JOURNAL OF OPTOELECTRONICS LASER ISSN:1005-0086

Volume 41 Issue 5, 2022

Mechanical Vibrations As An Alternative Energy Source Waves Energy - Piezoelectric Generators

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ABSTRACT In this research, techniques were developed that help to obtain energy using the movement of waves, where two models (stress - raft) were designed and through which the mechanism of obtaining energy using piezoelectric cells was clarified. We also connected it to a charging circuit capable of storing energy in a rechargeable battery, which was able to raise the battery voltage from 1.21 (V) to 1.23 (V) within 3 minutes, while in the second design (the raft) we got better results. And if we link several rafts together with a basin larger than the one used in the experiments, and with larger cells, the results will be better.

Keywords: waves, renewable energy, piezoelectric cells.

I. INTRODUCTION

Renewable energy is inexhaustible, and its source is natural, such as wind, water and the sun. The most important characteristic of it is that it is clean and environmentally friendly energy, as it does not release harmful gases such as carbon dioxide, and does not negatively affect the surrounding environment, and it does not play a negative role on the global warming. Renewable energy sources are different from non-renewable sources, such as fossil fuels and nuclear fuels, as these sources lead to global warming, and the release of carbon dioxide when used in addition to radioactive waste. Proceeding from the importance of renewable energy, a new type of business has recently emerged under the name of renewable energy trade, and most of its business has focused on harnessing renewable energy sources, and exploiting them to be a source of profit and financial benefit on the one hand, and on the other hand, the reason for protecting the environment and reducing Fossil fuel use, by promoting it. [1]

Renewable energy can also be produced from the movement of waves and tides or from geothermal energy. Some of these energies have gained more importance, and technologies to benefit from them are developing greatly, such as wind and solar energy, while others have received less importance, such as wave energy. Waves are considered a natural vibrational system that carries a large amount of energy that can be exploited through multiple mechanisms that convert the movement of vibrational waves into useful energy in different ways, if it is extracted through the techniques of converting the energy of multiple vibrations, especially piezoelectric materials and some mechanical and hydraulic systems. [2]

II. REFERENCE STUDY

Research was conducted at the University of UPPSALA in Sweden on the idea of a wave transducer, the system is a point absorber extracting energy containing a direct linear magnetic generator (LG) located at the bottom of the sea as shown in Figure (1).

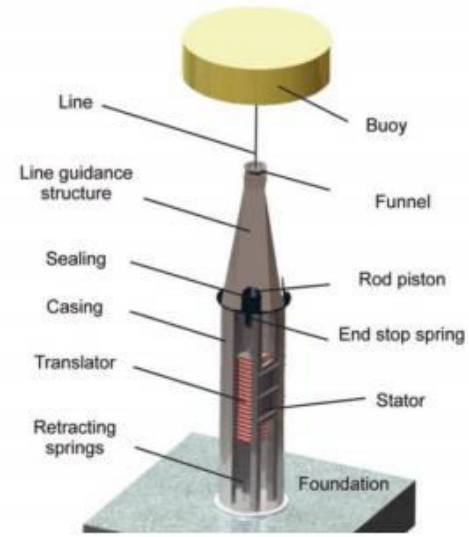

Figure 1: The energy-extracting point absorber tested at University of UPPSALA.

Ocean Power Delivery (OPD) company developed a hinged device to float freely. The device looks like a snake floating on the surface of the water, it consists of four tube sections connected to each other by three hinges, the four sections move relative to each other and the hinges convert this movement by a hydraulic power transmission system digitally controlled. [4]

- Total device length: 150 m
- Device Diameter: 3.5 m
- Device symmetry line spacing: 150 m (2-3 rows combined)
- Solid Structure Weight: 380 tons
- Rated power: (300 – 750) kW (depending on climate)
- Water depth: greater than 50 m
- Power Operating system: hydraulic, using biodegradable fluids.

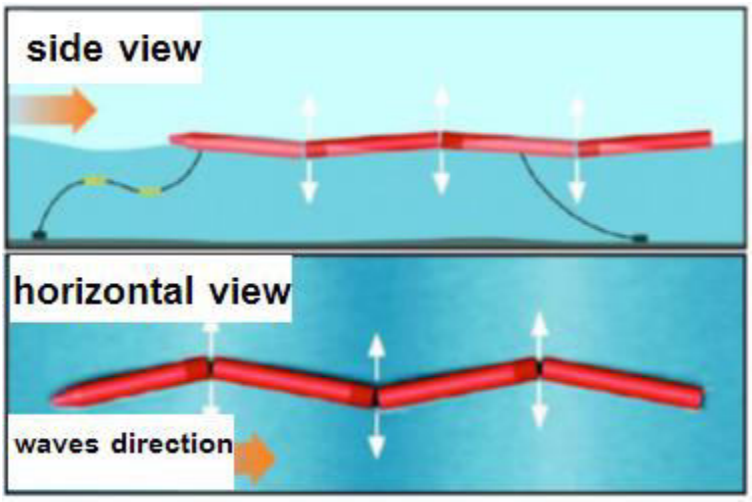

Figure 2: The working principle of The Pelamis [4]

Figure 3: The Pelamis system

Figure 4: Systems Field (The Pelamis)

III. DEFINITIONS

1. Piezoelectric generators

Piezoelectric generators have a crystal structure that provides them with the ability to convert mechanical pressure energy into electric charge and vice versa, that is, convert electrical voltage applied to it into mechanical stress, this property enables these materials to absorb mechanical energy from the surrounding medium, which is usually surrounding vibrations, and converting it into electrical energy that can be used to power other devices.

