INVESTIGATION OF SEA WAVE POINT ABSORBER: THE DUAL-DIRECTION MECHANISM

RAJA AHMAD SHURIM BIN RAJA ZAINOL
(Matric No. :137861)

UNIVERSITI SAINS MALAYSIA

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INVESTIGATION OF SEA WAVE POINT ABSORBER: THE DUAL-DIRECTION MECHANISM

by

RAJA AHMAD SHURIM BIN RAJA ZAINOL
(Matric No.: 137861)

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signature………………………… (RAJA AHMAD SHURIM BIN RAJA ZAINOL)

Date 27/07/2021

STATEMENT 1

This dissertation is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

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LIST OF SYMBOLS

a	area
A_{WP}	area of water plane
c_p	damping coefficients
c_r	radiation damping coefficient
c_{vd}	linearized viscous damping coefficient
c_ϕ	restoring spring coefficient
E	Energy
F_e	heave exciting force
F_h	hydrostatic force
F_r	heave radiation force
F_{we}	wave excitation
f_z	natural frequency
f_ϕ	natural frequency of floating body
g	gravitational acceleration
H_I	height of incident wave
H_R	Height of reflected wave
H_s	significant wave height
H_T	Height of transmitted wave
I_w	added mass moment of inertia
I_y	mass moment of inertia of the device
k_{hs}	hydrostatic stiffness
k_p	PTO stiffness
k_s	hydrostatic stiffness of the buoy
L	Wavelength
M	total mass of sea wave point absorber

m_w	added mass
ρ	density
P_w	Power of a wave period
T'	Wave period
T_e	energy period
ν_g	Speed of propagation
w_m	frequency maximal
w_n	damped natural frequency
w_o	undamped natural frequency
y	displacement in the vertical heave direction
$\dot{y}$	instantaneous velocity
$\ddot{y}$	instantaneous acceleration

LIST OF ABBREVIATIONS

PTO	Power take off
WEC	Wave energy converter
TWh	Terawatt- hour
RPM	rotation per minutes

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ABSTRAK

Tenaga gelombang laut adalah salah satu jenis sumber tenaga boleh diperbaharui lebih baik berbanding dengan tenaga suria dan angin kerana jumlah ketumpatan tenaga yang besar dan luar biasa. Disebabkan oleh beberapa masalah dan cabaran, teknologi untuk mengembangkan kepada sistem pengkomersialan yang dapat menuai tenaga gelombang laut masih kurang dalam beberapa komponen atau prinsip. Penterap ombak titik adalah salah satu teknologi atau prinsip pentukar tenaga gelombang yang sedap dalam proses perkembangan dan kajian, dan mempunyai masa depan yang cerah. Matlamat kajian ini adalah untuk menunjukkan perkembangan penterap ombak titik yang mampu menjana kuasa elektrik daripada dua jenis gelombang, gelombang puncak dan gelombang melalui. Rekaan ini menggunakan mekanisma barrel cam yang dapat menggunakan dua arah gerakan selari dan menukarkan ia kepada satu arah putaran. Kajian bermula daripada mereka rekaan mengunaakan perisian CAD iaitu SolidWorks. Garis sempadan dan pengiraan frekuensi resonansi telah ditentukan dan dikira sebelum simulasi bermula. Rekaan ini menjalani simulasi pergerakkan di dalam SolidWorks dan simulasi ketumpatan tenaga dijalankan di dalam perisian ANSYS. Putaran seminit tertinggi dicatatkan oleh barrel Cam 1 pada pelampung B dengan 220.82 putaran seminit manakala puarata putaran seminit tertinggi dicatatkan oleh barrel cam 1 pada pelampung C dengan 108.36 putaran seminit. Ketumpatan tenaga tertinggi dicatakan oleh pelampung C dengan 21.25 J/Kg.

INVESTIGATION OF SEA WAVE POINT ABSORBER: THE DUAL-DIRECTION MECHANISM

ABSTRACT

Ocean wave energy is one type of renewable energy resources that can be consider more reliable compared to solar and wind energy due to it vast and tremendous amount of energy density. Due to several issue and challenge, the technology to develop a commercialise system that can harvest the ocean wave energy is still lack in several component or principle. Point absorber is one of the Wave Energy Converter (WEC) technology or principle which still under development and research that can be consider having a bright future. In this paper, the development of sea wave point absorber that can generate the electricity from both type of wave, crest and trough. The design is using the barrel cam mechanism that can use the dual direction motion and transfer it into one single rotation. The research started by designing the design using the CAD software which is SolidWorks. The boundaries and calculation of the natural frequency of the floater is defined and calculated before the simulation started. The design is undergoing the simulation of motion in SolidWorks while the simulation of energy density is conducted using the ANSYS software. The highest rotation per minute achieves on barrel cam 1 with floater C with 220.82 RPM while barrel cam 1 with floater B has the highest average rotation per minutes with 108.36 RPM. The floater C has the highest energy density with 21.25 J/Kg.

