International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Design and Development of a Wave Power Generation System Using Lever Propulsion and Gear Mechanism

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ABSTRACT

The concept of renewable energy came forward to sustainably fulfill global energy demand, addressing the fossil fuel dependency and environmental effects over the years. This study investigates the idea of creating a device that turns ocean wave energy into electrical energy by utilizing lever propulsion and gear mechanisms on a relatively small scale. It aims to meet the energy needs of the fishermen community by utilizing the ocean as it's the largest and most available renewable energy source for Sri Lanka. This study designs and develops a prototype of the wave power generation mechanism that efficiently harnesses the energy from both upward and downward movements of the floater, resulting in fewer fluctuations to improve the efficiency of small-scale wave power generation units. The developed unit consists of ratchets and a lever mechanism, where the gear wheel is driven by a lever propulsion system that includes a ratchet mechanism and two connecting bars with bearing plates that are connected to the main lever. The main lever consists of a flotation device connected to its end that follows the ocean wave movements. The ratchet mechanism supports the large gear - wheel only turns in a single direction. The prototype was tested with both regular and irregular wave patterns and their maximum output Vrms values were noted as 9V and 13V respectively. It was demonstrated that few of these similar mechanisms can be connected with a flywheel with 30 kg of mass to ensure more smooth power output with fewer fluctuations. Given that Sri Lanka is in an area highly endowed with wave resources surrounding it, this project has the potential to fulfill the energy demand using a unique wave energy conversion mechanism.

Keywords: Wave Power Generation, Lever Propulsion, Renewable Energy, Ocean Engineering.

INTRODUCTION

RENEWABLE energy solutions must be created to sustain and meet the ever-increasing energy demand while replacing fossil fuels that are becoming more rare day by day. Because their economic growth and self-sufficiency will be predominantly based on the key sector of energy, all countries recognize the necessity for future energy supply. The rise in oil prices, the high usage of coal supplies and the possible environmental risk created by pollutants that are emitted by nuclear power plants and fossil fuel usage have led to advancements in renewable energy sources such as solar, hydro, wind, biological and ocean related energy creation projects. Ocean energy is provided by waves, tides, currents, salinity gradients, and natural temperature fluctuations in seawater [1]. Despite a wide range of design methodologies and over 1000 patents for ocean wave power production devices, few prototypes have been tested in real-world ocean situations [2]. As real-world examples, Sindhuja-I, was deployed by the researchers about six kilometers from the coast of Tuticorin in Tamil Nadu, where the sea has a depth of about 20 meters. Sindhuja-I can currently produce 100 watts of energy [3]. Also with eight paddles, each about the size of a small car, the Los Angeles pilot project will provide an installed power capacity of 100 kW per hour, enough to potentially power about 80 average homes near Los Angeles city [4]. It is not a novel idea to convert the energy of ocean surface waves into usable forms of energy. Wave energy is appropriate for states with long beaches and strong waves that reach land. It is pollution-free and never ends since waves never cease. Because of countries like Malaysia's long coastline [5], extracting energy from the waves might be a viable answer to the country's vast power requirement. According to the evaluation statistics, ocean wave energy is around 2000 TWh/year, accounting for 10% of the world's total electrical energy use. [6] Current wave energy conversion methods may be economically undesirable when compared to established energy sources such as fossil and hydro power. In contrast, wave power may be economically viable for isolated islands and the main continent. Because waves originate from storms far out at sea and can travel great distances with little energy loss, the power they generate is far more consistent and predictable, both day to day and season to season. Wave power generation is substantially smoother and more consistent than wind or solar power generation, resulting in higher overall capacity factors. Wind power is proportional to air speed, but wave energy is proportional to wave height. Waves generate much more power when averaged over a period of time because water is 850 times denser than air [7]. Wave energy requires half the land area of wind energy, has no access roads, and lowers infrastructure costs. While not yet competitive with fossil fuels, the economics of wave power are encouraging, and the prospects are brighter with advanced technology.

