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Application of Restoring Force Theory to Increasing Wave Power Generation under Weak Fluctuations

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ABSTRACT

The feasibility of extending the technique in practice to the development of wave power generation in an environmentally inadequate field are investigated by the application of restoring force theory to the increasing of wave power generation under the circumstances of weak fluctuations. Hydraulic model tests are carried out in the wave flume with regular waves as well as irregular waves to investigate over the efficacy of the wave power generation utilizing restoring force through elastic spring with ratchet wheel. The feasibility of the restoring device has been rudimentary confirmed by using a small-scale motor, tentatively, the ratchet wheel was adopt as a accumulation device to hoard up the amplitude of wave fluctuations with feeble energies to great potential, and the clockwork spring of a "pull-back car" then act as restoring device with sudden repercussions, which may create a greater quantity of wave power, the results are compared with that generate reciprocated by conventional oscillating movement, this improvement accrues at least twice power as much as that of original manner (reciprocation), the technique could be applied to the existing equipments for power generations to obtain a higher performance evaluation, especially in inadequate environment such as waves fields with weak fluctuations. The feasibility of the technique is applicable in practical applications to the development of existing wave power device, e.g. wave power and/or wind power generator.

KEY WORDS: Restoring force, Ratchet wheel, Elastic spring, Bladed rotor, Hydraulic model test, Wave power, Wave energy magnitude.

INTRODUCTION

Under the tendency towards environmental consciousness, clean regeneration energy such as solar power, wind power and ocean energy has becomes one of the research topics that are worth probing into. Considerable quantities of investigations in oceanographic engineering are conventionally invest in coastal protection branch, coastal hazard mitigation and their physical properties, such as wave breaking, wave absorbing or dissipating devices and constructions, ecological engineering method, etc. As a native proverbial saying 'Water can float a boat, so can it capsize it'. It is time for us to think contrarily as 'Though water may capsize a boat, so can it floats', i.e. to turn the hazardous wave power into useful renewable power might be the best way of coastal protection. Waves in the ocean contains a large amount of energies, this alternative energy source is one of the most typical representatives renewable power, how to develop effectively is therefore a popular topics for discussion. Wave energy is an alternative energy form of solar energy, which is proportional to the square of its height, as far as we may concern, such energy are not yet extensively developed as the result of its uncertainty, even though there are a considerable quantities of researches into the exploitation of wave power and are now in a pre-commercial stage, the nature and extend of environmental considerations remain uncertain, the wave heights and periods varies under different conditions, e.g. the dark night and daytime, winter and summer, etc., also, the circumstances of weak fluctuations are not feasible to build a large wave power plant, which are not able to produce sufficient motion and/or force to pump high-pressure hydraulic oil for power generation. Hence, many a little makes a mickle, how to make the best used of waves under limited fluctuation by the accumulation of wave with feeble energy to great potential, which may drive the generator to generate electricity, and has become an interesting research topic of a renewable energy in recent years.

There are presently many successfully developed wave energy converters demonstrated by pioneering scientists, such as Duck, CPelamis, OWC, FROG, PS FROG, TAPCHAN & MOWC, LIMPET, SeaFlow, Stringray, Archimedes Wave Swing, Pico, Oceanlinx, etc. (see João, 2008) and may be simply consolidated to four main technologies as OWC (Oscillating Water Column), AWS(Archimedes Wave Swing), Pelamis WEC(Wave Energy Converter) and Wave Dragon, the generation was achieved by hinged joints which the heave and sway motion pumps high pressure hydraulic oil. However, according to Elliott (1996), it was pointed out that in the UK's programme, a smaller scale options have turned out to be more commercially relevant compared with large scale projects. The low cost-benefit of electricity acquired from wave power will only be competitive when the cost of the power generation is substantially reduced, small scale renewable generation may be the most cost-effective way to bring electricity to remote villages. New innovations of different small hydro technologies are summarized and discussed. Although small hydro power devices may be a tendency to renewable energy generation, improvements and upgrading can still be worthwhile. Generally speaking, waves with great fluctuations are more power, specifically; wave power is mainly determined by wave height, wave length and its velocity of transmission. It is also well known that conversion of wave energy to electricity is generally anticipated to have limited environmental impacts. Take the maritime ambient wave conditions around Taiwan for example, most of the waves in the ocean are not sufficient and doesn't suffices for the generation of wave power, the significant wave heights are mostly lower than 1m, as shown statistically in Fig.1 and Fig.2, which are the average wave height gauged around Taipei Harbor and An Ping Harbor, respectively. The circumstances of weak fluctuations are not feasible to build a large wave power plant, which are not able to produce sufficient motion and/or force to pump high-pressure hydraulic oil for power generation.

However, inasmuch as the energy per unit area of waves on the water surface is proportional to the wave height square, great mechanical energy depends generally on great potential and/or force, i.e. sufficient wave height and wave velocity, nevertheless, as mentioned previously, waves in the ocean may not be sufficient for the generation of wave power due to its small fluctuations, even so, as revealed, "heaped-up earth becomes a mountain", "accumulated water becomes a river". This research is mainly emphasis upon the efficiency on the promoting of the conservation of mechanical energy to the electricity, and how to make the best used of waves under limited fluctuations and dynamics by the accumulation of waves with feeble energy to great potential, and then turn entirely into the generation of wave power.