CHAPTER 1 INTRODUCTION

1.1 Overview

Ocean waves are enormous unexploited energy resources, and the extraction of the energy potential can be considerable. The development of harvesting ocean wave concept started past 2 centuries. While the development consists multiple design and operation principle device which been proposed in literature and practice, it still under prototype and researching stage. Further development is needed to ensure the capabilities of the design to adapt with large scale energy harvesting[1].

With the climate change and increment of CO_2, the focus of generation of electricity resources are diverting to the renewable resources. Solar and wind energy has lower energy density compared to the ocean wave energy which is more productive to harvest and environmentally friendly. The process to develop a system or device that can generate energy from renewable resource is not a piece of cake task. If taken globally into account, the resources of ocean wave have higher total potential than the global electricity demand which is 16 000 TWh per year[2].

The majority of first- generation wave energy converters were based on the oscillating water column (OWC) principle and were deployed onshore. Following this first generation, WEC developers moved their project offshore, and the current second generation of devices is most often planned to be installed in the nearshore area which has less than 50 m water depth, where they avoid the main drawback of the first generation; decreased energy resource when waves approach the shore, low social acceptability of such plants and so on. Some WECs are made up of one or more lined wave actuated bodies. The so-called “point absorber” sub-family of these devices has a relatively modest light displacement and dimension in proportion to the wavelength[3].

Point absorber, in general are mechanical oscillator that function better as the wave frequency approaches their natural frequency. However, because of the sea surface has a continuous frequency wave spectrum, the efficiency of these devices may be reduced in real broad branded sea states. Once possible way to compensate for this loss it to provide the device with an active controller capable of adapting it response to the excitation[3].

1.2 Project Background

In this study, the sea wave point absorber that will be studied in this project is the semi-submerged sea wave point absorber with dual direction mechanism. The absorber will transform the oscillating motion of the sea wave into rotary motion. The rotation movement will connect to a shaft of a generator that will produce electricity. The focus of this mechanism is to utilize the movement of the floater which in two directions in linear motion. Two opposite directions of twisted is connected to become 1. one single shaft and it will be connected to the generator shaft. The movement of the floater is generated by the sea wave. The direction of the movement is up and down. The opposite direction of twisted will create the single rotation from two different linear movement which is up and down. The twisted shaft will be used to create the continuous rotation since the motion of the floater may not consistence due to the harmonic motion of the wave.

In the previous senior's design, the sea wave point absorber is consisting of the sea wave point absorber that generate the rotation movement from the movement of the floater. The limitation of this design is the rotation of the twisted shaft only been generated if the floater moves down. From the design, the spar tends to rotate at the opposite direction if the floater moves upwards. This happened due to the friction of the spar cap and the gear. The best angle of the twisted shaft already been determined and can be taken from the previous senior's design[4].

The frequency of the sea wave point absorber and the wave characteristic need to be determined in this project to increase the efficiency of the sea wave point absorber. The frequency needs to be equal or close with the wave characteristics which act as reference so it can produce a better result[5].

1.3 Problem Statement

The current demand for the fossil fuel increase by time because of the increment of population around the world while the supplies of it will run out on certain amount of time[6]. To overcome this problem new type energy resources is needed so that the sustainability of human being is taken care. One of the new types of energy is wave energy. This energy is clean compare to the common energy been harvested on fossil fuel which can make pollution and continual compare to solar or wind energy[5]. The development of system that can harvest the wave energy is already ongoing few decades back but only several systems had been deploy on real ocean due to several causes. Some of causes is the harsh environment[7] and single direction mechanism. The single direction has less efficiency due to movement of the absorber only in one direction.

1.4 Objective

The purpose of this project is to provide a reliable dual direction mechanism of a sea wave point absorber with high efficiency that can work as a wave energy harvester.