LITERATURE REVIEW

Over the years the world has been suffering from fossil fuel dependency and environmental disorders. So that the concept of renewable energy came forward to sustainably fulfill global energy demand. Since renewable energy brings economic growth through less dependency, nations keep exploring for renewable energy sources and investigating for utilizing them. As most of the earth surface is covered by the ocean and its huge potential to generate energy through waves, tides, salinity gradients and temperature fluctuations, the ocean has become the most promising energy source.

As of now, various ocean energy harnessing methods are being used all over the world. Most of them are focused on ocean wave power and tidal power. Amongst all OWCs, OWSCs, point absorbers, attenuators and WECs are the most common approaches to capture energy from sea waves to generate electricity. Further discussed is a review on similar scope researches and their key findings related to wave power generation.

Beirão, C. M. (2011, May) has participated in designing and developing a hydraulic power take-off prototype to be utilized in a wave energy converter (WEC), with the use of educational components for a partially submerged floating-point absorber [8]. It investigates a model featuring an electric generator with a floater type characterized as a buoy. Results include simulation of PTO hydraulic circuit with the help of special software (FluidSim) and pre-prototype, verification of the working principle of the hydraulic PTO with educational components and calculation of forces on the WEC and floating buoy motion equation.

Further study by Shane J. Burns and M.C.(2013,July) for the Limerick Wave, in which flywheel technology is employed to generate electricity from wave energy [9],develops amathematical model of operating principles of the WEC device and examines the performance of the scaled-up test rig. It also examines the power take-off mechanism and identifies two qualitatively different regimes of operation and discusses the optimization of the arm length of the device for ocean wave power extraction using real site data. Explores an experimental setup with an electric generator, utilizing a cylindrical floatation device as the floater type. It identifies two qualitatively different operational states of the wave energy converter, each corresponding to extracting a small or large amount of energy per cycle, and highlights the seasonal variance in wave properties that needs to be considered when designing the device shape and scale. Concludes that an arm length of 14m will result in maximum power extraction for a given season. Furthermore, the Design, Development and Experimentation of Deep Ocean Wave Energy Converter System [10] by Srinivasan Chandrasekaran, R. B. (2015, November) focusses on the design and development of a wave energy converter (WEC) system that uses a buoy-type point absorber mounted on an offshore platform to produce electric output for partially meeting operational energy demands. focusses on a particular model that has an 8-pole permanent magnet DC generator and a horizontal cylindrical buoy with an extended fin as the type of floater.

