experimental line graph converges to the theoretical line graph when wave amplitude and submerged plunger depth were higher. The data in Table 4.3 was plotted as shown in Figure 4.7.

Table 4-3 Wave amplitude on different depth of submerged triangular plunger

Depth of Submerged Plunger (cm)	Wave Amplitude (cm)							
	Data 1	Data 2	Data 3	Data 4	Data 5	Experimental Average	Theory	Error (%)
5.5	0.5	0.5	1.0	1.0	1.0	0.8	0.82	2.44
4.5	0.5	0.5	0.5	1.0	1.0	0.7	0.74	5.41
3.5	0.5	0.5	0.5	0.5	1.0	0.6	0.66	9.09
2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.58	13.79
1.5	0	0.5	0.5	0.5	0.5	0.4	0.50	20.00

Figure 4.7 shows the difference between the experimental and theoretical value where the experimental value gets closer to the theoretical value as the depth of submerged plunger increases because the measurement of wave amplitude could be recorded easier when the wave amplitude were higher. Hence, from the graph, the Artificial Wave Producer could produce wave pattern with triangular plunger similar to the theoretical values but with errors that could be avoided if the angle is taken into consideration and a deeper depth of plunger experiment were carried out as the experimental graph line converges close to the theoretical line as higher amplitude were produced. On the other hand, a more sensitive measurement could help into further reducing the error by providing a more accurate wave amplitude reading especially for small wave amplitude or by doing more repetitive data to reduce the error.

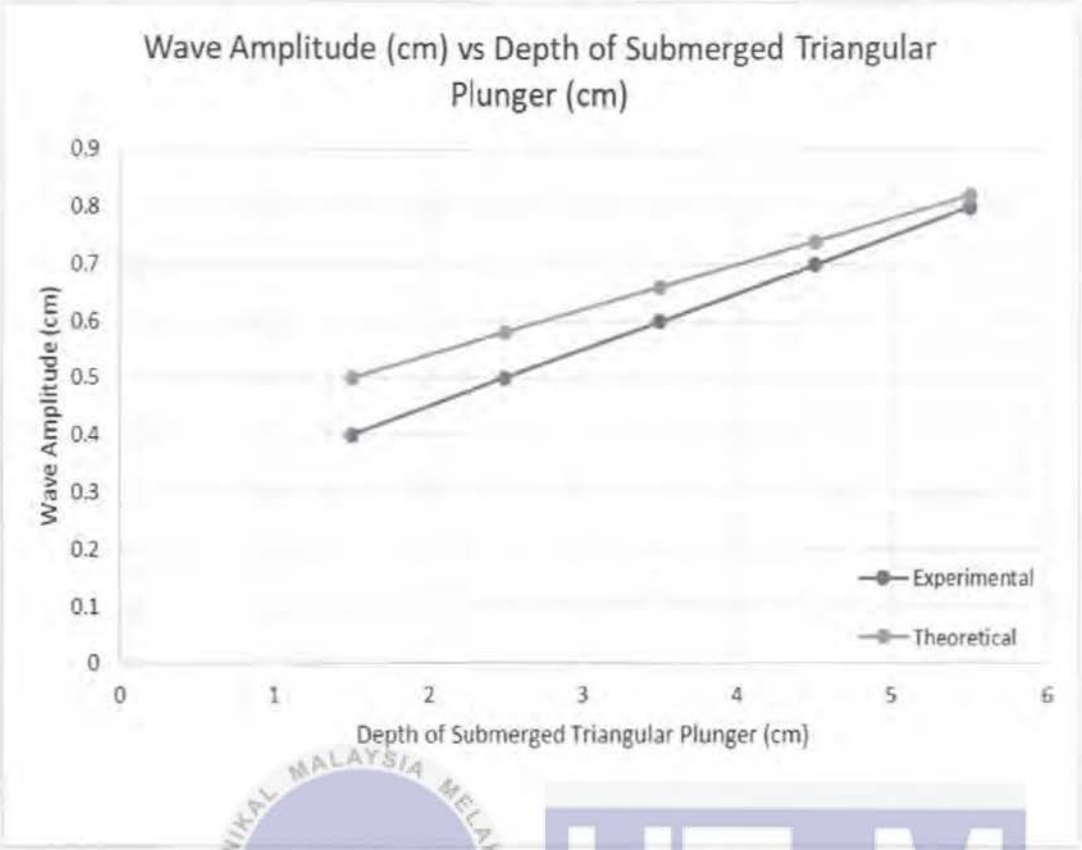

Figure 4.7 Comparison between experimental result and theoretical value for triangular plunger

Table 4.4 shows the experimental data with the theoretical value calculated from the linear equation for half circular plunger of (4.1) that was obtained from the experimental graph in Figure 4.1. The percentage error was highest at 1.5cm depth which shows 6.81% error but in comparison to the percentage error of triangular plunger, the half circular percentage error is much lower because of the volume of submerged half circular plunger is more significant than the triangular plunger that produces higher wave amplitude for easier measurement. The data in Table 4.4 was plotted as shown in Figure 4.8.

