Front. Energy 2013, 7(3): 279–287
DOI 10.1007/s11708-013-0268-4

RESEARCH ARTICLE

Srinivasan CHANDRASEKARAN, Arunachalam AMARKARTHIK, Karuppan SIVAKUMAR, Dhanasekaran SELVAMUTHUKUMARAN, Shaji SIDNEY

Experimental investigation and ANN modeling on improved performance of an innovative method of using heave response of a non-floating object for ocean wave energy conversion

Abstract To convert wave energy into usable forms of energy by utilizing heaving body, heaving bodies (buoys) which are buoyant in nature and float on the water surface are usually used. The wave exerts excess buoyancy force on the buoy, lifting it during the approach of wave crest while the gravity pulls it down during the wave trough. A hydraulic, direct or mechanical power takeoff is used to convert this up and down motion of the buoy to produce usable forms of energy. Though using a floating buoy for harnessing wave energy is conventional, this device faces many challenges in improving the overall conversion efficiency and survivability in extreme conditions. Up to the present, no studies have been done to harness ocean waves using a non-floating object and to find out the merits and demerits of the system. In the present paper, an innovative heaving body type of wave energy converter with a non-floating object was proposed to harness waves. It was also shown that the conversion efficiency and safety of the proposed device were significantly higher than any other device proposed with floating buoy. To demonstrate the improvements, experiments were conducted with non-floating body for different dimensions and the heave response was noted. Power generation was not considered in the experiment to observe the worst case response of the heaving body. The device was modeled in artificial neural network (ANN), the heave response for various parameters were predicted, and compared with the experimental results. It was found that the ANN model could predict the heave response with an accuracy of 99%.

Keywords ocean wave energy, point absorbers, heaving body, non-floating object, heave response ratio, artificial neural network (ANN)

1 Introduction

Wave energy technologies are usually classified by the method of capturing energy from waves, location at the sea and power take-off (PTO) system. The method of wave energy capture is classified into point absorbers or buoy; attenuators, oriented parallel to wave propagation at its surface; terminators, oriented normal to wave propagation; oscillating water column; and wave overtopping devices. Wave energy converters are categorized, based on their location, into onshore device; near shore device; and offshore device. Various PTO methods employed by different wave energy devices are seen in literature, but few are hydraulic ram, hydraulic turbine, pneumatic turbine, pump to shore, mechanical gearbox and linear generators [1,2].

Presently, most wave energy devices use the rise and fall motion of waves to produce other usable forms of energy, while a few use the sway motion of waves. Most existing devices focus on the fact that employed technology shall be simple in construction and working, maximum energy transmitted to internal components shall be limited even during rough weather, and devices shall be capable of harnessing maximum possible energy even from low dense waves. It is also seen that the design invoking precision and high technique manufacturing of internal components

Received January 23, 2013; accepted March 26, 2013

Srinivasan CHANDRASEKARAN
Department of Ocean Engineering, Indian Institute of Technology Madras, Chennai 600036, India

Arunachalam AMARKARTHIK (✉), Karuppan SIVAKUMAR, Dhanasekaran SELVAMUTHUKUMARAN, Shaji SIDNEY
Department of Mechanical Engineering, Bannari Amman Institute of Technology, TamilNadu 638401, India
E-mail: a.amarkarthik@gmail.com

shall result in high initial investment. Further, the use of hydraulic or pneumatic turbines requires uniform wave forces. Hence, a successful device shall be designed taking into consideration all the factors mentioned above.