The device shows a maximum efficiency of 23.47% at a 32-degree angle of rotation of the buoy for a 1.7m arm length. Experimental investigations were carried out on a scaled model of the proposed device in a random wave cum current flume. Furthermore, Marine Power Generation Methods and Future Developments research conducted by Shou Qiu, G. Y. (2023, April) [11] focuses on specifically tidal energy power generation, wave energy power generation, and ocean current power generation. The study also examines the background, history, and significance of the application of wave energy, tidal energy, and current energy in ocean energy. Investigates an experimental configuration utilizing a Kite-type Current Generator, paired with a floater type identified as a diffuser-augmented floating hydro turbine. It concludes that ocean energy will be developed enthusiastically in the future to substitute a portion of fossil energy. This study consists of a novel hybrid wave energy converting design done by combining super devices and an oscillating water column (OWC)., which operates more effectively than separate components. It highlights the successful development of a lightweight wave energy absorber and a semi-submersible vessel for ocean wave energy generation. Marco Rosati, T. K.-V. (2021, September) studied data-based hydrodynamic modeling of a fixed OWC wave energy converter [12] by developing a data-based hydrodynamic model of a single chamber oscillating water column (OWC) wave energy converter using system identification techniques. The model is derived from real wave tank data gathered from a narrow tank experimental facility at Dundalk Institute of Technology (DkIT). The research paper delves into a particular model that incorporates an electric generator. The research results show that system identification (SI) techniques can provide accurate and simple models of OWC devices, as long as suitable input signals are chosen during the experimental campaign. Poor performance can be expected if unsuitable input signals are used and it suggests that the data-based modeling techniques employed in the study can be extended to full-scale OWC devices, with high fidelity simulation using computational fluid dynamics (CFD). Design and Analysis of a Decoupling Buoyancy Wave Energy Converter a study by Pablo Torres-Blanco, J. Á.-F. (2023, July 27) [13] presents a new two-stage wave energy converter. During the first stage, wave energy is stored, raising a mass to a design height. During the second stage, the mass falls. The efficiency of the design under consideration was examined by simulations. In this study, a novel model using a conventional generator, direct drive linear generator, and a buoy as the floating body is considered. Results from the first stage of the simulation presented an effective aptitude for energy harvesting near the theoretical maximum of 50% of the incident energy. This is encouraging in comparison to other existing heaving wave energy conversion devices available today. The simulations in the second phase showed huge oscillations in the air turbine, near the mean power of the air turbine. These must be damped before the energy generated is transmitted to the electrical grid. Simulations have shown a decrease in power fluctuations, as a proportion of mean power, increasing linearly with the number of generating devices. Trevor Whittaker, M. F. (2012, January) has researched the nearshore oscillating wave surge converters and the development of the Oyster technology. [14] The research discusses the characteristics of the nearshore wave resources, the hydrodynamic principles of OWSCs, and the parameters that affect the design of OWSCs. In addition, the study takes into account the variability of wave force relative to critical design parameters like water depth and calculates the viable wave power resource that is harvestable by commercial size wave energy converters installed within wave farms. The test involves a variable speed induction generator connected to a floater configured as an Oyster, which is defined as a flap hinged to its lower edge to the seabed. Experiments indicate that wave force is a function of important design parameters, for instance, water depth. Wave force rises due to shoaling effects and the subsequent rise in the horizontal acceleration of the wave. Furthermore, the exploitable wave power resource, or the energy accessible to commercial wave power converters in wave farms, is a more appropriate measure compared to the gross wave power resource. Avikash Kaushik Chand, F. m. (2023, January) has taken note of design and optimization of a Rack and Pinion Type WEC Utilizing an Auxiliary Vibrating System [15] by introducing a new auxiliary vibrating system that can be utilized to enhance the power input to a wave energy converter with a rack and pinion type PTO in regular waves. Approximate the optimized power input for the system and study if adding an innovative vibrating system will enhance the power input of the system. This is determined from a particular model utilizing a direct-driven permanent magnet linear generator, with an Aqua buoy as the floater type. The vibrating system has doubled as a control method to smoothen the impact of the waves on the device as well as to increase the input power absorbed by the system. Also, with a rise in cumulative mass, both response amplitude and input power exhibit an increase over a specified range of stiffness. Similarly, an increase in stiffness also leads to an increase in response amplitude and input power for a specified range of overall mass.

METHODOLOGY

Design Step

A wave energy converter (WEC) device was modeled using a flywheel and lever propulsion mechanism as an energy converter. This mechanism is mounted on a frame that can be fixed to a shore using some fasteners, and since this is a prototype, the structure was made of aluminum. Further, this mechanism consists of a lever, ratchets, connecting bars and a large gear wheel. The large gear wheel is driven by a lever propulsion system that includes a ratchet mechanism and two connecting bars with bearing plates that are connected to the main lever. The main lever consists of a flotation device connected to its end that, in turn, follows the ocean's waves. The large gear wheel only turns in a single direction with the help of the ratchet mechanism. A self-geared DC electric motor is used to increase the rotational speed and generate electrical power using the rotational movement of the large gear wheel. Further a small gear wheel is used to connect the large gear wheel and the self-geared DC electric motor. Two views of the prototyped WEC are depicted in Fig. 1and Fig. 2, and the fabricated model is presented in Fig. 3. The length of the lever may vary with practical conditions; since this is a model, it is 2m, and the length of the connecting bars is 0.5m. Each connecting bar connects to the main lever using a bearing plate that includes four 607 type bearings on each bar. Each connecting bar connects to two bicycle ratchets to rotate the large gear wheel into a single direction in every floater movement.