Table 4-4 Wave amplitude on different depth of submerged half circular plunger

Depth of Submerged Plunger (cm)	Wave Amplitude (cm)							
	Data 1	Data 2	Data 3	Data 4	Data 5	Experimental Average	Theory	Error (%)
5.5	2.0	2.0	2.0	2.5	2.5	2.2	2.155	2.09
4.5	1.5	2.0	2.0	2.0	2.0	1.9	1.965	3.31
3.5	1.0	1.5	2.0	2.0	2.0	1.7	1.775	4.23
2.5	1.5	1.5	1.5	1.5	2.0	1.6	1.585	0.95
1.5	1.0	1.0	1.5	1.5	1.5	1.3	1.395	6.81

Figure 4.8 shows the difference between the experimental and theoretical value and the difference between the two values were found to be small. The slight error was due to the angle of submerged plunger similar to that of triangular plunger where every reciprocation of the plunger would have different angle of contact due to the hardware design. As to compare percentage error for both plunger, the half circular plunger has lower error than the triangular plunger. The error could be reduced by using a more sensitive measurement method because the current measuring method could only measure up to a 0.5cm scale division. Other way of reducing the error would be by increasing the repetitive data collection for the wave amplitude to get a more accurate and smaller average measurement.

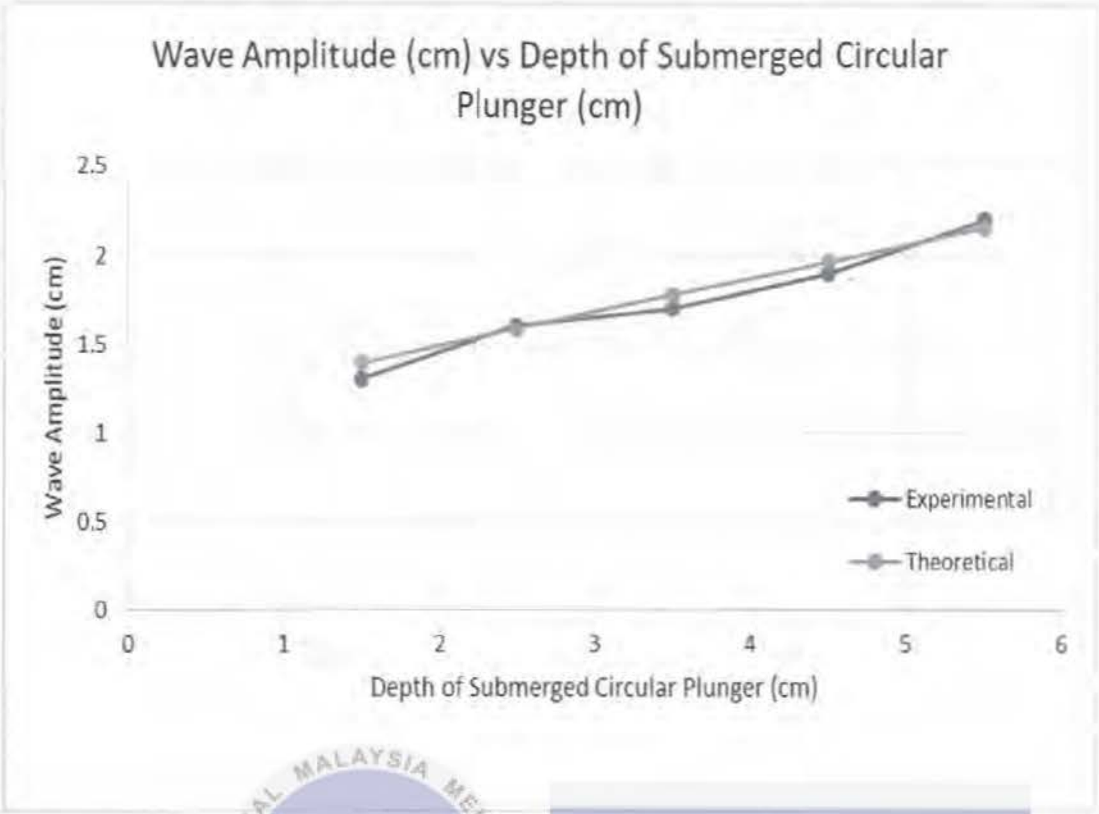

Figure 4.8 Comparison between experimental result and theoretical value for half circular plunger

