Medicon Agriculture & Environmental Sciences
Volume 4 Issue 3 March 2023
Research Article

Power from A Single Wave-Energy Absorber

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Received: February 08, 2023; **Published:** March 02, 2023

Abstract

Wave energy technologies have been around for decades. But for a variety of reasons, including rising oil prices, technological advancements and the sheer grit of a handful of pioneer developers, it has made a huge splash since 2005. This paper presented the result of power absorbed by a single wave-energy absorber.

Introduction

One of the major contributors to climate change is the carbon dioxide (CO_2) emissions produced by coal, oil and gas to generate electricity. Some of the world's leading climate scientists predict that if no action is taken, the world's average surface temperature will increase from 1.4 to 5.8^{0}C by the year 2100. The potential costs to society are enormous. Globally, temperature has already risen by 0.6^{0}C in the past century.

The world energy consumption is estimated to rise considerably over the next decades. Being constantly reminded that traditional methods of energy production are contributing to serious environmental problems; the governments worldwide have seen the urgent need for pollution-free power generation. The energy sector was forced through a renovating process, which sees an opening towards renewable energy. In the dynamic evolution of the renewable energy, wave energy is emerging since the ocean covers an estimated 70% of the earth's surface and provides a vast resource with virtually unlimited untapped energy potential.

Power from ocean waves is a derived form of solar energy, with wind being the agent that transfers the sun's energy to the sea surface. Winds that produce waves are caused by pressure differences in the atmosphere arising from solar heating. Once created, waves can travel thousands of kilometers with little energy loss. Even the longest waves do not begin to "feel the bottom" until they enter water depths of 300 meters or less. Consequently, wave energy generated anywhere within an ocean basin ultimately arrives at some island or continental margin of that basin virtually undiminished.

Wave energy is gathered along its coastlines, which total 336,000 km in length. At a global rate of 10^{12} to 10^{13} watts, the average wave energy flux worldwide is on the order of several to a few tens of kilowatts per meter of shoreline (kW/m), which is the typical flux that would be incident on a wave energy device.

The two components of energy within waves are potential energy and kinetic energy. Potential energy refers to the form or elevation of the wave, while kinetic energy is associated with the velocity of the water particles within the wave. Ocean wave energy conversion technologies therefore makes use of the kinetic energy trapped within the ocean's waves to produce electricity.

Section2 mentioned generally about wave-energy absorber. Section 3 provided basic theory background of power absorption of a single wave-energy absorber. Following in section 4, the results were given. In section 5, conclusion was given about this paper.

Wave-energy absorber

Renewable energy is the term used to describe a wide range of naturally occurring, replenishable energy sources. At present 5%-20% of current global energy needs are met from such renewable energy sources (mainly traditional biomass, hydroelectricity, wood and geothermal sources). Newer renewable energy technologies have the potential to meet an increasing proportion of global energy needs over the coming decades. These technologies include marine-based renewable: offshore wind, wave and tidal energy.

Ocean waves represent the most concentrated form of renewable energy and abundant resources are available around the world. However, finding a reliable and efficient method to extract that power has long been a barrier to commercialize wave-energy production. Over the past couple of years, this has begun to change with the emergence of various new wave-energy technologies.

A large number of wave energy devices have been invented, but only a small proportion of these have been tested and evaluated. Furthermore, only a few have been tested at sea, in ocean waves, rather than in artificial wave tanks.

As of the mid-1990s, there were more than 12 generic types of wave energy systems. Some systems extract energy from surface waves. Others extract energy from pressure fluctuations below the water surface or from the full wave. Some systems are fixed in position and let waves pass by them, while others follow the wave and move with them. Some systems concentrate and focus waves, which increases their height and their potential for conversion to electrical energy.

A wave energy converter may be placed in the ocean in various possible situations and locations. It may be located on the shore or on the sea bed in relatively shallow water. A converter on the sea bed may be completely submerged, it may extend above the sea surface, or it may be a converter system placed on an offshore platform.