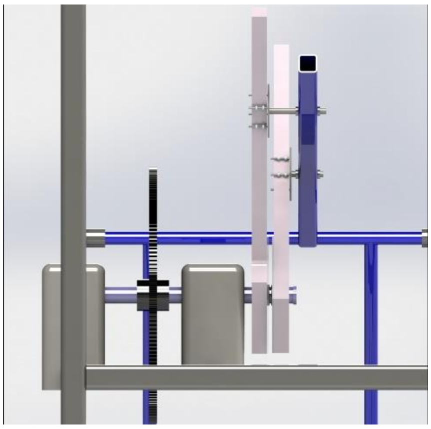

Figure 1: 3D model front view

Figure 2:3D model side view

A large gearwheel with an outer diameter of 0.305m, and 120 teeth is used. Further small gear wheel with an outer diameter of 0.051m, and 20 teeth is used. Additionally, a self-geared DC motor is used.

Figure 3: Prototype

Material Description

Sea wave power generation structures are designed to capture the kinetic energy of ocean waves and transform it into electrical energy and they are made of materials that are resistant to the harsh maritime environment. The following materials were identified as optimal for the construction of this structure:

Stainless steel: It is a corrosion-resistant as well as a strong material that is ideal for equipment manufactured for use near the ocean. Because corrosion resistance is a must in marine conditions, ensuring durability and reducing maintenance requirements. Furthermore, the great strength of this material enhances the structural integrity of the power generation mechanism.

Aluminum: Known for its lightweight, corrosion resistance, and excellent thermal conductivity. Aluminum plays a crucial role in the design of sea wave power generation structures. Because those properties increase longevity and help in the heat dissipation during the energy creation process. The material's low density facilitates ease of installation and reduces overall weight, making it an advantage for components that are exposed to dynamic wave forces.

Titanium: A light weight material known for its great strength which can validate the structural stability to withstand powerful sea waves. It ensures the durability of the power generation mechanism is guaranteed by its resistance to corrosion and capacity to endure extreme maritime conditions. Therefore, Titanium stands out as a valuable material for wave energy creation devices.

All of these elements grouped together provide us with a complete answer to the particular problems that the maritime environment possesses. Their combined properties provide durability and efficiency, making them ideal choices for sea wave power generation structures intended to operate effectively in close proximity to the sea.

Develop Stage

After identifying suitable materials, hardware design was started. The base structure was prepared by using aluminum box bars. Here, aluminum box bars were used because that was the most cost-effective for this model. Aluminum 1”1.3mm gauge box bars were used for this base structure (fig. 4).

Figure 4*:* Building the base structure

After finishing the base structure, bearing plate preparation was started (fig. 5). Two bearing plates are placed on the main leaver through two bearings (Model No. 6007) that are connected to the floating mechanism. Eight 607 bearings and two 6007 bearings (for the back side of the plate) were used to prepare those bearing plates.

Figure 5: Bearing plate

Then the ratchet mechanism and flywheel preparation were done. Instead of using a ratchet mechanism, two bicycle-free wheels are connected to the flywheel shaft to convert up-and-down floater motion to one-direction rotation. Also, bicycle freewheels would save time and the cost of cutting and preparing the ratchet mechanism (Fig. 6). The flywheel was connected to the main shaft and it was fixed to the base structure through the two bearings (Model No.60-22 bearing). Two connecting bars that connected to the bearing plates were connected to the free wheels through the chain. Then the two connecting bars were connected to the bearing plates, and the full structure was painted using anti-corrosive paint (Fig. 7).