Su et al. (2002) developed a higher conversion efficiency wave power device (OD) with an oscillating buoy, and was based on the hydrodynamic analysis on wave power devices in near shore zone by You (1993), their results revealed that the total efficiency is much higher than that of an Oscillating Water Column (OWC) wave power device. A range of systems with point absorbers on the surface and linear generators placed on the seabed was investigated by Thorburn et al. (2004); different topologies for the electric system transmitting power are discussed. A more efficient generator with a higher power factor was developed by Thorburn and Leijon (2007) presently by introducing a cable wound station and thereby excluding the transformers. Orer (2007) determined experimentally the energy efficiency of the plate wave energy converter, which indicated that the efficiency of the submerged plate wave energy converters can reach up to 60%. Josset and Clément (2007) present a numerical simulator of OWC wave plants to improve the productivity, and were applied to the European wave energy power plant seated on Pico Island. Emmanuel et al. (2008) proposed a contact-less force transmission system (CFTS) which has enhanced the design of a new direct-drive ocean wave energy converter (OWEC) using a ball screw as a gear system for fast speed and torque transmission.

In this article, hydraulic model tests are carried out in the wave flume with the elasticity of the restoring device to investigate over the efficacy of the wave power generation utilizing restoring force through elastic spring. Restoring force, e.g. elasticity, is a force of an elastic object that tends to pull an object back toward some original position when the object is displaced. For example, a catapult, a trebuchet, a slingshot or a bow, it arises as a consequence of a force that tries to restore the object to its original shape. One may not be able to fling a rock nor an arrow to a distant target bare-handed, yet could easily be accomplished by a bow. The distinguishing feature of active power can be applied to increase total wave power production if we can successfully develop the restoring force technique to exploit these resources reliably, this ideal was enlightened by "pull-back car" toys with a slightly pull back and greatly ongoing high speed action function, i.e. a great repercussion of ratchet wheel together with a revolved-tight clock spring can improve the powerless of weak fluctuations. Consequently, it is our aim to probe into how to use the restoring force theory to increase the efficiency of existing wave power devices.

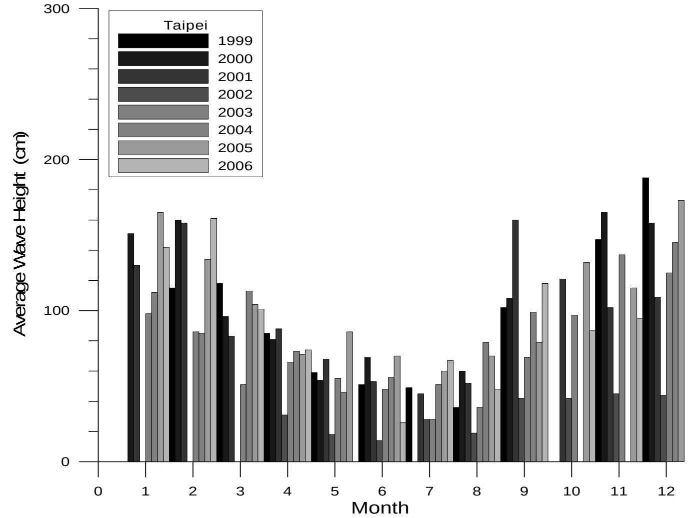

Fig.1 Maritime ambient wave conditions around Taipei harbor

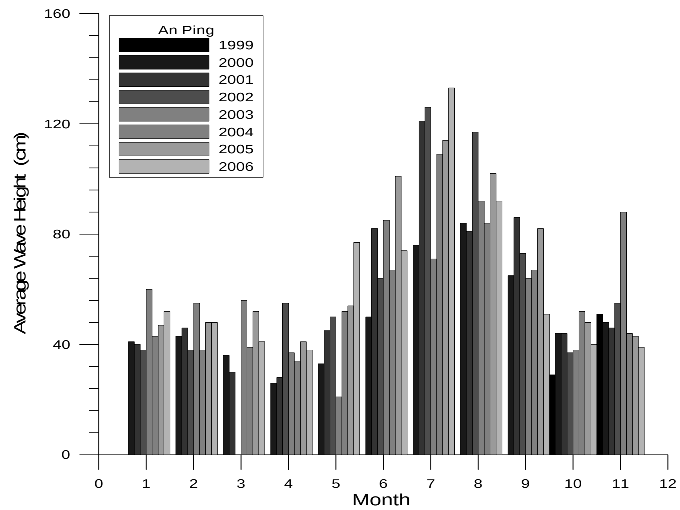

Fig.2 Maritime ambient wave conditions around An Ping harbor

EXPERIMENTAL SETUP

2.1 Theoretical Development

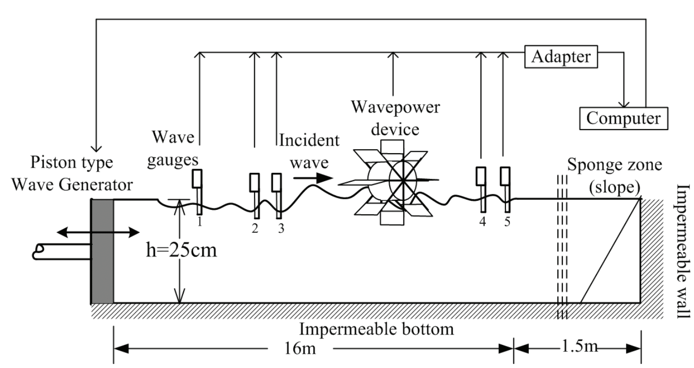

Fig.3 Schematic layout of wave flume and experimental setup

The laboratory testing were carried out in a 16m wave flume located at the Fluid Mechanics Lab of Tungnan University as shown schematically in Fig.3, the channel is 80cm wide and 60cm high, and the constant water depth is 25cm. A piston type wave generator is located at one end of the flume with the other end an absorbing 1:5 slope, the wave generator system was control by the Wave Generator Filter Unit produced of Canadian Hydraulics Center. The power device was tested both in regular and irregular waves in order to confirm the efficacy of the design concept. Waves are measured using 5 capacitance wave gauges with an adapter linked to the PC, the incident wave heights are measured with the first gauges while the 2nd and 3rd gauges are used for the calculation of reflection coefficient, and the 4th and 5th gauges are for transmission estimation. The model was installed in the middle of the tank with a distance of 10m from the generator. The power device is a bladed rotor looks similar as a water wheel as shown in Fig.4 and Fig.5, which is a framework made of light wood and Polystyrene to decrease its weight. The blades on the rotor were directly driven by the circular water currents as well as the buoyant force (see Jobb and Faizal et al., 2009). The movement of the blades moves in back and force without clock spring in Oscillation case while in the Restoring Force System the blades moves unidirectional with clock spring; the spring was revolved tight by accumulated small displacement and released when it reached an applicable range.