2. Wave energy

Sea and ocean waves are a huge source of energy that is largely untapped, as there is a great potential to extract energy from waves. Research in this field has been directed by the need to reach renewable energy goals such as wind energy and solar energy.

3. Principle

Ocean waves are generated under the influence of winds on the ocean surface. Once the ripples are created on the surface, there will be a front available at an acute angle against the wind that will be pushing it and so the waves are created and amplified. The exact mechanics of the interaction between wind and the sea surface is complex, but there are three main processes that can be related to the subject:

a) The air passing over the sea, which generates tangential pressure on the surface of the water and is the reason for the formation and growth of waves.

b) turbulent air flow near the sea surface rapidly generates Changeable stress and pressure. And when these frequencies agree with existing waves, these waves begin to increase.

c) When the waves reach a certain size, the wind can exert a greater force on the face of the wave, causing the wave to amplify.

Waves in deep water can travel thousands of miles without losing much energy until they lose their energy on the far shore. Ocean waves are a vibrating system in which water molecules move within orbits.

When the water depth decreases, the oscillations become smaller, near the shore and in shallow waters, the waves are affected by the ocean floor, which leads to a loss of energy due to the friction of water molecules with the bottom as shown in Figure (5).

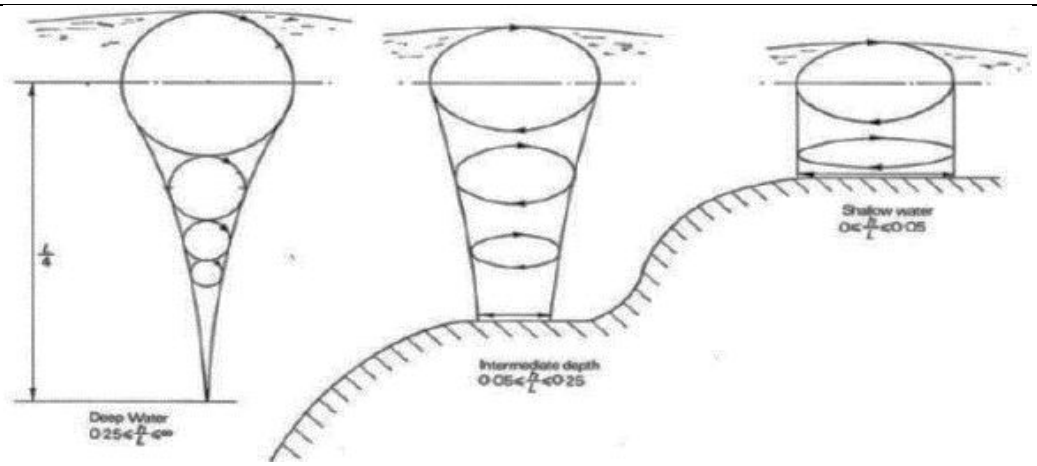

Figure 5: Orbits of water molecules in a sea wave at different depths

IV. SOME OF THE TECHNIQUES USED TO TAKE ADVANTAGE OF WAVE ENERGY

1. bioWAVETM Device

The bioWAVETM mechanism uses an undulation pattern to extract energy from waves, using relatively small cross-sectional circular blades (taking into account wavelength) and multiple blades to increase the energy intake of the device, with innovative features for dumping that allows the device to avoid overloading during stormy conditions. [2]

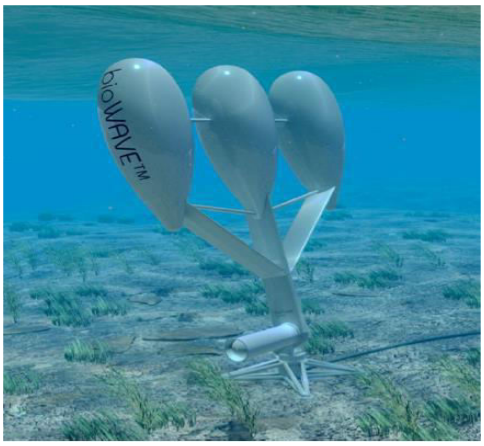

Figure 6: The general view of the bioWAVETM device.