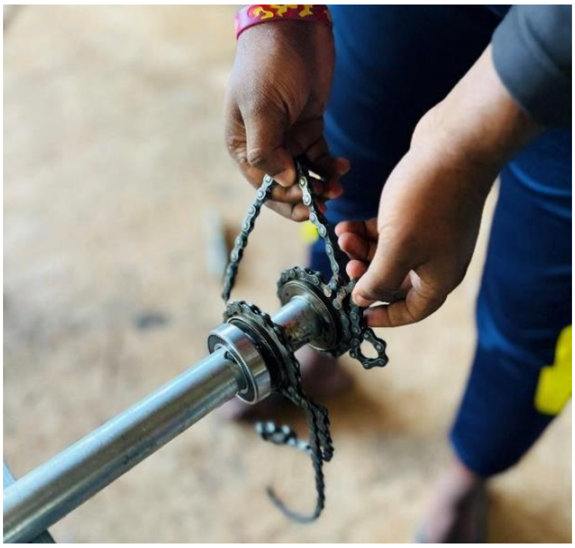

Figure 6*:* Assembling ratchet mechanism

Figure 7*:* Painted structure

Then the DC self-geared generator was fixed through the starting motor gear wheel to the flywheel because the starting motor gear wheel teeth usually match the ring gear teeth of the flywheel. Finally, the floater was connected to the base structure through the two connecting leavers and iron plate (Fig. 8).

Figure 8: Structure with the floater

Data Collecting Stage

- Regular Wave Patterns

Table 1. Regular wave pattern data

SN.	Wave	Time (s)	Floater moving height (m)
1	Regular wave 1	3	0.24
2	Regular wave 2	4	0.36
3	Regular wave 3	5	0.50
4	Regular wave 4	6	0.63
5	Regular wave 5	8	0.86

According to observations of the scenario of the wave patterns and behaviors were provided manually to the floater, and a set of data from regular average wave patterns were observed. This data is used to execute the test of lever propulsion and gear mechanism capability. The project goal is combining five or six mechanisms to output steady and cumulative wave forms from the generating electricity. Above data table indicates the time period and the height of the floater from its initial position when the waves impinge on the surface of the floater.