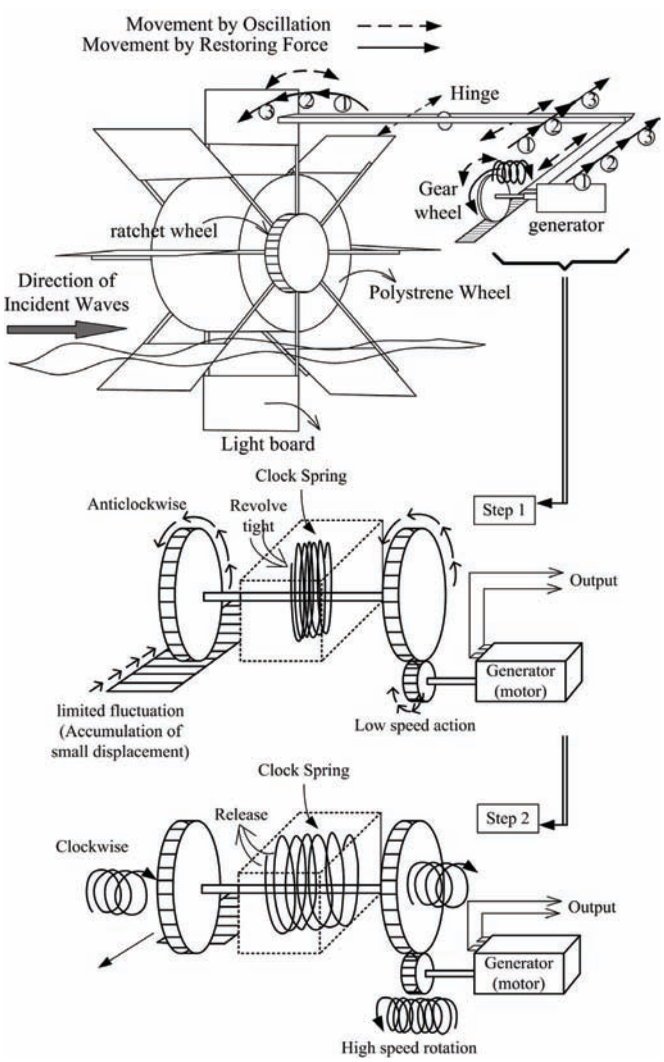

Fig.4 Illustration of wave power device with restoring force

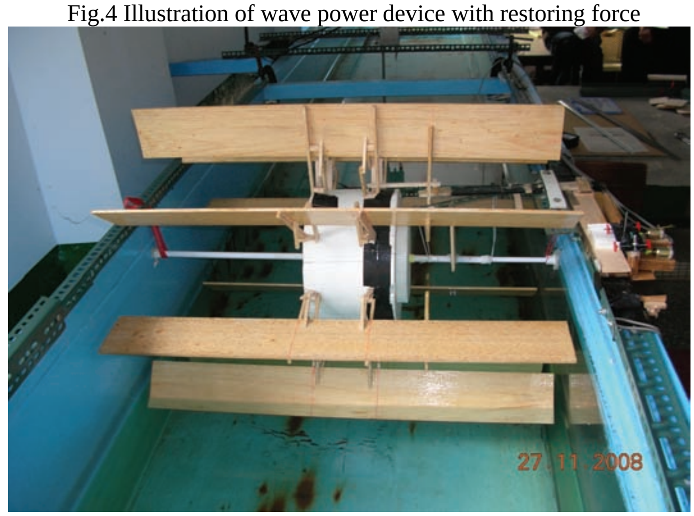

Fig.5 Schematic layout and setup of wave power device

In this study, the occurrence of electricity generations of waves mainly comprise two main stages in the system, the shaft work and power output, the first stage is the transition from wave energy to mechanical energy of some certain medium such as ratchet wheel, blades, shafts, spring, clockwork spring, piston, etc., the second stage is the conversion of power output through turbine mechanical energy via the generator (motor).

Since waves provide the motive power that turns the wheel, a simply designed ratchet wheel equipment as shown in Fig.6 was adopted to maintain uniform direction while the wheel revolves, i.e. the shafts is equipped with a ratchet wheel that allows motion in single direction like a weather vane or an anemoscope, and is acted as a gadget of an accumulation of displacement by amassing the trivial fluctuations of the bladed rotor. Similar usage was also developed by Thakker et al. (2009) in their impulse turbine where they called it self-rectifying turbines, that the turbines rotate in the same direction no matter what the direction of the air flow in the OWC, which are response to the need for turbines to extract power from bi-directional airflows. Moreover, the clockwork spring of a “pull-back car” was adopt as a device of the accumulation of potential energy by accumulating the wave amplitude of trivial fluctuations in all directions