2. Ocean Power Technologies (OPT) System

The Power Buoy, developed at the Ocean Power Technologies (OPT) Center, USA, consists of buoys of 5m diameter, mounted on a long tubular body likely to have been used to provide the mass reaction of the system. The system is anchored directly to the seabed by a set of anchors. [4]

- Diameter of the buoy: 5 m
- Height of the buoy: 20 m
- Device Symmetry Line Spacing: N/A (Not Available)
- Weight of Structure: 17 ton
- estimated power: 40 kW (according to the Hawaii experimental project)
- Water Depth: 30 m
- Operation power system: hydraulic oil.

Figure 7: OPT system

Figure 8: A field of point absorbent (OPT) devices.

V. PRACTICAL SECTION

1. Design of Test Device

Basin

This basin was made of glass with a thickness of 8 mm for the base, 5.5 mm for the sides with the following dimensions (125 X 40 X 50) cm. Glass plate was installed at the end of the basin tilted at an angle of 45°, which helps in generating the wave along the length of the basin. Plastic plate 40 cm long was installed at a distance of 20 cm from the beginning of the basin in order to carry out the experiments at different angles, thus the dimensions of the air chamber became (20X40X40) cm and the plastic plate was fixed with silicone rubber (Silicone G-1200) because it is

flexible and withstands the hit of the wave and the pressure resulting from it. The following figure shows the views of the basin with the dimensions.

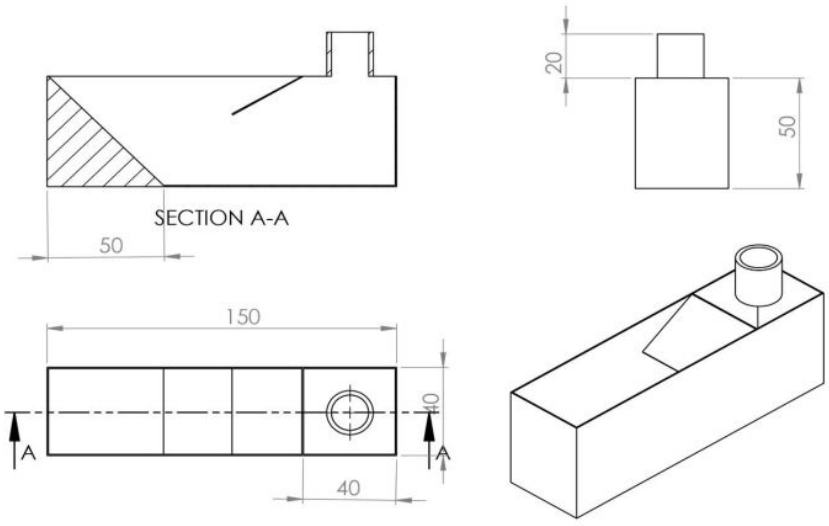

Figure 9: Views of the basin with dimensions

'

The following figure shows the basin used in the experiments:

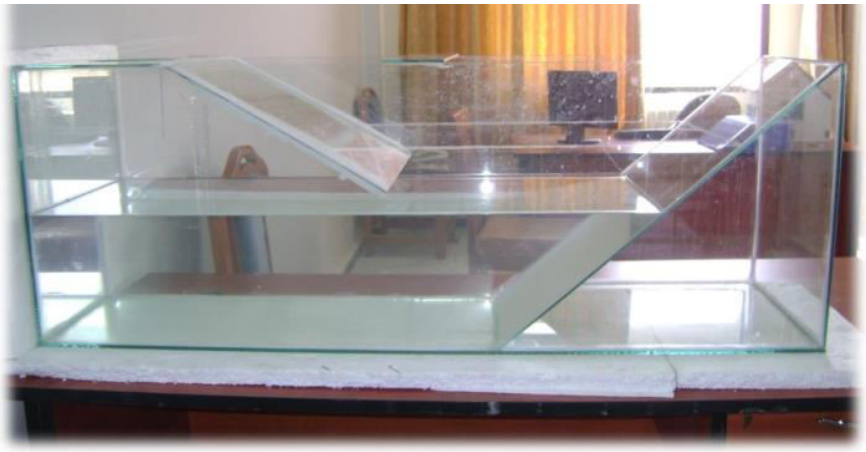

Figure 10: The basin used in the experiments

2. Electricity generation using piezoelectric generators (stress)

In the first experiment, electric power will be generated by exposing the piezoelectric generators to the stress caused by the movement of the rubber membrane that closes the air chamber.

Materials used in the design of the system

- A piezoelectric cell.
- Two glass plates with dimensions (20X20) cm with a circle in the center of the two pieces with a diameter of 10 cm.
- Two pieces of wood, 7 cm long and 2 cm thick.

- Rubber material (membrane rubber).
- Electrical connection wires.
- Plastic tube.

Design the experimental model

The rubber film was fixed on one of two glass plates and the other plate was placed on it to prevent air leakage, and then we fixed the two pieces of wood on the glass plate.

Then, fixing the plastic tube in the center of the rubber film with two magnets, one inside the tube and the other under the rubber film with a slit at the top of the tube opposite the existing space installed, and the photovoltaic cell was installed between the two pieces of wood on the one side and the opposite slit in the plastic tube, as shown in Figure 11.