2 Point absorbers in heave

Of the existing devices reported, heaving point absorbers are the most common. The proposed device is developed on a similar principle. Critical review of the existing mechanisms is conducted to compare the advantage of the newly proposed device. Most of the heaving point absorbers are designed for offshore applications, which are either submerged in water or floating on the surface [1]. As point absorbers are small in dimension in comparison to the average wavelength, they are restricted to heave motion only. A rotary, direct-drive wave energy device proposed ball screw arrangement is used for converting the heave motion of the float into rotation [2]. The float stores energy during its upward stroke as potential energy and supplies energy to the internal system during down stroke. A full scale prototype of linear generator, mounted on sea floor is connected to a floating buoy for harnessing wave energy [3]. The spring stores energy during the upward stroke of the piston as the wave crest passes. An improved device employing deep-draft spar and annular saucer shaped buoy that is restricted to heave motion with respect to the spar is made use of and the spring is loaded to restore the forces for down stroke [4]. A mechanical type of float and counter weight system of wave energy uses a surface floating buoy that is kept hanging by a cable, and counter weight is attached to the other end of the cable which runs through a pulley, enabling it to rotate when the float heaves. The cables slag during the upward stroke of the buoy so that the generator is disconnected through a ratchet mechanism [5]. Archimedes wave swing (AWS) [6] is a completely submerged linear generator type of wave energy converter built at the Portuguese coast. The device comprises of a floor-mounted cylindrical chamber enclosed by a floater that moves relative to the cylinder when encountered by waves. The air inside the cylinder acts as a spring and provides restoring force to the floater. The linear generators installed inside the cylinder produce electrical energy from the heave movement of the floater. A recent technology developed by Ocean Navitas Ltd [7], uses a unidirectional gearbox that produces continuous unidirectional rotation from the up and down motion of the buoy. The buoy stores and harnesses energy during upward stroke as potential energy and releases it in downfall to the unidirectional gearbox. A similar device is also employed on heaving body wave energy conversion and its performance is analyzed by adding a supplementary mass [8].

From the brief review of literature, it is seen that the employed devices have few common characteristics that make them less efficient in conversion and vulnerable to extreme conditions. All the heaving body type of wave energy converters use buoy or float to harness the up and down motion of ocean waves to produce other usable forms of energy. These buoys are specifically designed to move along the waves to provide maximum output. Many buoys are further developed to provide more than one heave amplitude ratios. The most efficient device has a demerit of having excessive heave displacement during extreme conditions. Many solutions have been provided to restrict the device from breaking during extreme heave displacements. Researchers have proposed various damping schemes such as mechanical stoppers, latching control, hydraulic damping through modifying float forms and modifying the natural frequency by changing the system mass to keep the buoy under control in extreme circumstances. The extremely rough and corrosive nature of the ocean environment makes any control strategy unreliable for a long working life.

All reviewed point absorbers use floating buoy to harness waves. The buoy is pushed up during the approach of crest by buoyancy force and pulled down by gravity during the wave trough. This action makes the buoy harness waves in the up stroke and produce potential energy or spring energy; meanwhile the portion of harnessed energy is transmitted to the power takeoff system. During the down stroke, the wave does not provide any energy to the buoy which releases the stored potential energy to the power takeoff system while coming down due to gravity. This action makes any floating buoy type of wave energy converters harness only one cycle of waves to produce usable energy while leaving the other wave cycle free.

It is also another difficulty for a few point absorbers that the buoys are connected through a rigid link at the wave surface. The breaking waves during rough weather lead to a huge mechanical stress on the device and damage the system. All the difficulties mentioned above make heaving buoy type of wave energy converters less efficient and vulnerable to extreme conditions.

3 Non-floating body in heave

In the present paper, an out of box device was proposed which used a non-floating object to harness waves [9] to produce electrical energy. The device looked like a conventional floater type of point absorber, but it was completely unique in its working principle. The uniqueness in the operation of the device provided improved performance per unit wave front and enhanced safety during extreme conditions.

The device was a near shore converter and had to be kept on a rigid platform or jetty well above the maximum sea level. The entire system would be kept on the platform and a non-floating object would be kept vertically hanging from the device through a metal rope. The said non-floating object would be the only part of the device which interacted with the waves and harnessed its energy. Figure 1 shows the solid model of the proposed device.