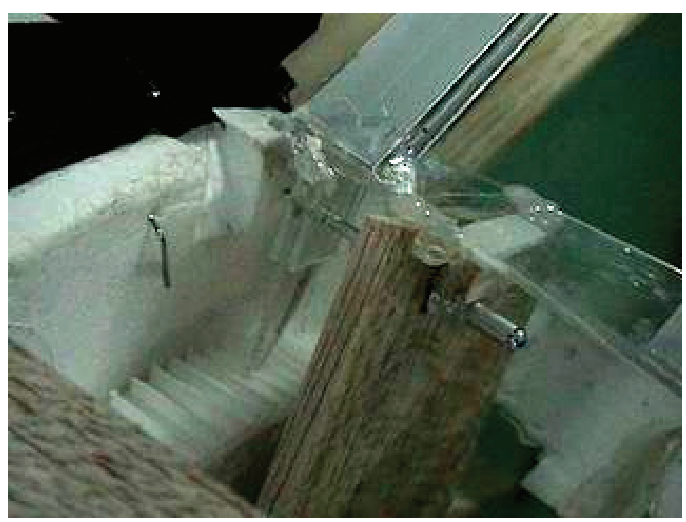

Fig.6 Simply designed ratchet wheel device

with feeble energy to great potential, which may acquire a greater potential energy for power generations. The fundamental purpose in this study is to investigate over the possibility and efficiency of the restoring force technique, the power generator adopted is a 3 Volt small-scale motor, therefore its generation of electricity is relatively small, but may output very considerable value when apply to the general full scale generator and/or farm solutions (see Thorburn, 2007).

The length of the blades is 78cm, slightly shorter than the width of the flume, with an interior included angle of 45°. The output power of the generator is measured directly as the electrical power by the InstruNet analog/digital I/O system, a data acquisition produced by GW Instrument, Inc. Exclude energy losses, the relation between reflection, transmission and power generation can be discussed. Experiments were carried out both in regular and irregular waves for wave period T and/or significant wave period $T_{1/3}$ of 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4 and 1.5 sec collocated with wave height H and/or significant wave height $H_{1/3}$ of 3, 4 and 5cm individually with a total of 26 varied wave properties, the running time is 90 sec. The Bretschneider-Mitsuyasu spectrum is used as the target spectrum for the generation of irregular waves, which can be expressed as:

$$S_0(f) = 0.257 H_{1/3}^2 T_{1/3}^{-4} f^{-5} \exp[-1.03(T_{1/3} f)^{-4}] \qquad (1)$$

where $H_{1/3}$ is the significant wave height, $T_{1/3}$ is the significant wave period, and f is the frequency. According to Goda (2000), the spectral peak frequency, f_p, is related to the significant wave period, T_p :

$$f_p = 1/T_p \qquad (2)$$

Where $T_p \cong 1.05 T_{1/3}$. Similar to that in physical applications of the wave generation theory, a transfer function must be multiplied to obtain the spectrum for the motion of the numerical wave generator, thus

$$S(f) = \alpha(f)^2 \cdot S_0(f) \qquad (3)$$

$\alpha(f)$ denotes the transfer function of wave amplitude and the stroke of wave paddle, whereas in the present study, a piston type wave generator was investigated, hence,

$$\alpha(f) = \frac{\sinh kh \cosh kh + kh}{2\sin^2 kh} \qquad (4)$$

k is the wave number, h is the water depth. Neglect the period which are excessively small or large, i.e. the associate period resolution can be express as:

$$T_{\min} < T < T_{\max} \qquad (5)$$

where T_{min}=0.5sec and T_{max}=4.5sec was chosen presently. The surface fluctuations can be expressed by:

$$\zeta(t) = \sum_{n=1}^{N} \sqrt{2df S(f_n)} \cdot \cos(\sigma_n t - \varepsilon_n) \qquad (6)$$

$$\sigma_n = 2\pi f_n \qquad (7)$$

Here ε_n and N denotes random variable number between 0 ~ 2π and total number of sampling, respectively.

RESULTS AND DISCUSSIONS

3.1 Small scale generator test

To investigate over the possibility and efficiency of the restoring force technique, a small-scale motor is adopted as a small-scale power generator, the power generation was tested by stirring the blades arbitrarily to revolve the wheels, the output voltage as well as current was record synchronously, the relation between the output voltage and current was known as Power(watt)=Voltage(Volt)×Current(Amp), and thus is shown and confirmed in Fig.7, from which it can be seen that the variation of voltage has connection with output wave power. Though the output power could be restored in an accumulator such as miniature battery, yet, the improvement and the efficiency of the restoring force device are simply discussed herein by the variation of output voltages for convenient.

Since the buoy rotors are to be located on the ocean surface, the blades move “back and force” or “up and down” in oscillation case according to the motions of the particle near the water surface as conventional manner of many successfully developed wave energy converters, the appearance of the output voltages was similar to the fluctuations. Moreover, in present method, the displacements of all fluctuations of the bladed rotor are accumulated by the ratchet wheel on the shafts, and the output power appeared like a thorn according to the unidirectional snap back motion as a result of the restoring force create by clockwork spring of the ‘pull-back car”. The improvements and efficiency are described as follow.