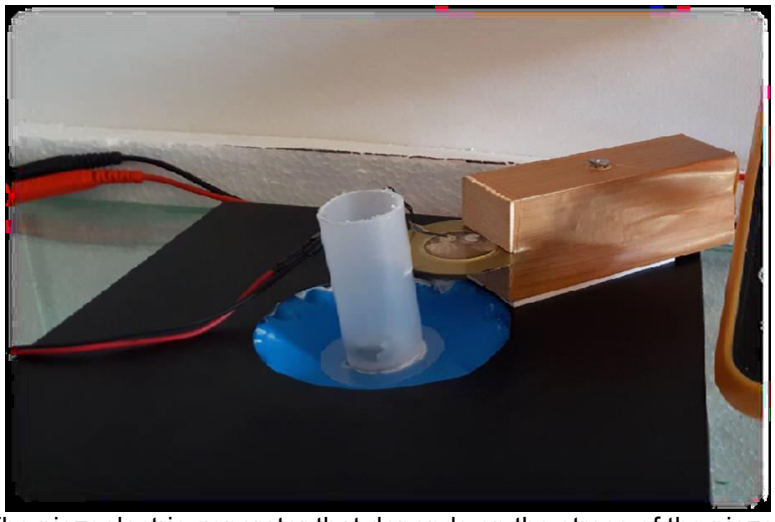

Figure 11: The piezoelectric generator that depends on the stress of the piezoelectric plate

Figures 12 and 13 show the final design of the system.

Figure 12): Final design of the piezoelectric generator

Figure 13: The final design of the piezoelectric generator within operating

3. Electricity generation using piezoelectric generators (impact)

In the second experiment, electric power will be generated by exposing piezoelectric generators to impact resulting from the movement of the raft system.

Materials used in the design

- piezoelectric cells
- plastic tubes
- glass balls
- Two pieces of Polystyrene
- scalar ruler

Experimental Model Design

Four piezoelectric cells were used, where two cells were fixed at the end of the two tubes and the last two cells on the tube cap, and they were fixed by silicone material (Silicon G-1200).

Figure 14: The piezoelectric cell fixed at the end of the tube

Figure 15: Piezoelectric cell fixed on the cap of the tube

Then, glass balls were placed inside each tube, which was tighten to prevent water from entering them.

Figure 16: Glass balls placed inside the tube

The electrical wires from the piezoelectric cells in the tubes were connected to the voltmeter through holes in the top of each tube (the tubes are sealed to prevent water going in) as in Figure 16, the two tubes were fixed to the two sides of the ruler in the middle by means of thermal silicone.

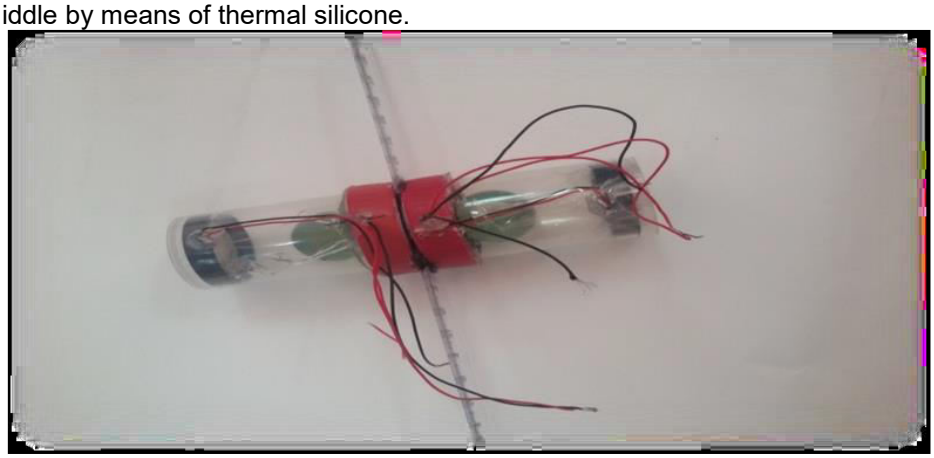

Figure 17: tube fixation

Then, the ends of the ruler are fixed from the middle of the two pieces of Polystyrene.

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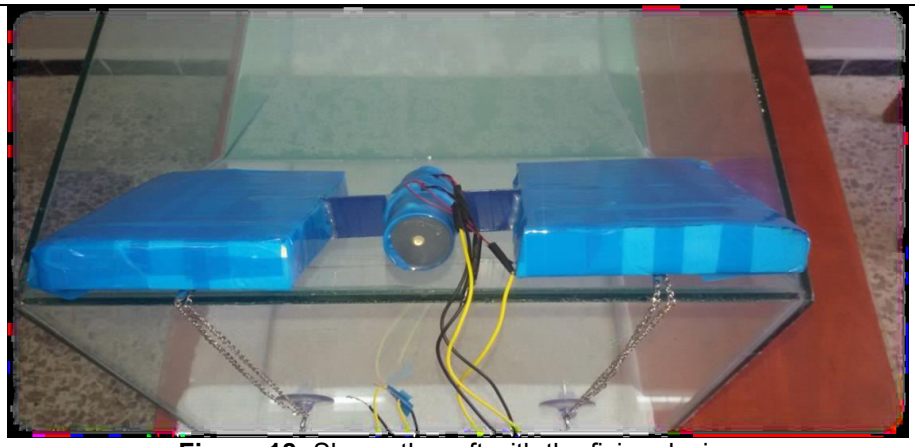