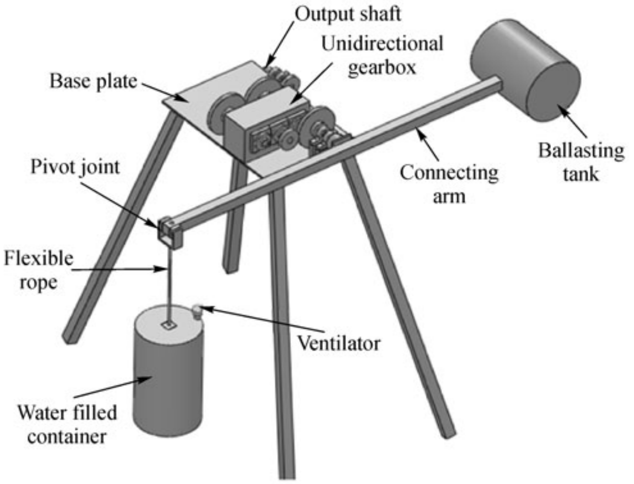


Fig. 1 Solid model of proposed device

3.1 Oscillating arm assembly

This was a straight rigid frame pivoted at its center on a bearing supported shaft. A vertically oriented non-floating object (in this case a cylindrical water filled steel container was used as non-floating object) was made hanging from one end of the arm. A ballasting tank was mounted on the other end of the arm as counter mass. The mass of the ballasting tank would be varied by filling or draining water into and from it. The length of the flexible cable or metal cable was made adjustable. Initially, the volume of the water container would be twice that of the ballasting tank.

3.2 Unidirectional gearbox

Many different methods were patented to convert both positive and negative directional rotation into continuous unidirectional rotation. The proposed unidirectional gearbox was also one such unique patent pending technology which provided energy in the form of continuous unidirectional rotation from alternatively rotating input shaft. The proposed unidirectional gearbox was simple in construction and converted alternative rotation at its input shaft into continuous unidirectional rotation at its output shaft with a conversion efficiency of approximately 95%.

3.3 Step up gearbox

Due to the fact that the frequency of ocean waves is very low, the speed of rotation from the unidirectional gearbox is lower than what is required by any conventional generator. Hence another gearbox was coupled with the unidirectional gearbox to increase the speed of rotation.

3.4 Electrical generator

A conventional rotary type of electrical generator was coupled with the output shaft of the step up gearbox to convert mechanical rotation into electrical energy.

4 Working of non-floating body heaving wave energy converter

4.1 Initial condition

The entire setup was mounted on a platform such that the hanging water container was completely immersed into the water surface. When the ballasting tank was filled with water, the container started rising above water as an action of balancing. The cable length was adjusted such that the arm was horizontal after the exposed height of the container reached the required height. Once all the initial arrangements were made, the arm was in equilibrium due to the balancing of effective mass (m) of the semi immersed container and counter mass (M).

4.2 Working

When an incidental wave passed the semi immersed container, as illustrated in Fig. 2, the effective mass (m) of the container got reduced due to the increase in surrounding water height, and the arm became unbalanced between its two ends. The counter mass (M) pulled the container up as an action of balancing. This action made the arm to oscillate in one direction. When the wave trough approached the container, the effective weight of the container increased due to the decrease in the water height around it, which, in turn, made the container side heavy and pulls the counter mass side up. This alternative balancing of forces made the arm continuously oscillate with respect to the point O.

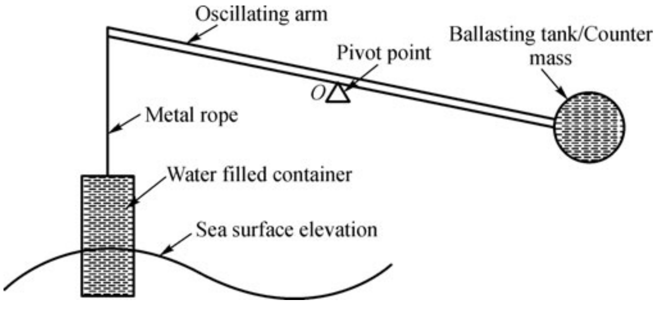


Fig. 2 Schematic of oscillating arm at incident wave

This oscillation of arm made the input gear of unidirectional gearbox rotate alternatively, and the unidirectional gearbox produced unidirectional rotation at its output shaft. This low speed high torque unidirectional energy was converted into high speed rotation by a step up gearbox and further converted into electrical energy through the rotary electrical generator.

4.3 Uniqueness

The oscillation of heaving body was caused by the variation in the effective mass of the container during wave action instead of by the pushing action of wave crest. Hence, the excessive heave response was not possible during extreme waves as the waves could not push the non-floating object up. The heave response of the arm was limited by changing the quantity of water in the ballasting tank. The heaving mass was connected via cable to the device and hence extreme forces were not transferred to the internal components of the device. As the wave does not push the container, the rope was always in tension and the energy could be harnessed in both wave cycles. No mechanical energy storing system was used such as mechanical or pneumatic spring or dead weight to store the energy for the down stroke and hence there was less mechanical damping.

