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Experimental Evaluation of a Point Absorber Wave Energy Converter in a Laboratory Wave Tank

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ABSTRACT: Ocean waves are one of the renewable energy sources that can supply part of the world's energy needs and thus reduce the rate of consumption of fossil fuels and other non-renewable sources. Wave Energy Converters (WEC) are systems that extract electrical energy from sea waves. For achieving this technology, experimental modelling is of great importance. For hydrodynamic modelling of this systems and analysing their performance in different conditions, a wave tank is needed to apply sea circumstances to the systems. In this study, we experimentally investigate a WEC which was made in Hydrodynamics, Acoustics and Marine Propulsion Laboratory at Babol Noshirvani University of Technology. A WEC is evaluated for a wide range of waves in the wave tank. Wave characteristics are presented by which the system had demonstrated pitch motion and acceptable extracted electrical energy. Moreover, according to data obtained for WEC performance and annual energy diagram of the Caspian sea, scales 1:5 and 1:6 are selected for making the WEC prototype. By selecting the scales of 1:5 and 1:6, extracted power from the prototypes are about 28 and 53 kilowatts, respectively.

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1- Introduction

Possibility of converting wave energy into usable energy has been an inspiration to many inventors and researchers [1]. In the leading countries in the field of wave energy technology, preliminary studies were developed for purpose of exploring wave energy resources. In 1978, McCormick presented a theoretical explanation of wave power extracted by a straight line array of sea wave energy converters [2]. Wick and Castel offered an energy converter named Isaacs wave energy pump in 1978 [3]. It consists of a vertical riser containing a flapper valve and a buoyant float at the surface; slack tethered, it responds directly to wave motion. Constructing various types of WECs is continued and till now more than 40 types of WECs are built and tested.

In this work, we used a wave tank to simulate waves. Furthermore, we have experimentally investigated the performance of the wave energy converter. In section 2, we introduced and explained wave tank and constructed model. In section 3, we presented characteristics of the Caspian Sea and its annual wave energy diagram. In section 4, we calibrated the wave tank by changing horizontal displacement of wave maker plate and the RPM of wave maker motor. The aim of these experiments was to simulate the Caspian Sea waves in the tank. During test, waves with different heights and periods were developed in the tank and evaluated the constructed WEC for extracting electrical energy. Finally, by considering converter performance in response to waves in the tank and by studying the data related to Caspian Sea waves, appropriate scales were achieved to build the prototype.

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2- Laboratory Equipment

For studying the designed WEC and according to the assessment and calculations, a wave tank with dimensions of 11 m length, 3 m width, and 3 m depth was designed and built in the Hydrodynamic, Acoustic and Marine Propulsion Laboratory at Babol Noshirvani University of Technology. The wave tank includes a wave maker system for generating required waves and a wave damper for simulating sea coast. The wave damper decreases the reversing wave effects on the WEC motion. Designed wave maker system has availability of 13 arm lengths with horizontal displacement of wave maker plate from 6 to 36 cm. This system has a 5 kilowatts motor and a reduction gearbox; it provides revolutions variety of 10 to 150 rpm for wave maker system.

Conducting comprehensive study for employing an appropriate WEC in the Caspian Sea, we obtained the concept of our model from the French SEAREV WEC [4]. We altered the power take-off mechanism entirely by applying a chain and gear system. Important motion for the WEC is the pitch motion (rotation around axis, perpendicular to pendulum); therefore, we designed pendulum for converting this oscillation. In fact, WEC pitch oscillation causing the movement of the pendulum and this motion is transmitted to generator by power take-off system. Power take-off system consists of several gears for rectifying the reciprocating rotation at first stage and then converting them in to an appropriate torque and RPM for transmitting to generator.

3- The Caspian Sea

Although the Caspian Sea is a closed water basin, however, due to the large area and depth of the sea as well as different weather systems passing over it, most of the time it experiences storms and elevated winds which subsequently results in storm waves. It has high potential for wave energy conversion; however unfortunately, it has not been considered as energy source so far.

4- Results

In this section, test results are reported. The tests include two parts. The first is related to wave tank calibration. In the second part we placed the model in the wave tank and after performing various examinations, obtained results are analysed.

The wave calibration tests are performed in first series of experiments. Experiments are executed for 13 arm length; for smaller size arms, motor RPM was changed from 10 to 70 rpm and for bigger size arms, it was changed from 10 to 30 rpm. Each arm has an individual horizontal displacement which generates waves with specific amplitude and wavelength. We analysed and measured characteristics of the waves, generated by wave maker plate in all cases. Then the results were we sorted and categorized based on wave height and period.

Figure 1. The WEC with lamps in the test system

In the next step, the WEC was placed in the wave tank. Tests were performed for every arm length and various motor revolutions. The WEC with illuminated lamps, which illustrate extracted power by the WEC, is shown in Fig. 1.

Table 1. The situations in which the lamps are well-lit

Arm Number	Motor Revolution (rpm)	Tank Wave Height (m)	Tank Wave Period (s)
10	27	11.2	2.084
11	27	7	1.954
12	28.5	10.4	1.937
13	28	14.6	1.994
14	28.5	21.3	1.986

As mentioned, experiments were completed for 13 arm lengths. Table 1 shows the results in which the lamps are well-lit and about 100 W can be derived from the WEC.

As previously mentioned, major priority for designing a WEC in order to extract maximum annual power is occurred in the period between 4 and 6 s and significant wave height of 0.5 to 1 m. Achieving wave desired properties, appropriate scale must be found between the model and prototype. Relations between the wave height, period and power of the model and prototype are obtained by:

$$\frac{H_2}{H_1} = \alpha_L \tag{1}$$

$$\frac{T_2}{T_1} = \alpha_L^{1/2} \tag{2}$$

$$\frac{P_2}{P_1} = \alpha_L^{3.5} \tag{3}$$

Where H is wave height, T is wave period, P is wave power and α_L is a dimension ratio of prototype and the model. By choosing α_L equal to 5 and 6 and computing the sea characteristics including wave period and height by Equations 1-2, for the conditions mentioned in Table 1, it can be seen that 3 modes from the 5 modes are in red zone of the combined scatter and energy diagrams of the annual energy corresponding to sea states. Although the other 2 modes are not in red zone, but they are still considered as the powerful and frequent waves of the Caspian Sea. Therefore, the scales 1:5 and 1:6 are the appropriate scales for constructing the prototypes. Extracted power from the model as displayed lamps in Fig. 1 were illuminated, was about 100 W. Determining 1:5 and 1:6 scales for prototype and applying Equation 3, extractable power from them at sea will be about 28 and 53 kW, respectively which are considerable amounts.

5- Conclusion

In this article, we experimentally investigated a constructed WEC in the wave tank of Hydrodynamic, Acoustics and Marine Propulsion Laboratory of Babol Noshirvani University of Technology. First, generated waves were calibrated and surveyed by wave maker system. Regarding the Caspian Sea wave specifications, calibration results were applied for generating specified waves. Then, we placed the WEC in the wave tank and evaluated its performance in a wide range of waves. The waves were presented in which system had suitable pitch motions and acceptable extracted electrical energies. Moreover, according to diagrams and data obtained for WEC performance and annual energy diagram of the Caspian Sea, scales 1:5 and 1:6 are selected for making the WEC prototype. Selecting the scales of 1:5 and 1:6, extracted power from them are about 28 and 53 kW.

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