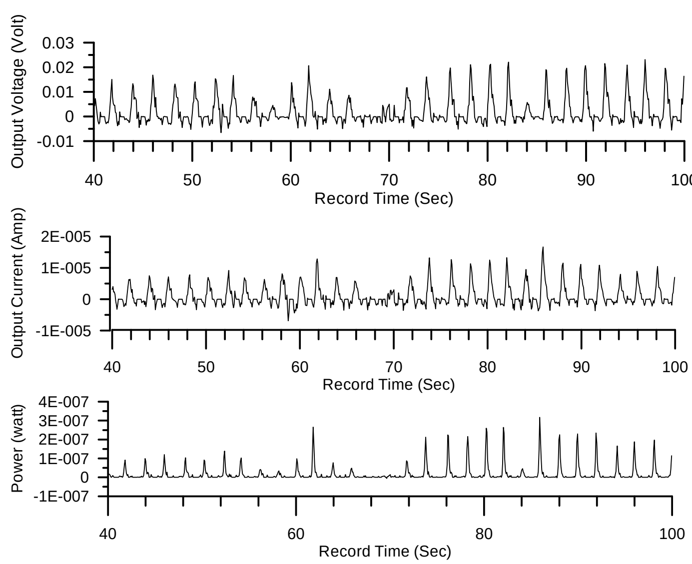

Fig.7 Relation between the output voltage, current and wave power

3.2 Regular waves

The output voltage is measured directly by the data acquisition system coincide with the wave generation and is arranged in Table 1, which shows the accumulative results running for 45sec, we can perceive the disparity between wave energy utilizing ‘Oscillating System’ (OS) which the blades moves in back and force while in the present ‘Restoring Force’ (RF) technique System the blades moves unidirectional, the R/O ratio indicates the relative value of this two accumulative output voltages, i.e. RF/OS, it reached more than 21.9 when the wave height *H* is 3cm collocate with wave period T=0.6 sec, this represents that the voltage output is enhanced 21 times as much as oscillating design when the wave height and wave period is rather small, the conventional power generators are almost ineffectual and idle under this circumstances. Nevertheless, the values of each measured voltage vary increasingly with the extending of wave period from T=0.6 to 1.5 sec in OS case, which increases from 0.11725 Volt/m^2 to 0.612434 Volt/m^2 when H=3cm, and 0.433658 Volt/m^2 to 0.997237 Volt/m^2, 0.607961 Volt/m^2 to 1.293803 Volt/m^2 when H=4cm and 5cm individually, this tendency was not conspicuous in RF whereas the output value is comparatively stable with little alterations, and thus will cause the overall R/O ratio to decrease progressively downwards accordingly, this indicates the present method are brought into full play specifically for environmentally inadequate field. The outcomes showed that generator using restoring force technique have increased the efficiency which accrues at least triple output value. The cause of the decreasing R/O ratio may due to the product of ΔD and Δk, i.e. $\Delta D \times \Delta k$, where ΔD is the displacement of the swaying blades which slightly increased along with the increasing wave length and Δk is the wave number per unit time which decrease substantially from T=0.6 to 1.5sec.

From Table 1 we also perceived that, though the values of measured voltages varied increasingly with the wave height from H=3cm to 5cm, including both the OS and RF, however, from Fig.8 it can be seen that the R/O ratio decrease contrarily instead, this is representative of the efficacy of the RF technique with ratchet wheel by using the restoring force (elasticity) to increase the work efficiency of existing wave power devices with limited fluctuations under disadvantageous environment, e.g. small fluctuate waves and/or short period waves, and it is anticipated that with a wave height of relatively lower fluctuate, the output power will be greatly improved. On the contrary, waves with favorable conditions are essentially feasible of considerable quantities of power generation with certainty, the efficacy of the RF technique

Table 1 Output Voltages and efficacy of the RF technique for Regular Waves

T (sec)	OS (Volt)	RF (Volt)	OS (Volt/m^2)	RF (Volt/m^2)	R/O Ratio
			H=3cm		
0.6	0.008911	0.195633	0.117250	2.574118	21.954102
0.7	0.025593	0.295559	0.336750	3.888934	11.548431
0.8	0.020263	0.244821	0.266618	3.221329	12.082169
0.9	0.030074	0.25692	0.395711	3.380526	8.542927
1.0	0.031308	0.223526	0.411947	2.941132	7.139581
1.1	0.031004	0.172736	0.407947	2.272842	5.571410
1.2	0.038153	0.214923	0.502013	2.827934	5.633187
1.3	0.039269	0.173366	0.516697	2.281132	4.414831
1.4	0.042785	0.246572	0.562961	3.244368	5.763048
1.5	0.046545	0.261492	0.612434	3.440684	5.618047
			H=4cm		
0.8	0.032958	0.28153	0.433658	3.704342	8.542084
0.9	0.052246	0.326466	0.687447	4.295605	6.248631
1.0	0.064728	0.267058	0.851684	3.513921	4.125850
1.1	0.066446	0.262051	0.874289	3.448039	3.943819
1.2	0.079474	0.29764	1.045711	3.916316	3.745124
1.3	0.090011	0.310343	1.184355	4.083461	3.447834
1.4	0.080339	0.321707	1.057092	4.232987	4.004369
1.5	0.07579	0.338429	0.997237	4.453013	4.465352
			H=5cm		
0.8	0.046205	0.307052	0.607961	4.040158	6.645428
0.9	0.070178	0.335299	0.923395	4.411829	4.777836
1.0	0.083653	0.340946	1.100697	4.486132	4.075718
1.1	0.077182	0.318027	1.015553	4.184566	4.120481
1.2	0.110581	0.399395	1.455013	5.255197	3.611787
1.3	0.13606	0.360167	1.790263	4.739039	2.647119
1.4	0.109913	0.327532	1.446224	4.309632	2.979920
1.5	0.098329	0.35913	1.293803	4.725395	3.652330

proposed presently are comparatively ineffectual, which procure the decrease of the R/O ratio.

Results provided for the case of *H*=5cm with *T*=0.8 sec by applying the RF technique compared with standard OS results are shown in Fig.9 and Fig.10, respectively. The solid lines represent the variations of output voltages running for 40 sec, and the dotted lines illustrate the relative variations of accumulative output voltages, accumulative curve represents the accrue of output voltage in time series, which in this case the accumulative power is only 0.046205 volt with OS and is 0.307052 volt when applying the RF technique, since the area of each wheeling blade is 0.076m^2 (0.76m×0.10m), the volume of production is equivalent to 0.607961 volt/m^2 and 4.040158 volt/m^2 individually. Remarkable is the stably output voltage fluctuation, the variation of accumulative power in the OS case appears linear; the generation of the electricity is unremitting. On the contrary, even though the power generations in the RF cases seem intermittent, by accumulating small displacement to great interval, a sudden repercussion may create a quantity of wave power up to 0.2 volt per strike, thus the accumulation of output power reached 6.6 times as much as that of the former case. Fig.11 and Fig.12 demonstrated a case of longer period *T*=1.5sec, the accumulative power of which increases up to 0.098329 volt with the OS whereas is 0.35913 volt when applying the RF technique. Perceive the diversity of the variation of output voltage contrast between *T*=0.8 sec and 1.5 sec, the output power increases substantially with OS cases, but remain comparatively steady with RF. The comparison of accumulative voltage between varied wave properties and power device as well as the efficacy of the RF technique is shown in Fig.13, which exhibited that the generation of wave power is greatly improved.