The problem of positioning large structures out at sea so as to move in response to the slow undulations of the ocean surface, and the conversion of that motion to usable energy belongs to mechanical, civil, electrical and marine engineers. Nevertheless, before that stage is reached, a decision has to be taken on the type of device, whether linear or modular, surface or submerged, which is to be chosen for small scale tank tests leading up to the full-scale prototype. The abundant power which is available in the ocean makes it certain that any device, large or small, will be capable of transferring some of this wave energy to mechanical energy with a greater or lesser efficiency. But how does the new inventor decide on his device-on its shape, size, spacing from its neighbours? [1].

It is here that applied mathematician, especially if he has knowledge of hydrodynamics, can continue to make valuable contributions to the fundamental understanding of the complex interaction between waves and energy-absorbing structures.

Power absorbed by Wave-energy absorbers

Wave energy can be considered as a concentrated form of solar energy. Winds, generated by the differential heating of the earth, pass over open bodies of water, transferring some of their energy to form waves. 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 distance over which it blows.

A single absorber

We consider first a single body constrained to make small simple harmonic oscillations of radian frequency ω in response to an incident regular wave also of frequency ω. For simplicity the motion is assumed to be restricted to just single mode operation with linear damping proportional to velocity. This assumption of linear damping is only required in what follows to ensure a body response at the incident wave frequency only. We shall primarily be concerned with the maximum achievable capture width rather than the details of the body dynamics [1].

The hydrodynamics wave force on the body in the direction of its induced motion, $F(t)$, may be write.

$$F(t) = F_S(t) + F_R(t) \qquad (1)$$

Where $F_S(t)$ is the force on the body assuming it to be held fixed in the incident wave and $F_R(t)$ is the force on the body assuming it to be oscillating with its induced motion in the absence of the incident wave. It is customary to write.

$$F_R(t) = -MU(t) - BU(t) \qquad (2)$$

Where M, B are the (real) frequency-dependent added mass and damping coefficients for the body in its mode of motion, and is the velocity of the body. It is worth noting, however, that (2) is purely conventional and only applies to simple harmonic motions at the fundamental frequency ω. The correct description of the motion of a floating body as a function of time involves a convolution integral describing the continuing influence of previous body motions on its present motion.

The mean rate of working of the hydrodynamic forces on the body is.

$$P = \overline{F(t).U(t)}^{t}$$

where $^{-t}$ denotes time average over a period.

Clearly, from (1) and (2).

$$P = \overline{F_S(t)U(t)}^{t} - \overline{BU^2(t)}^{t} \qquad (3)$$

since $\overline{\dot{U}(t)U(t)}^{t} = 0.$

if we write $F_S(t) = \mathrm{Re}\{X_S e^{i\omega t}\}$

$$U(t) = \mathrm{Re}\{U_0 e^{i\omega t}\}$$

then (3) becomes.

$$P = \tfrac{1}{2}\mathrm{Re}\{X^*{}_S U_0\} - \tfrac{1}{2}B|U_0|^2 \qquad (4)$$

After some elementary integration. Here * denotes the complex conjugate.

By re-arranging (4) we obtain.

$$P = \frac{1}{8}|X_S|^2 / B - \tfrac{1}{2}\left|U_0 - \tfrac{1}{2}X_S / B\right|^2 .B \qquad (5)$$

Now B, which describes the wave-making ability of the body, is necessarily positive so that P is maximized by choosing $U_O = \tfrac{1}{2}X_S / B$ in (5) whence.

$$P_{\max} = \frac{1}{8}|X_S|^2 / B \left(= \tfrac{1}{2}B|U_0|^2\right) \qquad (6)$$

and it follows that the maximum mean power that can be absorbed is equal in magnitude to the last term in (4), and this is achieved when the velocity is in phase with the exciting force.