Figure 18: Shows the raft with the fixing device

VI. RESULTS

Stress System Results (Piezoelectric Generator – Strain):
The following notation will be adopted for experiments:
Experiment name (S or I) - experiment number - number of waves generated - air chamber angle. where S is stress and I is impact

• Experiment S-1-5-90:

Table 1: shows the results and values obtained

Experiment Name	Experiment No	Water Height (cm)	the Angle	Voltmeter	Number of Moves	Voltage (v)	Voltage when stopping motion (v)
S-1-5-90	1	15	90	DC	5	12.38	(6.12÷0.97)
						7.03	
						4.38	
						2.8	

• Experiment S-2-10-90:

Table 2: shows the results and values obtained

Experiment Name	Experiment No	Water Height (cm)	the Angle	Voltmeter	Number of Moves	Voltage (v)	Voltage when stopping motion (v)
S-2-10-90	2	15	90	DC	10	12.4	7.44
						10.78	4.28
						5.85	3.26
						5.65	0.98

• Experiment S-3-7-60:

Table 3: shows the results and values obtained

Experiment Name	Experiment No	Water Height (cm)	the Angle	Voltmeter	Number of moves	Voltage (v)	Voltage when stopping motion (v)
S-3-7-60	3	15	60	DC	7	6.65	3.56
						4.62	2.91
						5.08	1.68
						1.82	0.61

• Experiment S-4-7-60:

Table 4: shows the results and values obtained

Experiment Name	Experiment No	Water Height (cm)	the Angle	Voltmeter	Number of Moves	Voltage (v)	Voltage when stopping motion (v)
S-4-7-60	4	15	60	DC	7	11.91	3.82
						7.37	2.12
						6.25	1.75
						4.51	0.53

• Experiment S-5-7-60:

Table 5: shows the results and values obtained

Experiment Name	Experiment No	Water Height (cm)	the Angle	Voltmeter	Number of Moves	Voltage (v)	Voltage when stopping motion (v)
S-5-7-60	5	15	60	AC	7	11.64	6.08
						10.7	3.39
						7.22	3.27
						1.25	0.76

• Experiment S-6-10-30:

Table 6: shows the results and values obtained

Experiment Name	Experiment No	Water Height (Cm)	the Angle	Voltmeter	Number of moves	Voltage (V)
S-6-10-30	6	15	60	DC	7	10.24
						7.67
						4.36
						0.21

• Experiment S-7-10-30:

Table 7: shows the results and values obtained

Experiment Name	Experiment No	Water Height (Cm)	the Angle	Voltmeter	Number of Moves	Voltage (V)
S-7-10-30	7	15	30	AC	10	13.75
						10.68
						6.27
						2.37

• Experiment S-8-20-30:

We also conducted two experiments with the angle 30 and using the oscilloscope, where each square in the screen represents 5V with the voltage device:

Table 8: shows the results and values obtained

Experiment Name	Experiment No	Water Height (Cm)	the Angle	Voltmeter	Number of Moves	Oscilloscope	Voltage (V)
S-8-20-30	8	15	30	DC	20	12	4.22
						9	3.58
						7	2.38
						4.5	2.12
						3	1.78

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• **Experiment S-9-20-30:**
Number of moves: 10

Table 9: shows the results and values obtained

Experiment Name	Experiment No	Water Height (Cm)	the Angle	Voltmeter	Number of Moves	Oscilloscope	Voltage (V)
S-9-20-30	9	15	30	DC	20	10	0.88
						9	0.82
						8	0.4
						5	0.32
						2	0.08