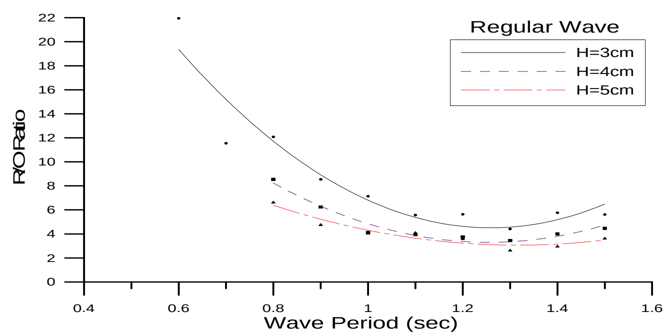

Fig.8 Variation of R/O ratio for monochromatic waves

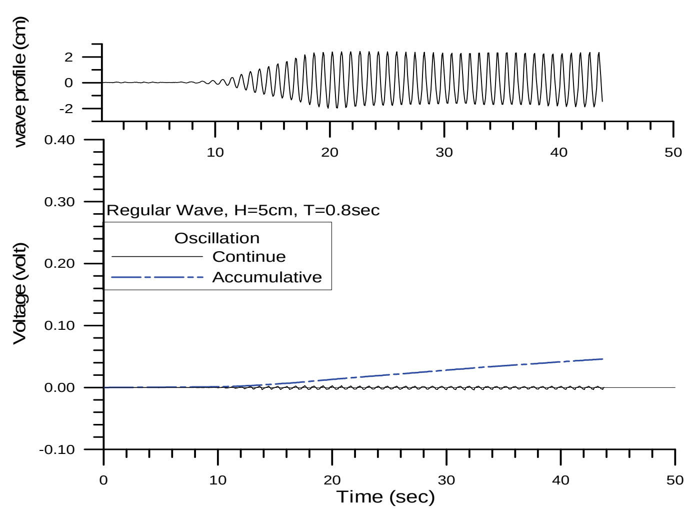

Fig.9 Accumulative energy extracted for wave power device by oscillation. (H=5cm, T=0.8 sec)

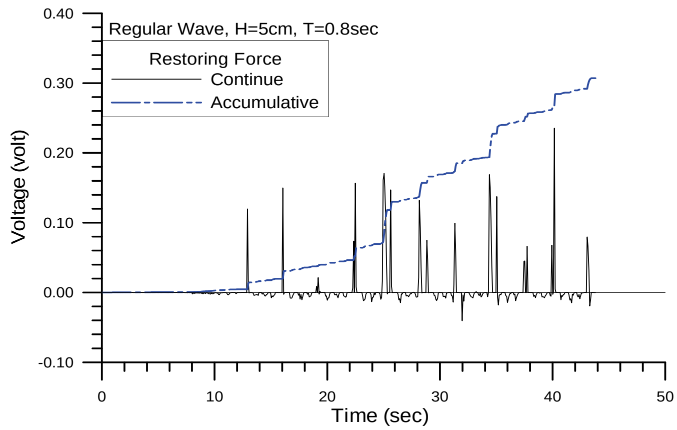

Fig.10 Accumulative energy extracted for wave power device with restoring force technique. (H=5cm, T=0.8 sec)

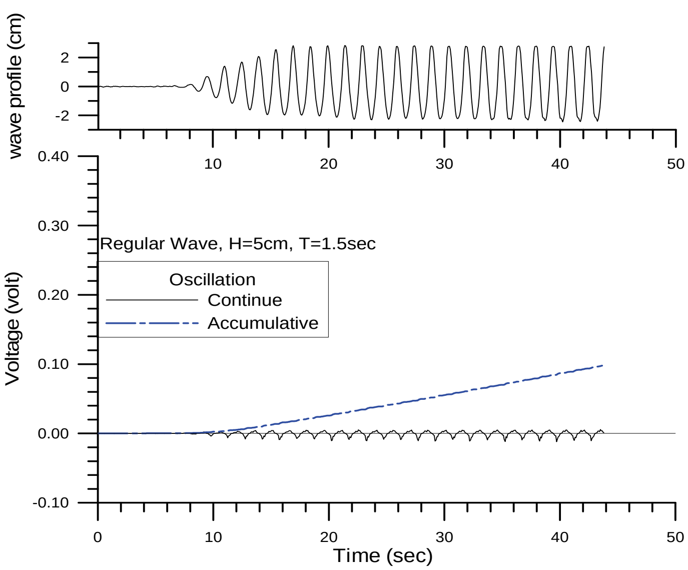

Fig.11 Accumulative energy extracted for wave power device by oscillation. (H=5cm, T=1.5 sec)

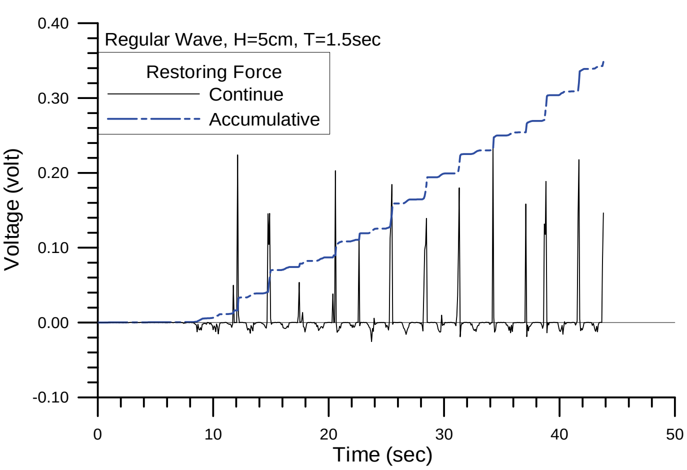

Fig.12 Accumulative energy extracted for wave power device with restoring force technique. (H=5cm, T=1.5 sec)