1.5 Scope Of Work

The dual direction sea wave is designed based on previous senior's design using the SolidWorks software. The simulation of the prototype needs to be done after the design been finalized. The prototype needs to be fit inside the small tank with cross section of 30cm x 90cm which a test will be conducted in it. The displacement of the floater, barrel cam rotation and the movement direction will be observed. The natural frequency of the device and the wave characteristic will be studied.

CHAPTER 2 LITERATURE REVIEW

2.1 Type Of Sea Converter

The sea wave converter has 3 type which are attenuator, point absorber and terminator[8]. The attenuator is a device that lie parallel to the predominant wave direction and ride the waves. The point absorber is a device that have smaller dimension than the incident wavelength. It can be floating structure or submerge below the water depends on n the pressure differential and move up and down. The terminator is a device that have principal axis that parallel to the wave front or its perpendicular to the predominant wave direction[8]. The advantage of the point absorber is the wave course is less crucial because of the small size of the device[7].

Figure 2.1 Attenuator Device[7]

Figure 2.2 Point Absorber Device[7]

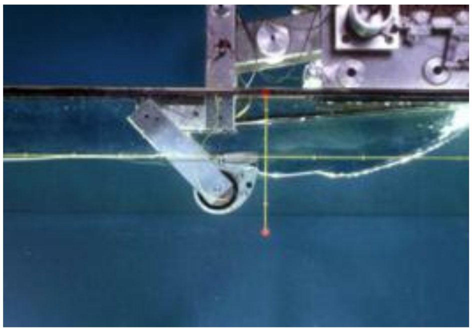

Figure 2.3 Terminator Device[7]

2.2 Mode Of Operation

The sea wave converter consists of several mode in operation. First is submerged pressure differential. This mode uses the pressure difference above the device between the wave crest and trough and it consist of two part which are seabed fixed air-filled cylindrical chamber and moveable upper cylinder. This mode creates the movement downward when the crest passed the device which make the water pressure above the device to compress the air inside the cylinder. The water pressure will reduce, and the cylinder will move upwards as the trough passed by the device. Unexposed to the heavy slamming forces experience same as floating device and reduce the visual impact is one of the advantages of this mode. This mode generally locates at the nearshore[8].

The second mode is oscillating wave surge converter. It generally consists of a hinged deflector and terminator. This mode generates the movement of back and forth of the terminator by using the velocity of the wave. This mode generally locates at the nearshore which the top of deflector is above the water surface and the hinged it on the seabed[8].

The third mode is the oscillating water column. This mode consists of a chamber with an opening to the sea below the waterline. This mode generates the movement of the turbine with using the pressure of the water that been forced to flow into the chamber as the wave reach the device will push out the air inside the chamber into a turbine and flow out to the atmosphere. When the water flow back into the sea from the chamber, the air will flow back inside the chamber though the turbine. This mode located at the shoreline[8].

The fourth mode is the overtopping device. This mode consists of a large pair of curve reflector. This mode generates the movement of the turbine by gather the waves that flow up a ram and over the top of into a raised reservoir which the water later will flow back to the sea though a turbine which located below the reservoir[8]. This method normally located onshore or floating offshore[9].

2.3 Challenge

There are several challenges for ocean wave energy harvester even it has different size, technologies and type of operation. First is the seasonal variation. It is proven that sea states are not consistent, and it is variable throughout the year. Due to the variance of condition, its is hard to design a WEC that can handle and function efficiently. Second challenge is large wave period. High energetic location tends to have large wave period. WEC need to be large in size and mass in order to match the device natural frequency with frequency of the waves which WEC need to resonance to achieve the highest energy capturing. When the device is large, it difficult in term of design, manufacturing, transportation and also maintenance. Next challenges is theoretical difficulties. The wave energy harvesting contain boundary element method of hydrodynamics, finite element method of fluid mechanics, mechanical to electrical energy transfer, power electronic and control theories. Having this multiple method which make it become intense modelling. Next is the PTO mechanism. The main PTO mechanism is linear generator, power hydraulic, turbine and linear to rotation motion transmission mechanism. This PTO normally been designed on consistent condition which difficult to achieve due to seasonal variance of ocean wave. Some of the PTO is design to operates high velocities and low force but it is opposite to ocean wave condition which is low velocities and high force. Then if the device is place offshore which 40Km to 50 Km from the landline and maybe submerged under the water, the maintenance of this device will be difficult due to contamination issue of the surrounding ecological environment. Due to ocean wave condition which have high force exerted on WEC, it become a new challenge whether the device can hold on or survive under extreme condition and force exerted on the device[10].