It follow from (6) that a good wave absorber is a body for which is $|X_S|$ large and B is small. Not unexpectedly, it turns out these quantities are related to each other. Thus it may be shown, by using Green's Theorem and the method of stationary phase, that, in deep water.

$$B = \frac{1}{8\lambda P_W}\int_0^{2\pi}\left|X_S(\theta)\right|^2 d\theta \qquad (7)$$

Where is the wavelength of the incident wave train, and

$$P_W = \tfrac{1}{2}\rho g A^2.C_g = \rho g^2 A^2 / 4\omega$$

is the mean power in the incident wave per unit crest length, C_g being the group velocity. Also $X_S(\theta)$ is the exciting force on the fixed body due to an incident wave making an angle $\pi + \theta$ with the positive x-axis.

$$l_{\max}(\beta) \equiv \frac{P_{\max}}{P_W} = \lambda\left|X_S(\beta)\right|^2 \Big/ \int_0^{2\pi}\left|X_S(\theta)\right|^2 d\theta \qquad (8)$$

Where $l(\beta)$ defines a capture width, or absorption width, being as the width of the two dimentsional wave-train having the same mean power as the body extracts.

A single absorber in a channel

Most wave-tank experiments on wave-energy absorbers are carried out in narrow tanks where the influence of the side walls cannot be ignored. It follows since the side walls are theoretically equivalent to an infinite array of image devices that such experiments are modeling an infinite array of devices in long crested regular or random beam seas [1].

It is desirable, therefore, to extend the theory for single devices to this situation so that comparison of theory and narrow-tank experiments can be made.

We return to equation (7) since the theory leading to this result remains the same. To make further progress, we need a relation between X_S and B for bodies in channels. This can be achieved by an application of Green's theorem. Thus, provided the wavelength λ is greater than the channel width, it can be shown that

$$X_S = \rho g A A^{+}.d \qquad (9)$$

and $$B = \frac{\rho\omega}{2}\left(\left|A^{+}\right|^2 + \left|A^{-1}\right|^2\right).d \qquad (10)$$

These results are a direct extension of the strictly two-dimensional results of Haskind to bodies in channels, the only difference being the factor *d*. The quantities A^+ and A^- are the complex potential amplitudes of the wave-trains which are radiated in the upstream and down-stream directions due to forced motion of the body with unit velocity. The incident wave is assumed to come from the upstream direction.

Combing (9) and (10) gives.

$$B = \frac{\left|X_S\right|^2}{8P_W d}\cdot\frac{\left|A^{+}\right|^2}{\left|A^{+}\right|^2 + \left|A^{-}\right|^2} \qquad (11)$$

which, on substitution in (7) gives.

$$P_{\max} = P_w.d\frac{|A^+|^2}{|A^+|^2 + |A^-|^2} \quad (12)$$

For a cylinder which completely spans the wave-tank this gives the well-known two-dimensional result for the maximum efficiency.

$$\eta_{\max} = \frac{P_{\max}}{P_W.d} = \frac{|A^+|^2}{|A^+|^2 + |A^-|^2} \quad (13)$$

For cylinders with cross-sections such as a Salter "duck" extremely high efficiencies can be achieved since its shape is such that $|A^+| << |A^-|$

For cylinders oscillating about an axis of symmetry.

$$\eta_{\max} = \frac{1}{2}$$

Showing that at most half of the incident wave energy can be absorbed. This result remains true for isolated symmetric bodies in channels since from (12).

$$l_{\max} = \frac{P_{\max}}{P_W} = \frac{1}{2}d \quad (14)$$

$$P_{\max} = \frac{1}{2}P_W.d$$

Results

A single Absorber

Relationship between Maximum mean power and Exciting force when Damping coefficient varied.

Result

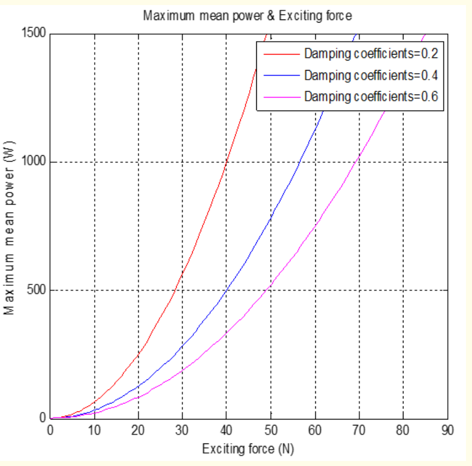


Figure 1: Graph Maximum Mean Power & Exciting force when damping coefficient varied.

Relationship between Maximum mean power and Velocity of the body when Damping coefficient varied.