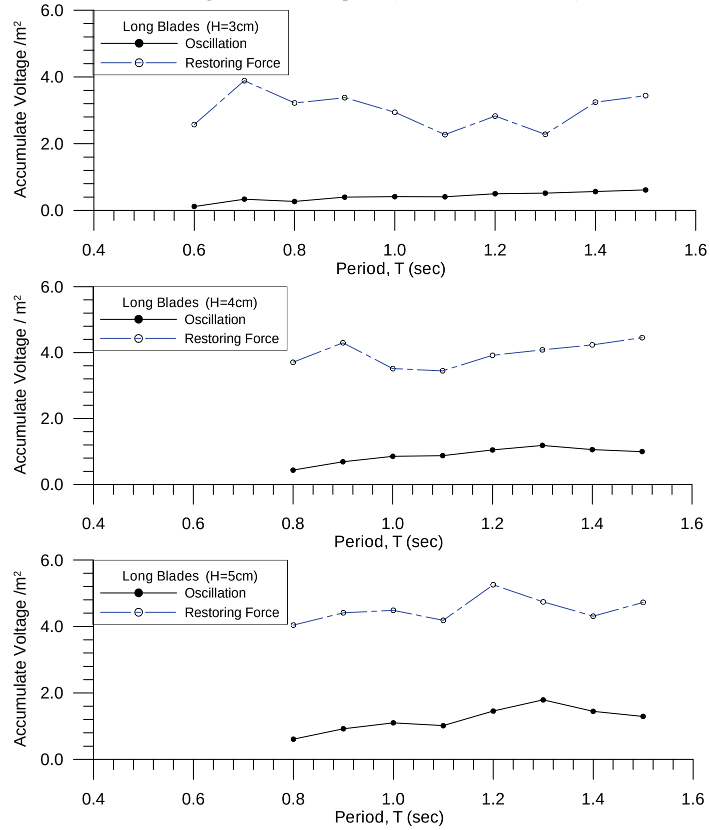

Fig.13 Comparison of accumulative voltage between varied wave properties and power device for regular waves.

3.3 Irregular waves

Waves in the ocean are far from regular wave theory and therefore simulations for irregular waves are essential for a realistic wave load determination. The results are also confirmed by irregular wave tests, the best performance rate is always achieved when using monochromatic waves, however, regular wave test is yet necessary to interpret the physical response simply and conveniently. Unlike regular waves that result in a stationary value of maximum power according to it's established fluctuation. To generate more realistic results, irregular waves test which is calculated by superimposing numerous components of sinusoidal waves were usually proposed since a high performance buoy-type wave power device should amass energy from all directions in the ocean. Random waves are more complicated but realistic about comprising of various monochromatic component waves not only with random phase, different amplitude and frequency, but also in various directions.

Table 2 shows the output voltage measured by the data acquisition system coincide with the wave generation, from which we can perceive the R/O ratio reached more than 13.68 when the incident wave height $H_{1/3}$=3cm collocate with significant wave period $T_{1/3}$=0.6 sec, with a efficiency of 1368%, i.e. the output voltage enhanced nearly 13 times when utilizing RF technique, which is as much as that of traditionally oscillating designed OS. Similar to that of regular wave tests as discussed, an accession of output voltage varied increasingly with the extending of wave period from T=0.6 to 1.4 when utilizing the OS, this tendency was also not conspicuous in the RF cases resembling regular wave test, while the output value is comparatively stable with little alterations, and thus cause the R/O ratio to decrease progressively downwards, accordingly. Fig.14 shows the variations and tendency of R/O ratio for irregular waves. Compare the alterations with that of monochromatic wave cases in Fig.8; the amplitude of variation is much more sensitive for monochromatic wave cases since the curvature is larger, and the best performance rate occurred when H=3cm, though the productivity seems to be rather higher for monochromatic wave cases in corresponding period, however, when the incident wave height (both H and $H_{1/3}$) reached 4cm, it appears that the value of R/O ratio for irregular wave cases are contrarily larger than that of monochromatic wave cases, which achieved more efficiency when adopting the RF technique, this may due to the acquisition of higher quantity of component waves within (during) identical time interval for random waves.