5 Experimental arrangement

An experimental setup shown in Fig. 1 was designed and fabricated to test in 1 m deep, 2 m wide wave flume at Indian Institute of Technology Madras. Preliminary studies were conducted to find the heave response of water filled container with respect to wide range of regular waves. Undamped free oscillation in regular wave represented the worst case scenario. Hence, the study was done without connecting any electrical generator or exposing it to irregular waves to find the heave response in extreme conditions.

The wave periods experimented was between 1 and 3 s for the laboratory model, which could be scaled up to the required wave field. The model was kept 5 m from the wave peddle at the 2 m wave flume at IIT madras. The container was installed 0.8 m from side walls.

The device was a two degree of freedom system, the arm had a freedom to oscillate in heave, and the container had a freedom to oscillate in the surge. The surge motion of the container was not constrained to study the effect of it in over all conversion.

5.1 Water container

Four water containers, as shown in Fig. 3, made of steel with a height of 0.7 m with different dimensions and shapes were used for the experiment. Three of them were circular in the cross section with a diameter of 0.2, 0.3 and 0.4 m. One of the floats was with a cross section of square, having a side of 300 mm. All the containers were bottom opened and with an air vent at the top to drain the air out during installation.

Fig. 3 Containers used for the experiment

5.2 Oscillating arm

The oscillating arm was 2 m in length and was pivoted at its center by a bearing supported shaft. A 6 mm metal rope was connected at one end of the said arm and a worm gearbox was fixed to vary the length of the rope. There were arrangements to hang the container at the outer end of the rope.

5.3 Unidirectional and step up gearboxes

An unidirectional gearbox and step up gearbox to step the speed for 12 times were fabricated and coupled together. The entire assembly was mounted on the wave flume and the container was kept hanging from the trailing end of the arm.

6 Experiment

An experimental setup depicted in Fig. 4 was used for the experiment. A 0.3 m diameter and 0.7 m high cylindrical water container was employed for the first phase. The tank was inverted and immersed into the wave flume. The top air vent was kept open until the container got completely immersed into water. Once the container was completely filled with water, the air vent was closed and the counter mass got loaded at the other end of the arm. A counter mass of 25 kg was initially loaded and the arm was made horizontal by adjusting the length of the rope.

An accelerometer was mounted on one end of the oscillating arm to measure the heave acceleration. A 10 kg flywheel was coupled at the output shaft of gearbox to provide mechanical damping.

The main focus of the experiment was to measure the

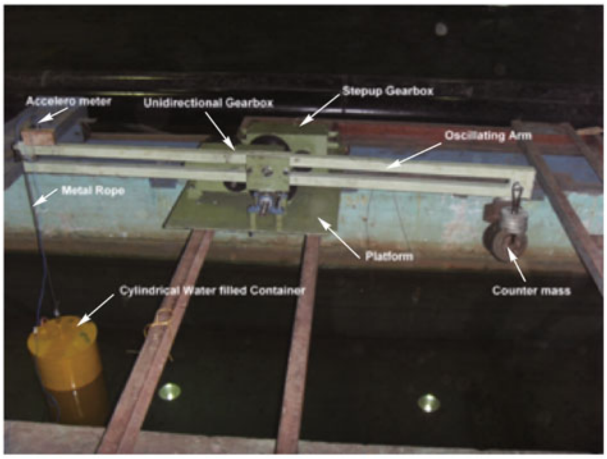


Fig. 4 Experimental setup at 2 m wave maker

heave response of the arm for various wave and device parameters. The power output and efficiency of the device was directly proportional to its heave response and hence it was decided to analyze the heave response.

It was found from the experiment that the heave response of the device exceeded the maximum wave amplitude in most of the cases, which suggested that the conversion rate of the proposed device was significantly higher. It was also found that the heave response was dependent on variables such as counter mass, wave period, and wave height for a particular container diameter.

The experiments were conducted by varying each parameter and heave responses were noted. To study the device, the experiments were conducted for all possible combination of variables and heave responses were noted.

The counter mass was varied in three different levels between 34 and 46 kg with 6 kg difference. The 10, 20, 25 and 30 cm high waves were used for all counter masses and the wave period was varied from 2 s to 3 s with a 0.2 s variation.