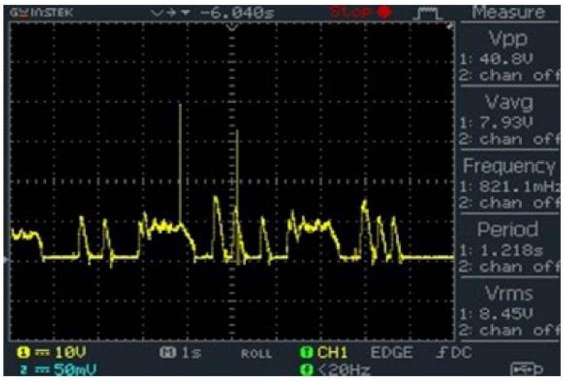

Figure 9: Regular wave 1

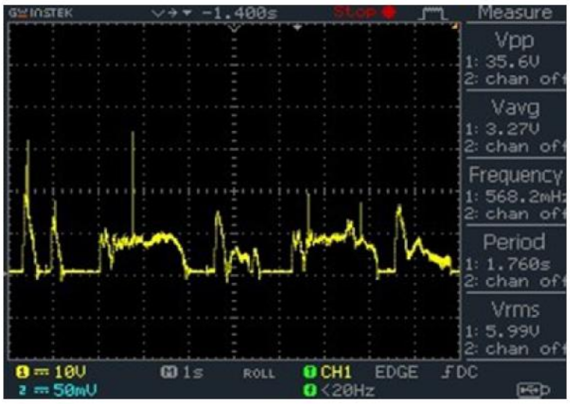

Figure 10 *:* Regular wave 2

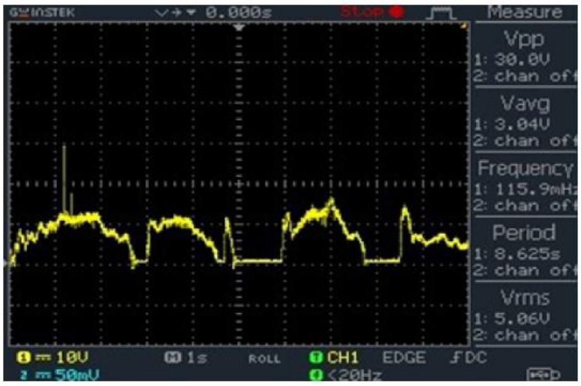

Figure 11*:* Regular wave 3

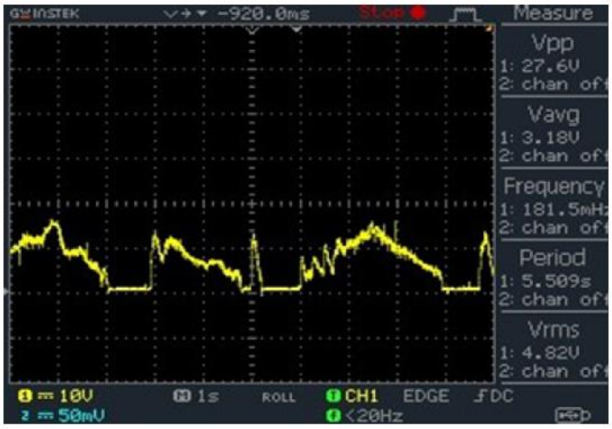

Figure 12: Regular wave 4

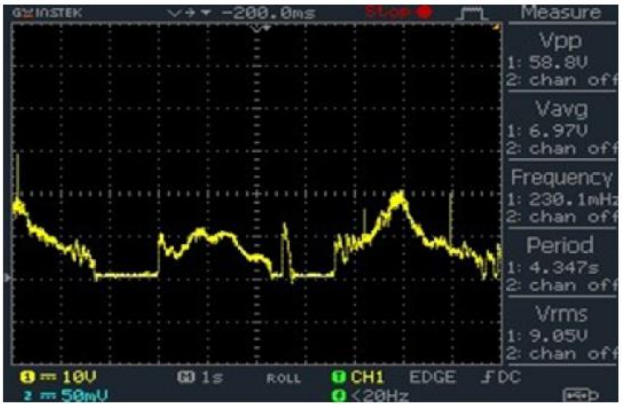

Figure 13*:* Regular wave 5

Above figures display the voltage (Y axis) vs time (x axis) based signal output from generated electricity in 3 seconds to 8 seconds of regular wave patterns. Peak voltage (Vpp) of above patterns is 4.88V. Root mean square Root mean square voltage (Vrms) represents the Direct current voltage that dissipates the same amount of power as the average power dissipated by the alternating voltage and Vrms fluctuated between 5V to 10V.