Result

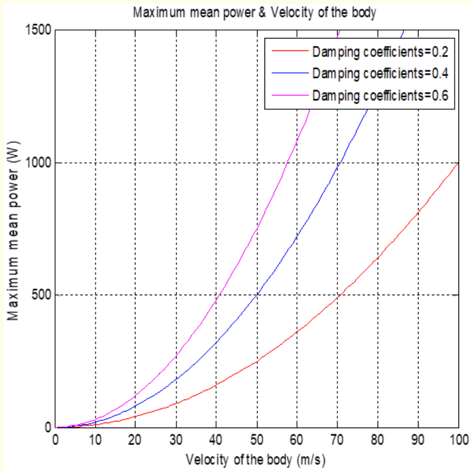


Figure 2: Graph Maximum Mean Power & Velocity of the body when damping coefficient varied.

A single absorber in a channel

Comparison of Maximum absorbed power between systems of a single absorber in a channel

Result

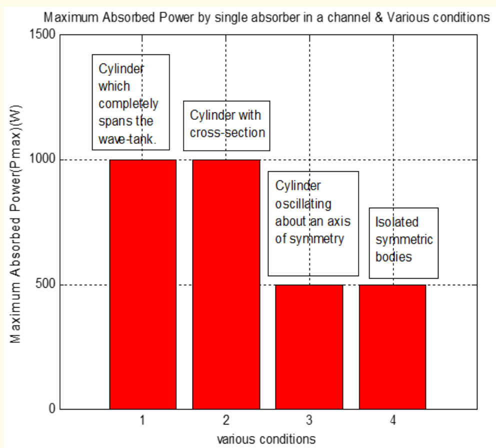
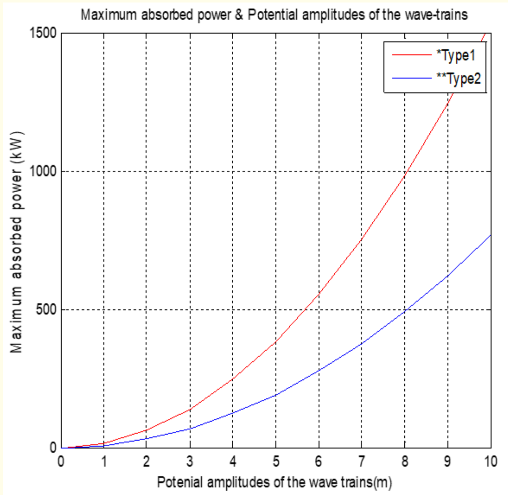


Figure 3: Comparison of Maximum absorbed power between systems of a single absorber in a channel.

Relationship between Maximum absorbed power by a single absorber in a channel and potential amplitudes of the wave-trains.

Result



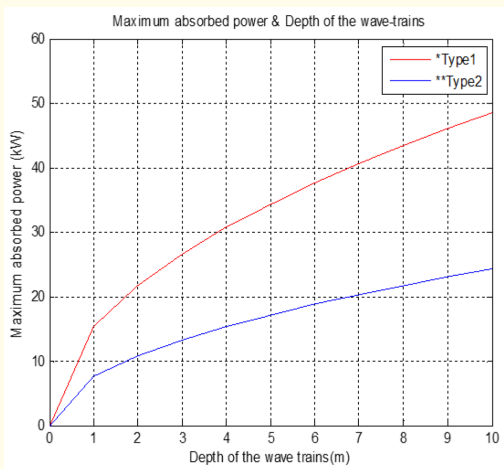
*Type1= Cylinder which completely spans the wave-tank, Cylinder with cross section.

**Type 2= Cylinder oscillating about an axis of symmetry, Isolated symmetric bodies.

Figure 4: Graph of Maximum Absorbed Power by a single absorber in a channel when potential amplitude of the wave-trains varied.

Relationship between Maximum absorbed power by a single absorber in a channel and depth of the wave-trains.