4.4 Wavelength with changes of Plunger Frequency

Table 4.5 shows the wavelength reading for half circular plunger while Table 4.6 shows the reading for triangular plunger. From both tables, it can be seen that both wavelength reading has the same exponential graph pattern as plotted in Figure 4.9 but the exponential graph for half circular plunger is steeper than the triangular plunger due to higher wavelength at 150 PWM value. In terms of comparing the plunger frequency, the triangular plunger frequency is higher than the half circular plunger frequency even though the PWM value were set the same for both half circular and triangular plunger experiments because the half circular plunger weighs heavier than the triangular plunger. The heavier weight reduces the reciprocating motion at the Scotch Yoke mechanism as the motor requires more torque for every full rotation. Hence, this caused more captured frames between 2 crests for half circular plunger which directly increases the wave period and wavelength. The data for both tables were plotted as shown in Figure 4.7.

Table 4-5 Wavelength with changes of plunger frequency for half circular plunger

PWM	Plunger Frequency (Hz)	No. of Frames between 2 crests	Period, T (s)	Wavelength (m)
150	1.50	91	0.7583	0.8970
175	1.90	77	0.6417	0.6424
200	2.10	54	0.4500	0.3159
225	2.50	50	0.4167	0.2709
250	2.70	38	0.3167	0.1565

Table 4-6 Wavelength with changes of plunger frequency for triangular plunger

PWM	Plunger Frequency (Hz)	No. of Frames between 2 crests	Period, T (s)	Wavelength (m)
150	2.00	66	0.5500	0.4719
175	2.10	56	0.4667	0.3398
200	2.50	49	0.4083	0.2601
225	2.90	38	0.3167	0.1565
250	3.40	34	0.2833	0.1252

Based on Figure 4.9, it can be seen that both triangular and half circular plunger produced exponential graph with a steeper exponential graph for half circular plunger. This was due to big difference for the first two wavelength for 1.50Hz and 1.90Hz which causes the graph to be steeper than that of the triangular plunger. This is because of the plunger frequency was low which produces longer wavelength from longer wave period which was contributed by the weight of the half circular plunger which is heavier than that of the triangular plunger.