To obtain the worst case response, regular waves were used and heave response were noted. Table 1 presents the average maximum heave response (MHR) observed from the experiment for each combination and a comparison of the measured and predicted heave response by ANN.

Table 1 Comparison of measured and predicted heave response by ANN

Experimental observation						Predicted
Serial No.	Mass/kg	Wave amplitude/cm	Wave period/s	MHR/cm	Heave response ratio	ANN model MHR/cm
1	34	10	2	18	1.8	18
2	34	10	2.2	21	2.1	21
3	34	10	2.4	16	1.6	15
4	34	10	2.6	12	1.2	13
5	34	10	2.8	12	1.2	13
6	34	10	3	20	2.0	20
7	34	20	2	36	1.8	36
8	34	20	2.2	44	2.2	44
9	34	20	2.4	33	1.7	33
10	34	20	2.6	24	1.2	24
11	34	20	2.8	24	1.2	24
12	34	20	3	15	0.8	14
13	34	25	2	41	1.6	40
14	34	25	2.2	48	1.9	48
15	34	25	2.4	41	1.6	41
16	34	25	2.6	32	1.3	32
17	34	25	2.8	30	1.2	30
18	34	25	3	21	0.8	21
19	34	30	2	38	1.3	39
20	34	30	2.2	52	1.7	51
21	34	30	2.4	48	1.6	48
22	34	30	2.6	35	1.2	35
23	34	30	2.8	58	1.9	58
24	34	30	3	50	1.7	50
25	40	10	2	14	1.4	12

(*Continued*)

Experimental observation						Predicted
Serial No.	Mass/kg	Wave amplitude/cm	Wave period/s	MHR/cm	Heave response ratio	ANN model MHR/cm
26	40	10	2.2	21	2.1	21
27	40	10	2.4	17	1.7	17
28	40	10	2.6	15	1.5	15
29	40	10	2.8	22	2.2	22
30	40	10	3	15	1.5	15
31	40	20	2	27	1.4	27
32	40	20	2.2	43	2.2	43
33	40	20	2.4	42	2.1	42
34	40	20	2.6	33	1.7	33
35	40	20	2.8	42	2.1	42
36	40	20	3	37	1.9	37
37	40	25	2	32	1.3	32
38	40	25	2.2	49	2.0	49
39	40	25	2.4	52	2.1	52
40	40	25	2.6	35	1.4	35
41	40	25	2.8	48	1.9	48
42	40	25	3	39	1.6	39
43	40	30	2	38	1.3	38
44	40	30	2.2	52	1.7	52
45	40	30	2.4	62	2.1	61
46	40	30	2.6	48	1.6	48
47	40	30	2.8	48	1.6	48
48	40	30	3	43	1.4	43
49	46	10	2	15	1.5	14
50	46	10	2.2	24	2.4	24
51	46	10	2.4	19	1.9	19
52	46	10	2.6	14	1.4	15
53	46	10	2.8	26	2.6	26
54	46	10	3	20	2.0	20
55	46	20	2	23	1.2	23
56	46	20	2.2	40	2.0	40
57	46	20	2.4	44	2.2	44
58	46	20	2.6	37	1.9	37
59	46	20	2.8	48	2.4	48
60	46	20	3	40	2.0	40
61	46	25	2	30	1.2	30
62	46	25	2.2	48	1.9	48
63	46	25	2.4	58	2.3	58
64	46	25	2.6	41	1.6	41
65	46	25	2.8	55	2.2	55
66	46	25	3	48	1.9	48
67	46	30	2	32	1.1	32
68	46	30	2.2	49	1.6	50
69	46	30	2.4	65	2.2	63

(*Continued*)

Experimental observation						Predicted
Serial No.	Mass/kg	Wave amplitude/cm	Wave period/s	MHR/cm	Heave response ratio	ANN model MHR/cm
70	46	30	2.6	53	1.8	54
71	46	30	2.8	68	2.3	66
72	46	30	3	52	1.7	52

7 Artificial neural network (ANN)

ANNs are modeling tools, which can be used to model complex input and output relations. Presently, the ANN is used in a variety of fields to replace complex mathematical equations. It is also successfully applied in various ocean sciences and energy systems. For example, Kalogirou reviewed the application of ANN in energy systems [10], Deo and Sridhar Naidu used observed data to forecast wave parameters [11], Pao used ANN to forecast electricity market pricing [12], Tsai and Tsai converted pressure transducer signals into various wave parameters using trained neural network [13], Carballo and Iglesias used ANN [14] to determine power performance of Oscillating Water Column at a particular coastal location.