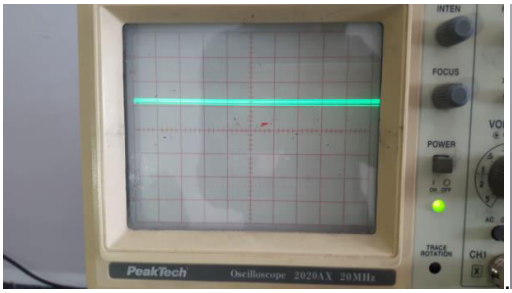

Figure 19

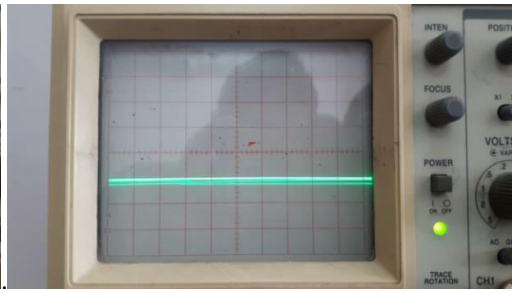

Figure 20

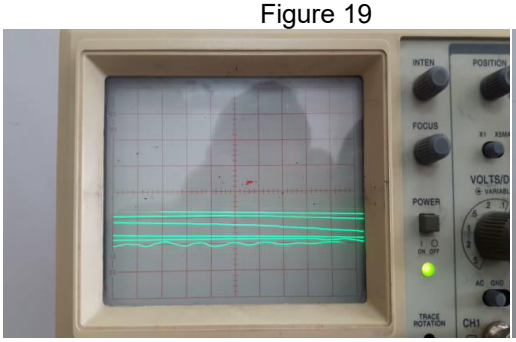

Figure 21

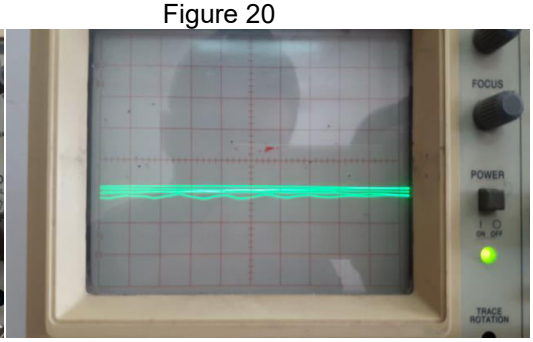

Figure 22

Figures 19, 20, 21, and 22 show some of the values that we obtained using the Oscilloscope, Instantaneous values of the voltage produced by the piezoelectric generator

The results of the raft experiment

• **Experiment I-1-10-0:**
We perform several experiments without taking any angle and by generating several successive waves and using a Voltmeter (continuous - alternating).

Table 10: shows the results and values obtained

Experiment name	Experiment No	the angle	Voltmeter	Voltage (V)
I-1-10-0	1	without angle	DC	4.22
				3.58
				2.38

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				2.12
				1.78

• Experiment I-2-10-0:

Table 11: shows the results and values obtained

Experiment Name	Experiment No	the Angle	Voltmeter	Voltage (V)
I-2-10-0	2	without angle	DC	1.52
				0.48
				0.23
				0.21

• Experiment I-3-10-0:

Table 12: shows the results and values obtained:

Experiment Name	Experiment No	the Angle	Voltmeter	Number of Moves	Voltage (V)
I-3-10-0	3	without angle	AC	10	1.01
					0.87
					0.73
					0.68
					0.07
					0.14
					0.36

• Experiment I-4-10-0:

We perform an experiment with a number of movements (10) and a continuous voltage scale, and the cells are connected to the sequence.

Table 13: shows the results and values obtained

Experiment name	Water height (Cm)	Voltmeter	Number of moves	Voltage (V)
I-4-10-0	15	DC	10	0.29
				0.26
				0.14
				0.1
				0.07
				0.01

After that, the raft was fixed by (chain) at the bottom of the basin as shown in Figure 23, and then three experiments were performed.

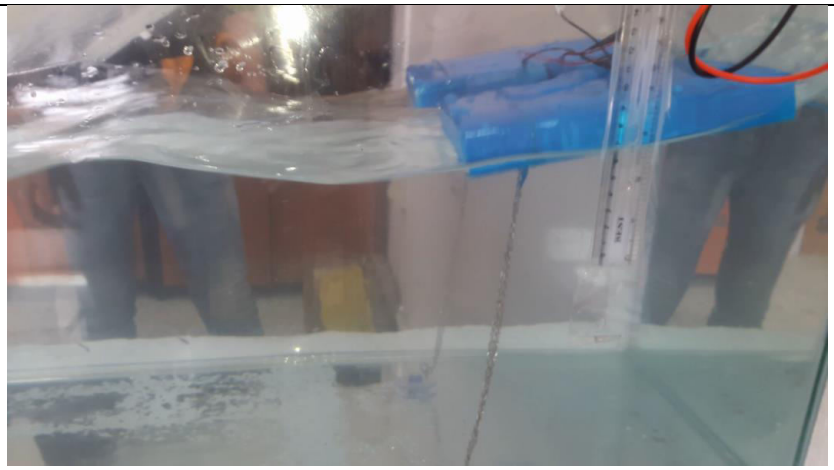

Figure 23: shows how to fix the raft at the bottom of the basin

• Experiment I-5-10-0:

Table 14: shows the obtained results and values

Experiment Name	Experiment Number	Voltmeter	Voltage (V)
I-5-10-0	5	DC	0.52
			0.4
			0.33
			0.13
			0.22
			0.01

• Experiment I-6-10-0:

Table 15: shows the obtained results and values

Experiment Name	Experiment Number	Voltmeter	Voltage (V)
I-6-10-0	6	AC	0.25
			0.17
			0.11
			0.08
			0.05
			0.03

• Experiment I-7-10-0:

Table 16: shows the obtained results and values

Experiment Name	Experiment Number	Voltmeter	Voltage (V)
I-7-10-0	7	DC	1.99
			1.41
			0.97
			0.35
			0.14
			0.09

Through the study and the conduct of experiments, and the results obtained, it can be noted that in the event that the piezoelectric generators are subjected to stress, the greatest value of the voltage measured by the (Millimeter) scale

(alternating voltage) was the greatest value of the voltage 13.75 V for one piezoelectric cell with a diameter of 26 mm in the event that you want to obtain a greater value for the voltage, it is preferable to use piezoelectric cells of a larger diameter or to use several cells in parallel. This technique can be used to charge a battery that can be used later through a charging circuit or using the voltage generated by these cells directly to provide energy for some devices that are difficult to be electrically supplied, such as ocean sensors and GPS sets.