Irregular Wave Patterns

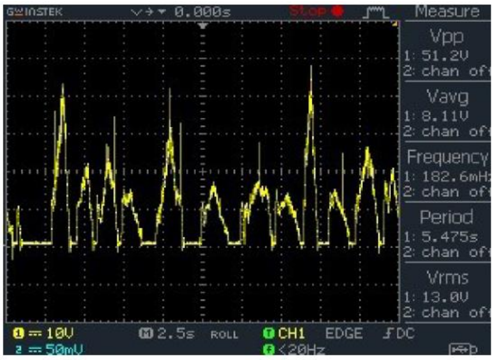

Figure 14: Irregularwave1

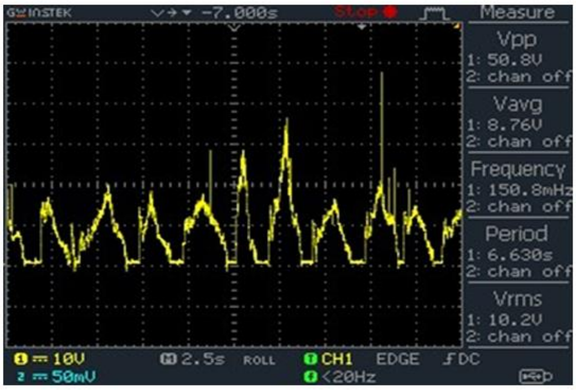

Figure 15 :Irregularwave2

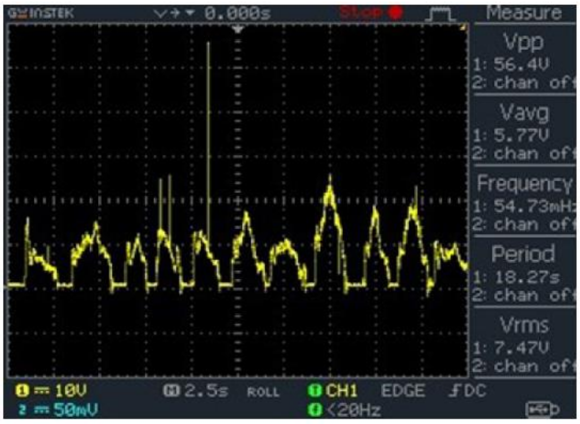

Figure 16: Irregularwave3

The voltage (Y axis) vs. time (X axis)based signal output from generated electricity at various time intervals with irregular wave patterns is shown in the above representation. The peak-to-peak voltage (Vpp) of the mentioned patterns varied from 39V to 57V. 7.03V is the calculated average voltage (Vavg) of the wave patterns above. Vrms ranged from7V to 13V. Above wave patterns are considered as most usual wave types, because uniform waves do not originate in the sea.

RESULTS AND DISCUSSION

Performance of the prototype was analyzed as summarized with the hand-generated wave conditions data. The data obtained showed apparent voltage fluctuations corresponding to power output waveforms and thus encouraged deeper exploration of current mechanism workings. Attempts were made to integrate together a set of data sets to achieve uniform visualization there by giving more detailed information. Below are combined several output data points of different waveforms on a single graph so as to provide an overview of the trends in the output wave performance. The average performance of the integrated dataset was finally evaluated and compared with other similar mechanisms to show how efficient and reliable the mechanism was. The presented graph in Fig. 17, showing the continuous wave of power output, consisted of an average of the wave patterns delivered to the model.

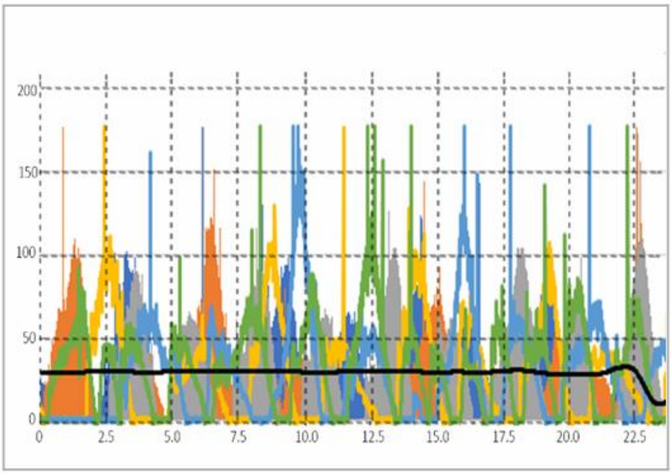

Figure 17*:* Resulting graph

Through this technique the prototype output wave forms were enhanced. It involved the discussion of mechanism possibilities and constraints in an actual operational context. The investigation is also meant to open a forum for possible advancement and improvements that will automatically make the mechanism more efficient in harnessing wave energy to produce energy.

CALCULATION

This calculation was performed to select a suitable flywheel for the next step of this research.

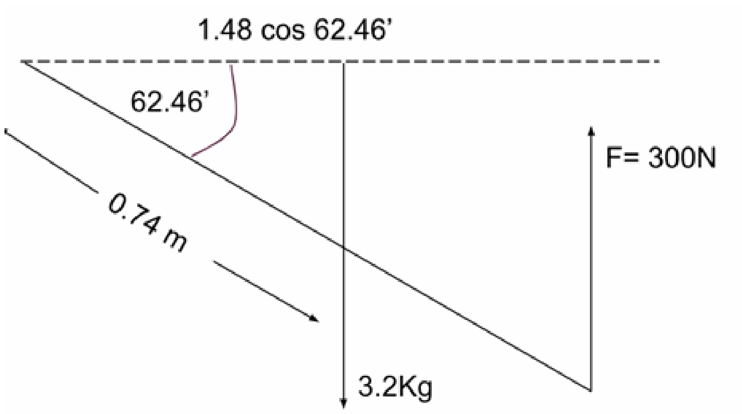

Figure 18: Lever and floater sketch

The above diagram (Fig. 18) shows a side view of the lever and floater. The lever has a length of 1.48m. It is assumed that a 300N upward thrust is caused by the sea wave, and there is a 32N downward force caused by the weight of the lever. Additionally, a lever angle position of 62.46 degrees is selected for calculation purposes. The torque (τ) generated by the lever is caused by the sea wave,