In the present study, the proposed novel device was modeled on the ANN and its heave response was predicted. The predicted values were experimentally verified and it was found that the trained network predicted the heave response with an accuracy of 99%.

The principles and methodologies of training a ANN was elaborated by Kalogirou [10], while Tsai and Tsai [13] presented the methodology of choosing weights, advantages of back-propagation neural networks (BPNN) in wave energy applications and selection of layers. With reference to these studies, the proposed device was modeled on the ANN using Matlab.

7.1 Methodology

The wave height, wave period and counter mass were the input parameters, which decided the heave response of the arm. These parameters were normalized between − 1 to 1 and imported into Matlab.

7.2 Output parameter

The heave response in centimeter of arm was the only output parameter for the present study, as it was directly proportional to the harnessed energy for a particular counter mass.

7.3 Target data

Initially the ANN was supplied with corresponding heave responses obtained from experimental observation for the given input parameters. The ANN used these parameters to train itself by adjusting weights with each input parameters and combines to get the output.

7.4 Training network

BPNN was chosen as the network type [13] and gradient decent method (GDM) was selected as the training function with 2 layers. 10 neurons were selected for initial training and could be increased if further accuracy was needed. Once the network was designed, the input and test data were uploaded to the network whose learning rate and momentum coefficient were varied by fixing epochs to required runs. The network was trained by fixing the target value as zero. The learning rate and momentum coefficient were varied until the output was closer to zero. Once the least value was obtained from the trained network, the network was exported and saved.

7.5 Simulation

The trained network behaved as the device and predicted the heave response once the required input parameters were given. To validate the accuracy of the network, various input combinations were uploaded to the trained network and the network was simulated. The network provided predicted heave response once the simulation was done. These values were de-normalized and compared with experimental observations. From the study, it was found that the predicted values were matching with an accuracy of 99%. The predicted and experimented values were given in Table 1. Figure 5 displays the network configuration with layers, Fig. 6 demonstrates the various training parameters, and Fig. 7 exhibits the training of network.

8 Results and discussion

It was revealed from the experiment that the device exhibited significantly higher heave response than incident wave amplitude between wave periods of 2 to 3 s. The heave response of the proposed non-floating type of wave energy converter was much higher than a conventional buoy type of wave energy converter. As the container was only pulled by the counter mass instead of by the wave, the

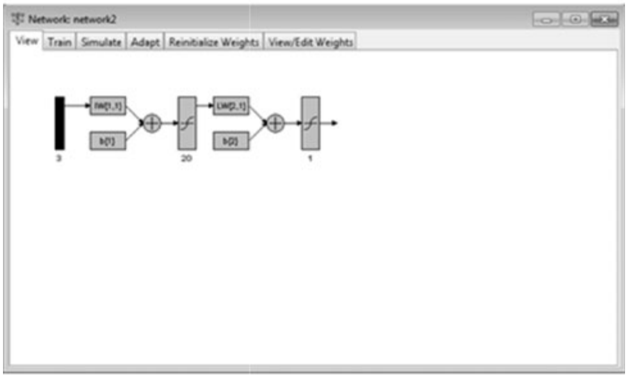
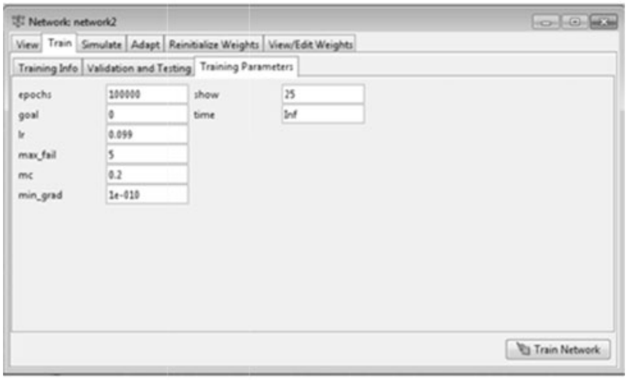
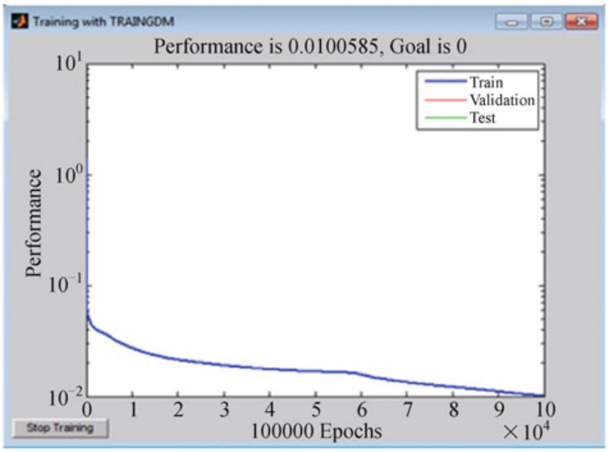