In the case of using piezoelectric generators and affecting them by hitting (the raft), where the piezoelectric cells were connected in parallel, it was noticed that the greatest value of the voltage was 1.52 V, while when connected in series, the maximum value was 0.52 V and in these two cases the raft was fixed to the bottom of the basin. The reason for the decrease in the value of the voltage in the event that the piezoelectric cells are connected in series is that the voltage in the four cells is generated by opposite signals and thus the value is reduced or absent. In case the raft is free to move without restriction, and the use of piezoelectric cells of a larger diameter, or the connection of several rafts together to form a sea snake, will inevitably lead to obtaining a greater voltage value, as it has been noted that the power generated by both systems is of the mW rate, which is suitable for the aforementioned applications Previously.

Through previous experiments, we found that in the case of exposing the piezoelectric cells to stress, the value of the voltage is much greater than if the piezoelectric cells were subjected to hit (the raft). But it must be taken into consideration that the material that generates the voltage does not break in both cases.

VII. CONCLUSION

Mechanical vibrations have received great attention from researchers and designers, as they are considered a great source of potential energy because they are abundant, sufficient, and untapped. It can be used in several ways, and researchers in this field have developed techniques that help to obtain energy by taking advantage of the movement of waves, and this is what was studied in this research. Two models (stress - raft) were designed and through which the mechanism of obtaining energy using piezoelectric cells was clarified, and we connected it to a charging circuit capable of storing energy in a rechargeable battery, where it was able to raise the battery voltage from 1.21 v to 1.23 v within 3 minutes, while in the second design (the raft) we got better results If we link several rafts together with a larger basin than the one used in the experiments and with cells of a larger size, the results will be better.

VIII. RECOMMENDATIONS AND SUGGESTIONS

1. Attention and focus on technologies related to wave energy because of their actual contribution to the field of clean energies.
2. Interest in applying techniques for obtaining electrical energy by using piezoelectric plates to be used in self-lighting of public buildings such as universities, schools or industrial establishments.
3. Attempting to design and manufacture a piezoelectric cell with different diameters and shapes to suit the different applications available for investment.
4. In the event of conducting later experiments (the raft) and in order to obtain better results, it is preferable to connect several rafts with each other (forming a snake) and using cells of a larger diameter (if available) with a basin larger than the one used in the experiments.
5. The models that were designed are simplified and experimental prototypes that need a lot of modifications, but they were manufactured within the available capabilities.

REFERENCES

[1] L. Rodrigues," Wave power conversion systems for electrical energy production", Noisty University of Lisbon, Caparica – PORTUGAL, 2008.
[2] C.A. Gonzalez, G. Kloos, T. Finnigan , Development of a multi-bladed 250 kW pitching wave-energy converter, Proceedings of the 8th European Wave and Tidal Energy Conference, Uppsala, Sweden, 2009
[3] Viñolo, C., Toma, D., Mànuel, A., & del Rio, J. (2013). An ocean kinetic energy converter for low-power applications using piezoelectric disk elements. The European Physical Journal Special Topics, 222(7), 1685-1698.
[4] [4] D. Navarro et al., CALIFORNIA OCEAN WAVE ENERGY ASSESSMENT, Electric Power Research Institute (EPRI), USA, May 2007.
[5] B. Drew, A. R Plummer, andMN Sahinkaya, A review of wave energy converter technology, IMechE Vol. 223 Part A: J. Power and Energy, 16 June2009.
[6] A. Anvar, and D. Yang Li, Ocean Wave Kinetic Energy Harvesting System for Automated Sub Sea Sensors, World Academy of Science, Engineering and Technology Vol:6 2012-12-21,2013.
[7] E. Enferad , D. Nazarpour, Ocean's Renewable Power and Review of Technologies: Case Study Wave , INTECH ,open science | open minds , 2014