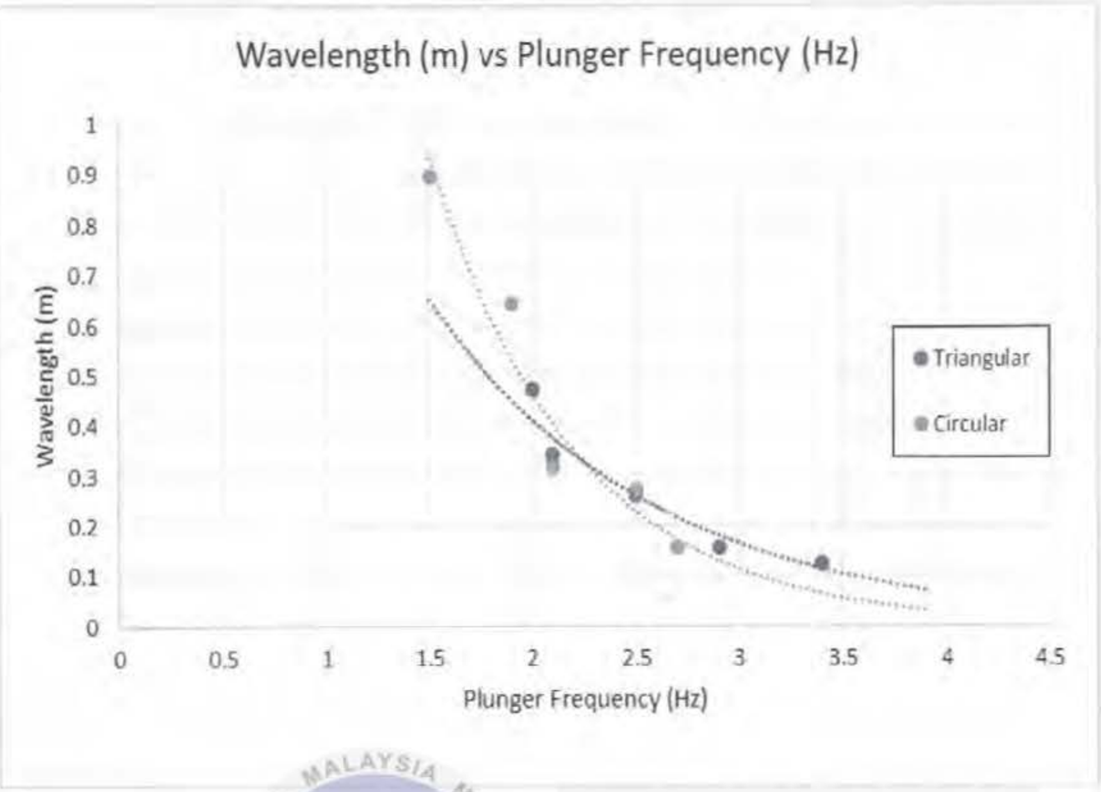

Figure 4.9 Relationship of water wavelength with changes of plunger frequency

4.5 Theoretical Plunger Velocity with Experimental Generated Wave Velocity

From trigonometric calculation, the angle θ is 47.28° and substituting the angular velocity of motor as 39.79 rad/s converted from 380 rpm, the velocity of plunger is 1.215m/s. By using (3.5) the wave velocity calculation results are shown in Table 4.7. From Table 4.7, it can be deduced that all of the wave velocity is lower than the calculated theoretical plunger velocity and this shows that the experimental wavelength is valid because the loss of experimental wave velocity was due to several factors which include energy loss when converting from rotational to reciprocating motion.

In comparison between the wave velocity by triangular plunger and circular plunger, the wave velocity were almost similar when the plunger frequency were the same which for instance at 200 PWM value of triangular plunger and 225 PWM value for half circular plunger which both were at 2.50Hz, had wave velocity of 0.6370 m/s and 0.6501 m/s respectively. Hence, it can be concluded that the wave velocity for both linear and circular were almost similar when the plunger frequency were similar.

Besides, the loss of energy was also due to friction of the Scotch Yoke mechanism and the friction in reciprocating linear wooden actuator towards the guided slot which could be reduced with firm attachment of the circular disc to the motor shaft and the linear actuators for both top and bottom has to be perfectly fit into the guided slot so that the conversion of rotational to linear motion is smooth when the vibration of the whole system is minimal.

Table 4-7 Wave velocity with calculated theoretical plunger velocity

PWM	Wave Velocity (m/s)		Theoretical Plunger Velocity (m/s)
	Linear	Circular	
150	0.8580	1.1829	1.215
175	0.7280	1.0011	
200	0.6370	0.7020	
225	0.4942	0.6501	
250	0.4419	0.4942	

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The Artificial Wave Producer was able to generate wave patterns of linear and circular with the use of triangular and half circular shaped plunger. The graph pattern for wave amplitude shows that the Artificial Wave Producer could generate wave with increasing wave amplitude along with the increase of the depth of submerged plunger for both triangular and half circular plunger but the half circular plunger produces higher wave amplitude due to its larger design. From the comparison of experimental and theoretical values, it can be concluded that the Artificial Wave Producer was able to produce wave with a certain error that is close to the theoretical graph of wave amplitude versus depth of submerged plunger with higher acceptance when the depth of submerged plunger increases. On the other hand, the wavelength of the generated waves by both half circular and triangular plunger has the similar exponential graph pattern influenced by the plunger frequency. Lastly, the wavelength results were supported with the theoretical plunger velocity comparison to the generated wave velocity through experiment because the wavelength results would not be valid if the wave velocity exceeds the theoretical plunger velocity.

5.2 Recommendation

There are couple of loop holes for improvements where the main improvement could be done on the hardware design itself by using a tougher and more stable material for the linear actuator and Scotch Yoke mechanism to prevent energy loss from vibration during reciprocation while the smoothness of motion conversion in the Scotch Yoke mechanism can be further improved by selecting a lesser friction material such as a smooth wood coated with waterproof paint to prevent water absorption. Besides, the measuring method can be further improved with a smaller scale of division or by using a more sensitive and accurate method such as wave probes that could help to obtain a more accurate data. Apart from that, designing the plunger that is wide enough to fit in a customised wave flume could help to reduce linear waves from dispersing into a curved-like circular waves. Moreover, in demand of producing a smoother circular waves, a conical shaped of plunger can be used to prevent water splashes produced by flat and even half circular surface of plunger. The last but not least, in desire to produce higher wave amplitude, the design of plunger should be in larger volume so that it could displace more water when submerged and the level of submerged depth can be added onto the actuator itself with accurate marking so that the plunger can be fixed onto different levels of measurement to be submerged into the water.