Fig. 5 ANN network model



epochs 100000
goal 0
lr 0.099
max_fail 5
mc 0.2
min_grad 1e-010
show 25
time Inf

Fig. 6 Network training parameters


Training with TRAINGDM

Performance is 0.0100585, Goal is 0

Fig. 7 Network training

maximum acceleration of the container was limited and not increased further by extreme waves.

The device could be conveniently modeled in the ANN and its various responses could easily be predicted for real world applications.

From the experimental observations and results, the device characteristics for various devices and wave parameters were studied to optimize the device for maximum performance.

Impact of wave height: It was found from the experiments that the device performance increased with the increase in incidental wave amplitude irrespective of period and counter mass. Figure 8 shows the heave response of the device for 2.2 s wave for various wave amplitudes. It can be seen that the average heave response steadily increases with the increase in wave amplitude.

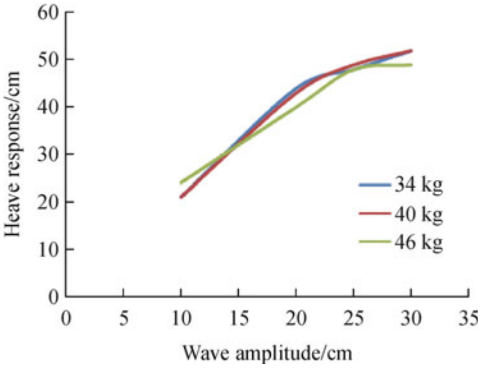


Fig. 8 Heave response of container for 2.2 s period wave

Impact of counter mass: Fig. 9 shows that the increase in counter mass increases the overall performance of the device in higher period waves. For lower wave periods of approximately 2.2 s, all counter masses exhibit similar performance, above which higher counter mass performs well. This character results from the increase in natural period of the device due to the increase in overall mass of the system.

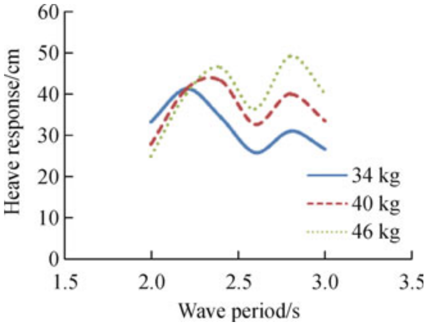


Fig. 9 Variation of heave response of container with respect to wave period

Impact of two degrees of freedom: Fig. 9 shows the heave response of the device when wave period and counter mass are varied. It can be seen from Fig. 9 that there are two peaks for each counter mass. It is experimentally seen that the left peak is caused by the wave period matching with the natural period of arm while the second peak is derived from the matching of wave period with the natural period of container in surge. The experiment shows that the freedom to the container in surge gives advantage at higher counter masses and hence constraining the container only in heave is not necessary.