[8] J. A. Pinkster, LOW FREQUENCY SECOND ORDER WAVE EXCITING FORCES ON FLOATING STRUCTURES, PhD-thesis, Delft University of Technology , 1980.
[9] Tolkoff, S.W., Robotics and Power Measurement of the RoboTuna, Masters Thesis, MIT 1999.
[10] Shinjo, N. Investigation into the uses of Shape Memory Alloy of Biometric Propulsion of Underwater Vehicles, PhD. Dissertation, Florida Institute of Technology, August, 2005.
[11] M. Rahm, Ocean Wave Energy, Deparment of Engineering Science, Electricity, Uppsala University, SE-75121 Uppala, Swedan, 2010.
[12] Alireza Khaligh, Omer C. onar, energy Harvesting: Solar, Wind, and Ocean Energy conversion systems, CRC Press, Taylor and Francis Group, 2009.
[13] Murray, R., & Rastegar, J. (2009, April). Novel two-stage piezoelectricbased ocean wave energy harvesters for moored or unmoored buoys. In Active and Passive Smart Structures and Integrated Systems 2009 (Vol. 7288, p. 72880E). International Society for Optics and Photonics
[14] Rastegar, J. and Murray, R. ,2008, Novel Two-Stage Electrical Energy Generators for Highly Variable and Low-Speed Linear or Rotary Input Motion. Proceedings of ASME IDETC/CIE.
[15] Rastegar, J., and Murray, R.,2007, Novel Vibration-Based Electrical Energy Generators for Low and Variable Speed Turbo-Machinery, SPIE 14th Annual International Symposium on Smart Structures and Materials 6527-33.
[16] Dhanak, M. R., & Xiros, N. I. (Eds.). (2016). Springer Handbook of Ocean Engineering. Springer
[17] G.W.Taylor, J.R. Burns, S.M.Kammannm, W.B. Powers, and T.R.Welsh, The Energy Harvesting Eel: a small subsurface ocean/river power generator, IEEE Journal of Oceanic Engineering, 26 (4), 539–547, 2001.
[18] Chiba, S., Waki, M., Kornbluh, R., & Pelrine, R. (2008, April). Innovative power generators for energy harvesting using electroactive polymer artificial muscles. In Electroactive Polymer Actuators and Devices (EAPAD) 2008 (Vol. 6927, p. 692715). International Society for Optics and Photonics.
[19] Tanaka, Y., Oko, T., Mutsuda, H., Patel, R., McWilliam, S., & Popov, A. A. (2014, August). An Experimental Study of Wave Power Generation Using Flexible Piezoelectric Device. In The Twenty-fourth International Ocean and Polar Engineering Conference. International Society of Offshore and Polar Engineers.
[20] Sodano, HA, Inman, DJ, and Park, G (2004). A Review of Power Harvesting from Vibrations Using Piezoelectric Materials, Shock Vib Digest, 36(3), 197–205.
[21] Li, S, and Lipson, H (2009). Vertical-Stalk Flapping-Leaf Generator for Wind Energy Harvesting, Proc ASME 2009 Conf Smart Mater Adapt Struct Intell Syst, San Francisco, CA, USA, OMAE, SMASIS2009-1276.
[22] Khaligh, A, Zeng, P, and Zheng, C (2010). Kinetic Energy Harvesting Using Piezoelectric and Electromagnetic Technologies—State of the Art, IEEE Trans Ind Electron, 57(3), 850–860.
[23] Erturk, A, and Inman, DJ (2011). Piezoelectric Energy Harvesting, Wiley, 412 pp.
[24] Mutsuda, H, Kawakami, K, Kurokawa, T, Doi, Y, and Tanaka, Y (2010). A Technology of Electrical Energy Generated from Ocean Power Using Flexible Piezoelectric Device, Proc ASME 29th Int Conf Ocean Offshore Arct Eng, Shanghai, China, OMAE, 3, 313–321.
[25] Tanaka, Y, Matsumura, K, and Mutsuda, H (2012). An Experimental Study of Power Generation and Storage Using a Flexible Piezoelectric Device, Int J Appl Electromagnet Mech, 39(1–4), 603–608.
[26] Tanaka, Y, et al. (2014). Forced Vibration Experiments on Flexible Piezoelectric Devices Operating in Air and Water Environments, Int J Appl Electromagnet Mech, 45(1–4), 573–580.
[27] Viñolo, C., Toma, D., Mànuel, A., & del Rio, J. (2013). An ocean kinetic energy converter for low-power applications using piezoelectric disk elements. The European Physical Journal Special Topics, 222(7), 1685-1698.
[28] Wu, N., Wang, Q., & Xie, X. (2017). U.S. Patent No. 9,726,143. Washington, DC: U.S. Patent and Trademark Office.
[29] Jabbar, H., Hong, S. D., Hong, S. K., Yang, C. H., Jeong, S. Y., & Sung, T. H. (2017). Sustainable micro-power circuit for piezoelectric energy harvesting tile. Integrated Ferroelectrics, 183(1), 193-209
[30] Caliò, R., Rongala, U. B., Camboni, D., Milazzo, M., Stefanini, C., De Petris, G., & Oddo, C. M. (2014). Piezoelectric energy harvesting solutions. Sensors, 14(3), 4755-4790.
[31] M. Nath Gupta , Suman, and S.K. Yadav, "Electricity Generation Due to Vibration of Moving Vehicles Using Piezoelectric Effect," ISSN 2231-1297, Volume 4, Number 3 (2014), pp. 313-318 , © Research India Publications,2014..