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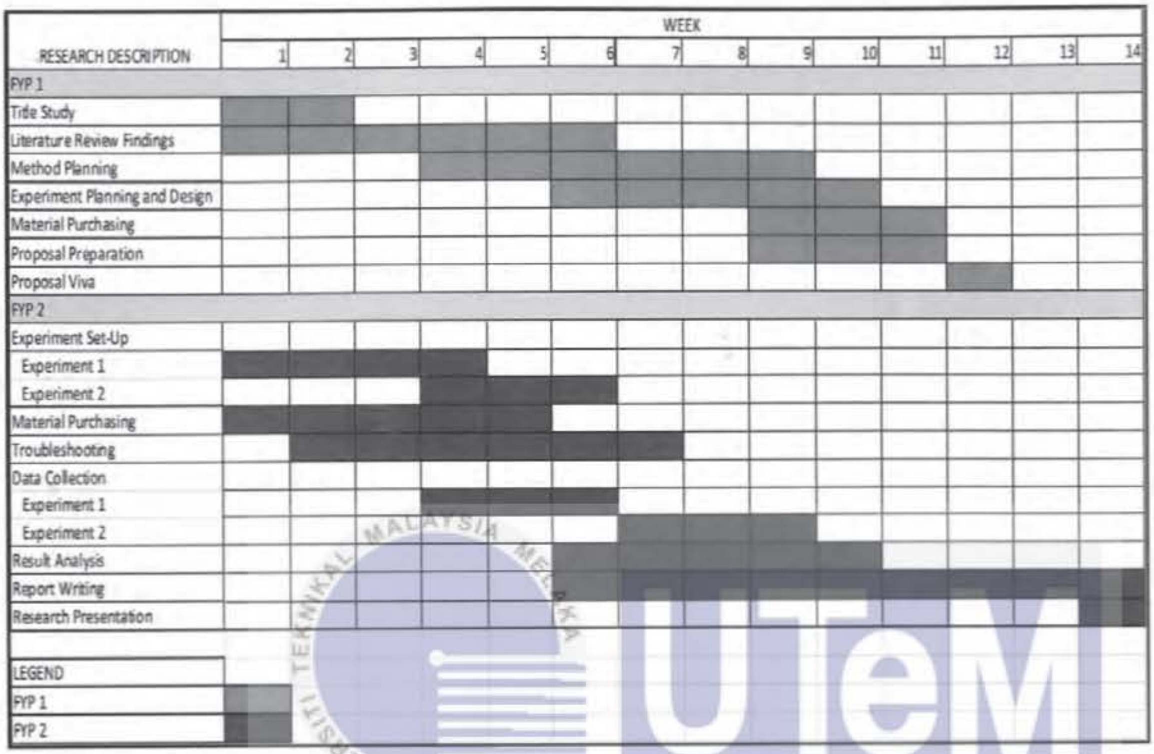
APPENDICES

APPENDIX A RESEARCH GANTT CHART



RESEARCH DESCRIPTION	WEEK 1	2	3	4	5	6	7	8	9	10	11	12	13	14
FYP 1														
Title Study	▒	▒												
Literature Review Findings	▒	▒	▒	▒	▒	▒								
Method Planning				▒	▒	▒	▒	▒	▒					
Experiment Planning and Design						▒	▒	▒	▒	▒				
Material Purchasing									▒	▒	▒			
Proposal Preparation									▒	▒	▒			
Proposal Viva												▒		
FYP 2														
Experiment Set-Up														
Experiment 1	█	█	█	█										
Experiment 2				█	█	█								
Material Purchasing	█	█	█	█	█									
Troubleshooting		█	█	█	█	█	█							
Data Collection														
Experiment 1				█	█	█								
Experiment 2							█	█	█					
Result Analysis						█	█	█	█	█				
Report Writing						█	█	█	█	█	█	█	█	█
Research Presentation														█

LEGEND	
FYP 1	▒
FYP 2	█

APPENDIX B ARDUINO CODINGS

```
 int In1 = 7;
int In2 = 8;
int ENA = 5;
int SPEED = 200 ;

void setup()
{
  pinMode(In1,OUTPUT);
  pinMode(In2,OUTPUT);
  pinMode(ENA,OUTPUT);

  digitalWrite(In1,HIGH);
  digitalWrite(In2,LOW);

  analogWrite(ENA,SPEED);
}

void loop() {
  // put your main code here, to run repeatedly:

}
```

APPENDIX C HALF CIRCULAR PLUNGER

APPENDIX D TRIANGULAR PLUNGER