$$\tau = Fd$$

$$\tau = 300\,N \times (1.48 \times cos\,62.46)\,m - 32\,N \times (0.7 \times cos\,62.46)\,m$$

$$\tau = (205.29 - 10.94)\ \mathrm{N.m}$$

$$\tau = 197.35\,N.m$$

Expected rpm of flywheel = 1000 rpm

$$\omega = \frac{2\pi \mathrm{N}}{60}$$

$$\omega = \frac{2\pi \times 1000\ \mathrm{rpm}}{60}$$

$\omega = 104.72\ \mathrm{rad/sec}$

Generated power (P) by lever is caused by the sea wave,

$P = \tau\omega$

$P = 197.35\ \mathrm{N.m} \times 104.72\ \mathrm{rad/sec}$

$P = 20666.492\ \mathrm{W}$

Assumed that 20% of Power reduction is happened due to friction, sound and other environmental condition,

Hence power delivered to the flywheel shaft (P0) is,

$P0 = P \times 0.8$

$P0 = 20666.492 \times 0.8$

$P0 = 16533.193\ \mathrm{W}$

Assuming the coefficient of fluctuation of speed (CS) as 0.01.

Work done per cycle = $\frac{60P_0}{N} = \frac{60 \times 16533.193\ W}{1000\ rpm}$ = $991.99\ \mathrm{J/sec}$

Assuming the coefficient of fluctuation of Energy (CE) as 0.1

Energy Difference = Work done per cycle × C_E

= 991.99 × 0.1

= 99.199 J/sec

Assume the radius (k) of the flywheel is 1.5 Feet = 0.1524 m.

Hence, the mass (m) of the flywheel is,

Energy difference = $mk^2\omega^2Cs$

99. 199 J/sec = m×0.15242 m×104.722 rad/sec×0.01

m = 38.94 Kg

CONCLUSION

The present innovative model of wave power generation was designed to utilize a floater that moves vertically with the sea waves so as to build up pressure for the mechanism, the rotation of which generates electricity. This prototype harnesses the movement due to both rise and fall of the floater in comparison to simple standardized small scale wave power generation techniques such as rack and pinions which generally take in the power when the floater moves only in one direction.

The main purpose was to figure out whether it's really possible to make a device that would take power from waves and to understand whether the generator continues producing energy if the floater draws the energy from the up and down motions of the waves. Proposed actual materials for the mechanical parts or for the floater were not used in creating the model of this mechanism. Besides that, it should be mentioned that its size may vary a lot due to these obstructions and the properties of the wave currents.

It was demonstrated that this system actually could convert wave power to electric energy through a prototype (an output Vrms range from 7V to 11V had been achieved by this prototype) and then found those similar mechanisms can be connected together for the purpose of ensuring more stable output with

Cheaper fluctuations.

ACKNOWLEDGEMENTS

First, our sincere gratitude goes to our experienced supervisor Eng. Vimukkthi Vithanage for his leadership, continual assistance and knowledge transferred during the research project duration.

We acknowledge Prof. K.R. Koswattage, Dean of the Faculty of Technology, and Dr. N.P. Liyanawaduge, Head of Engineering Technology department, for their guidance that allowed students to perform well in academic and research spheres. Regarding all the lecturers of the Faculty of Technology, Sabaragamuwa University of Sri Lanka, we would like to express our deep thanks for their instruction and continuous feedback which helped us improve the final product.

Also we acknowledge the huge contribution made by the non-academic employees of the university for the completion of our project. Moreover, we would like to give our regards to our families, friends and everyone else who have helped to make our research project a successful one.

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