Net energy conversion is proportional to the system mass and heave response of the device. The use of a non-floating object gives an advantage of having higher mass per unit wave front than the floating buoy and hence the overall energy conversion is increased. Due to the unique working principle of the device, the heave response of container is four times the wave amplitude in wave periods which is closer to the natural period of oscillating arm. Both the above characteristics make the device have an exceptionally higher energy conversion rate. As the wave energy is harnessed by the balance of masses instead of by the pushing action of the wave, the energy transfer from the wave to the device is limited up to the capacity of the counter mass and hence excessive energy cannot be transferred into the device in extreme conditions. The heave response of the device is mainly based on the container diameter and the counter mass. Changing diameter of the float is not possible in the real sea scenario but the ballasting tank can be drained completely and the container can be immersed into water or be emptied to bring it above the water surface to prevent the device from getting damaged by extreme waves.

9 Conclusions

The investigation on using a non-buoyant object as replacement to floating bodies in a point absorber has been conducted and the performance characteristics were studied. The present study has been performed by disengaging the electrical PTO system and recording the heave response of the container. The net energy conversion is proportional to the heave response and the mass of the container. Hence, the variation in heave response has been given importance in the present study to estimate the energy conversion. The heave response ratio is the ratio between heave responses of the container and the corresponding wave amplitude. Any device is considered to be performing well when its heave response ratio is more than unity. The experimental investigation shows that the heave response ratio of the device reaches up to 2.6 when the wave frequency is closer to the natural frequency of the device. Further study on the device characteristics has indicated that the variation in the heave response of the device is proportional to the counter mass, wave amplitude and wave period. From the analysis it has been found that the counter mass significantly affects the performance of the device. At higher frequency waves, improved performance is achieved by reducing the counter mass and vice versa for lower frequency waves. As the experimental investigation has been performed and results have been obtained, it becomes important to model the device using a tool for making further analysis. Presently, ANN is extensively used by many researchers to model any system to replace a conventional mathematical tool. In the present study, it is proposed to find the possibility of using ANN for ocean wave energy conversion application. The study reveals that, using ANN for modeling a wave energy converter is very much possible with greater accuracy.

References

1. De O, Falcão A F. Wave energy utilization: a review of the technologies. Renewable & Sustainable Energy Reviews, 2009, 14 (3): 899–918
2. Falnes J. A review of wave-energy extraction. Marine Structures, 2007, 20(4): 185–201
3. Eriksson M, Waters R, Svensson O, Isberg J, Leijon M. Wave power absorption: experiments in open sea and simulation. Journal of Applied Physics, 2007, 102(8): 084910-1–084910-5
4. Elwood D, Yim S C, Prudell J, Stillinger C, von Jouanne A, Brekken T, Brown A, Paasch R. Design, construction and ocean testing of a taut-moored dual-body wave energy converter with a linear generator power take-off. Renewable Energy, 2010, 35(2): 348–354
5. Agamloh E B, Wallace A K, von Jouanne A. A novel direct-drive ocean wave energy extraction concept with contact-less force transmission system. Renewable Energy, 2008, 33(3): 520–529
6. Polinder H, Damen M E C, Gardner F. Linear PM generator system for wave energy conversion in the AWS. IEEE Transactions on Energy Conversion, 2004, 19(3): 583–589
7. Al-Habaibeh A, Su D, McCague J, Knight A. An innovative approach for energy generation from waves. Energy Conversion and Management, 2010, 51(8): 1664–1668
8. Vantorre M, Banasiak R, Verhoeven R. Modelling of hydraulic performance and wave energy extraction by a point absorber in heave. Applied Ocean Research, 2004, 26(1–2): 61–72
9. Amarkarthik A, Chandrasekaran S, Sivakumar K, Sinhmar H. Laboratory experiment on using non-floating body to generate electrical energy from water waves. Frontiers in Energy, 2012, 6(4): 361–365
10. Kalogirou S A. Applications of artificial neural networks in energy systems: a review. Energy Conversion and Management, 1999, 40 (10): 1073–1087
11. Deo M C, Sridhar Naidu C. Real time wave forecasting using neural networks. Ocean Engineering, 1998, 26(3): 191–203
12. Pao H T. Forecasting electricity market pricing using artificial neural networks. Energy Conversion and Management, 2007, 48(3): 907–912
13. Tsai J C, Tsai C H. Wave measurements by pressure transducers using artificial neural networks. Ocean Engineering, 2009, 36(15–16): 1149–1157
14. Carballo R, Iglesias G. A methodology to determine the power performance of wave energy converters at a particular coastal location. Energy Conversion and Management, 2012, 61: 8–18