2.4 Location

The sea wave energy converter can be affected by the location of the device place. There are 3 type of location that can place the sea wave converter[8]. First is at the shoreline. The shoreline can be considered as the physical interface of land and water[11]. This location has several advantages which are near to the utility network, easy to maintain and low possibility of damage due to shallow water. The disadvantage of this location are it has low wave power as the water is shallow and the issue of the tidal range[8].

The second location is the nearshore. The nearshore is still consider as the shallow water due to the depth is less than one quarter of the wavelength. The device located in nearshore normally been attached to the seabed. The disadvantage of the nearshore is low wave power as the water is shallow[8].

The third location is the offshore. Offshore is consider as deep water. The device that places at the offshore has advantage of the higher wave power can be converted compared to the shoreline or nearshore. The disadvantage of the offshore is the device is difficult to build as it need to survive harsh environment[8].

2.5 One-Body Point Absorber

According to Al Shami [10], one body point absorber is the simplest type of the wave energy harvester. This device basically a floating buoy which force from the large wave exerted against the fixed reference which normally fixed at the bottom of the sea. By using this device, the energy is harvested with power take off (PTO) that place between the buoy and fixed reference. The dynamic of this device can be studied in frequency domain or time domain. For each domain has its own upper hand and drawback. The frequency domain is simple and non-computationally demanding as its advantage while having the nonlinear element such as higher order waves, non-linear wave excitation force and complex mooring are disadvantage of using the frequency domain. The time domain usually uses a non-linear numerical model or computational fluid dynamic based on finite element analysis as its simulation. The time domain tends to be more accurate compared to the frequency domain but for the one body point absorber, the frequency domain simple method is enough to for the modelling of one body point absorber. So, frequency domain is reliable to solve the dynamic of one-body point absorber and the linear equation based on Newton's second law of motion in single degree of freedom can be used. The equation can be defined as[10]: -

$$M\ddot{y} + k_p y + c_p \dot{y} + k_{hs} y + c_{vd} \dot{y} + c_r \dot{y} = F_{we} \qquad [2.1]$$

For the time domain, the Cummins's equation can be applied on the point absorber[10]:

$$(m + m_a^{\infty})\ddot{y}_{(t)} + \int_{-\infty}^{t} RIF\,(t - \tau)\dot{y}_{(t)} d\tau + k_{hs} y_{(t)} = F_{(t)}^{wave} - F_{(t)}^{ext} \qquad [2.2]$$

Based on to Liang Ai[12], the two one-way bearings and output shaft having the engagement and disengagement that create the rotation in one direction. With this condition of engagement and disengagement the equation of the power take off system with the mechanical motion rectifier can be conclude. The system is disengaged, and rotational generator is decoupled with the driving rack and pinion when the rotation of the output shaft is larger than the rotation speed of driving pinion. The system will be engaged when the rotation speed of output shaft is equal to rotation speed of driving pinion. The power take off system is modelled as linear damping system in many literature (Heath et al., 2000; Elwood et al., 2010; Babarit et al., 2012; Vicente et al., 2013). The dynamic equation of a buoy oscillating in heave can be written as:

$$mX = F(t, x, \dot{x}, \ddot{x}) - F_{PTO} \quad [2.3]$$

Where x is the displacement of the buoy in heave, m is the mas of the buoy and $F(t, x, \dot{x}, \ddot{x})$ is the heave hydrodynamic force. The $F(t, x, \dot{x}, \ddot{x})$ can be decomposed as:

$$F(t, x, \dot{x}, \ddot{x}) = F_h(x) + F_r((t, \dot{x}, \ddot{x}) + F_e(t) \quad [2.4]$$

Where $F_r((t, \dot{x}, \ddot{x})$ is the heave radiation force exerted by the water on the buoy as a result of the buoy's oscillation in absence of incident waves, $F_e(t)$ is the heave exciting force exerted by incident waves while the buoy fixed and F_h is the heave hydrostatic force which can be expressed as

$$F_h = k_s x = \rho g \pi a^2 x \quad [2.5]$$

The $k_s x = \rho g \pi a^2 x$ is defined as the hydrostatic stiffness of the buoy.

2.6 Wave Energy Resources

According to Al Shami[10],wave is created from the blowing wind on the surface of the ocean. The thermal radiation from the sun create a change in air temperature that eventually generate the propagating wave along the surface of the