Result

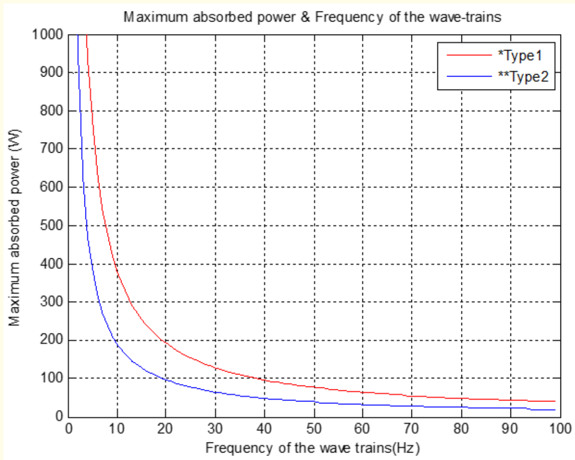


*Type1= Cylinder which completely spans the wave-tank, Cylinder with cross section.

**Type 2= Cylinder oscillating about an axis of symmetry, Isolated symmetric bodies.

Figure 5: Graph of Maximum Absorbed Power by a single absorber in a channel when depth of the wave-trains varied.

Relationship between Maximum absorbed power by a single absorber in a channel and frequency of the wave-trains.
Result



**Type1= Cylinder which completely spans the wave-tank, Cylinder with cross section.*
***Type 2= Cylinder oscillating about an axis of symmetry, Isolated symmetric bodies.*

Figure 6: Graph of Maximum Absorbed Power by a single absorber in a channel when frequency the wave-trains varied.

Conclusion Remarks

Power from waves may be the future for a reduction in the use of fossil fuels. Seventy percent of the world surface is covered by water. Vast oceans generate energy in the form of waves by carrying tones of water across their expanse. Since 1799, man sought to realize the potential of wave energy, but only in the last decades of the 20th century have devices been developed to realistically harness the power of the sea. It is an important alternative and renewable resource as it can potentially provide vast amounts of electricity without pollution, the risk of fuel running out and minimal environmental impact. Wave energy may also free developing countries from dependence on oil. In this paper, power from both two dimensions device was analyzed. The result can be concluded as follows:

1. The graph between maximum mean power and exciting force were plotted in Figure 1 when damping coefficient varied for a single energy-absorbing body, oscillating in a single mode. The graph yielded the parabola curve because of the equation 6 which was $P_{\max} = \frac{1}{8}|X_S|^2 / B$. From the equation, maximum mean power is quadratic with exciting force. And the more damping coefficient was, the less maximum mean power it became.
2. The graph between maximum mean power and velocity of the body were plotted in Figure 2 when damping coefficient varied for a single energy-absorbing body, oscillating in a single mode. The graph yielded the parabola curve because of the equation 6 which was $P_{\max} = \frac{1}{2}|U_0|^2 B$. From the equation, maximum mean power is quadratic with velocity of the body. And the more damping coefficient was, the more maximum mean power it became.
3. Figure 3 showed the comparison between maximum absorbed power of different systems of a single absorber in a channel. Maximum absorbed power of cylinder which completely spans the wave-tank and cylinder with cross section were equal, which comes from the same equation $P_{max} = P_w.d$. Maximum absorbed power for cylinder oscillating about an axis of symmetry was equal to maximum absorbed power for isolated symmetric bodies, from the same equation which was $P_{\max} = \frac{P_w.d}{2}$, and half the amount of two maximum absorbed power mentioned earlier.
4. The graph between maximum absorbed power by a single absorber in a channel of both types when potential amplitude of the wave-trains varied were plotted in Figure 4. Both types were: type 1, Cylinder which completely spans the wave-tank, Cylinder

with cross section and type 2, Cylinder oscillating about an axis of symmetry, Isolated symmetric bodies. The reason that graph yielded parabola curve because of the quadratic equation $P_W = \frac{1}{2}\rho g A^2 . C_g$

5. Figure 5 showed a graph between maximum absorbed power by a single absorber in a channel of both types when depth of the wave-trains varied. It can be seen that when depths of the wave-trains increased, it increased the maximum absorbed power because of the equation $P_W = \frac{1}{2}\rho g A^2 . C_g$.
6. Figure 6 showed a graph between maximum absorbed power by a single absorber in a channel of both types when frequency of the wave-trains varied. It can be seen that when frequency of the wave-trains increased, it decreased the maximum absorbed power because of the equation $P_W = \rho g^2 A^2 / 4\omega$.

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