Table.2 Output Voltages and efficacy of the RF technique for Irregular Waves

$T_{1/3}$ (sec)	OS (Volt)	RF (Volt)	OS (Volt/m^2)	RF (Volt/m^2)	R/O Ratio
			$H_{1/3}$=3cm		
0.6	0.007743	0.105947	0.101882	1.394039	13.682939
0.7	0.01073	0.078923	0.141184	1.038461	7.355359
0.8	0.011997	0.099497	0.157855	1.309171	8.293490
0.9	0.012663	0.115548	0.166618	1.520368	9.124852
1.0	0.014914	0.112967	0.196237	1.486408	7.574561
1.1	0.01971	0.12166	0.259342	1.600789	6.172501
1.2	0.021406	0.149787	0.281658	1.970882	6.997431
1.3	0.022695	0.109663	0.298618	1.442934	4.832033
1.4	0.023554	0.093226	0.309921	1.226658	3.957969
1.5	0.007743	0.105947	0.101882	1.394039	13.682939
			$H_{1/3}$=4cm		
0.6	0.017764	0.2	0.233737	2.631579	11.258726
0.7	0.019333	0.190855	0.254382	2.511250	9.871981
0.8	0.020378	0.164	0.268132	2.157895	8.047895
0.9	0.022222	0.21208	0.292395	2.790526	9.543695
1.0	0.026086	0.204964	0.343237	2.696895	7.857241
1.1	0.030057	0.196956	0.395487	2.591526	6.552750
1.2	0.037878	0.195583	0.498395	2.573461	5.163499
1.3	0.040216	0.219907	0.529158	2.893513	5.468147
1.4	0.041845	0.220107	0.550592	2.896145	5.260055
			$H_{1/3}$=5cm		
0.6	0.02861	0.22024	0.376447	2.897895	7.698008
0.7	0.034625	0.238267	0.455592	3.135092	6.881357
0.8	0.040078	0.254133	0.527342	3.343855	6.340960
0.9	0.04191	0.282157	0.551447	3.712592	6.732450
1.0	0.046467	0.282186	0.611408	3.712974	6.072826
1.1	0.052049	0.28071	0.684855	3.693553	5.393187
1.2	0.058386	0.296447	0.768237	3.900618	5.077364
1.3	0.061322	0.289425	0.806868	3.808224	4.719758
1.4	0.063352	0.292555	0.833579	3.849408	4.617928

Fig.15 and Fig.16 show the results for a case of significant wave height H1/3=5cm with significant wave period T1/3=1.0 sec by applying both the present RF technique and standard OS, respectively. The output voltage fluctuation of the variation of accumulative power in the oscillation case reveals that in these two cases the accumulative power is 0.046467 volt with original oscillation system and is 0.282186 volt when applying the RF technique, that is to say, this improvement lead to an active power increase from 0.046467 volt to 0.282186 volt per generation, and the volume of production is equivalent to 0.611408 volt/m^2 and 3.712974 volt/m^2, respectively. A sudden repercussion under this circumstances may create a greater quantity of wave power up to 0.16 volt per strike, thus the accumulation of output power reached 6 times as much as that of the OS case.

As perceived in Fig.17, a maximum efficiency is attained when $H_{1/3}$=3cm with $T_{1/3}$=0.6 sec, and is minimized accompanied the increasing fluctuations of wave under circumstances of superior condition of fluctuations.

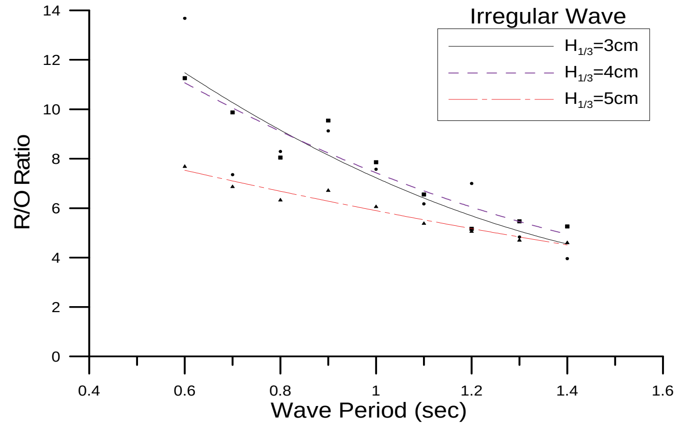

Fig.14 Variation of R/O ratio for Irregular waves

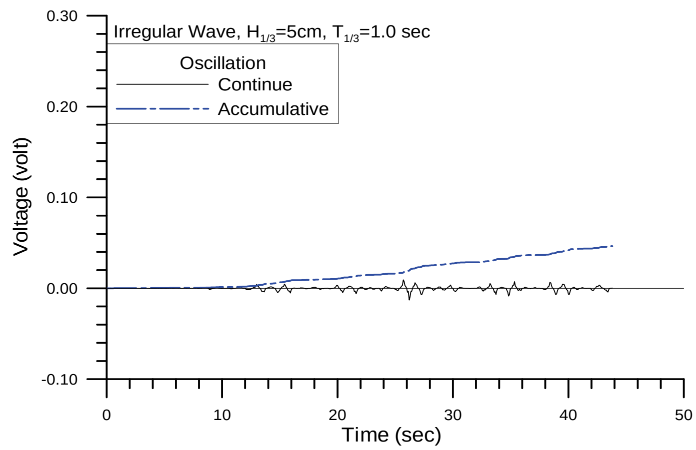

Fig.15 Accumulative energy extracted for wave power device using oscillation for irregular waves. ($H_{1/3}$=5cm, $T_{1/3}$=1.0 sec)

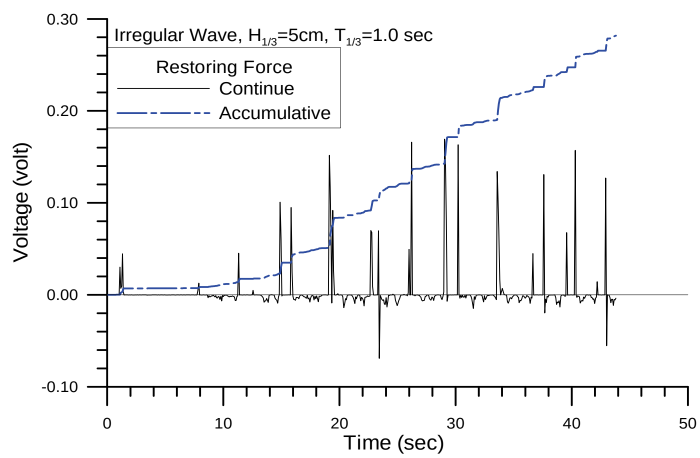

Fig.16 Accumulative energy extracted for wave power device using

restoring force technique for irregular waves. ($H_{1/3}$=5cm, $T_{1/3}$=1.0 sec)

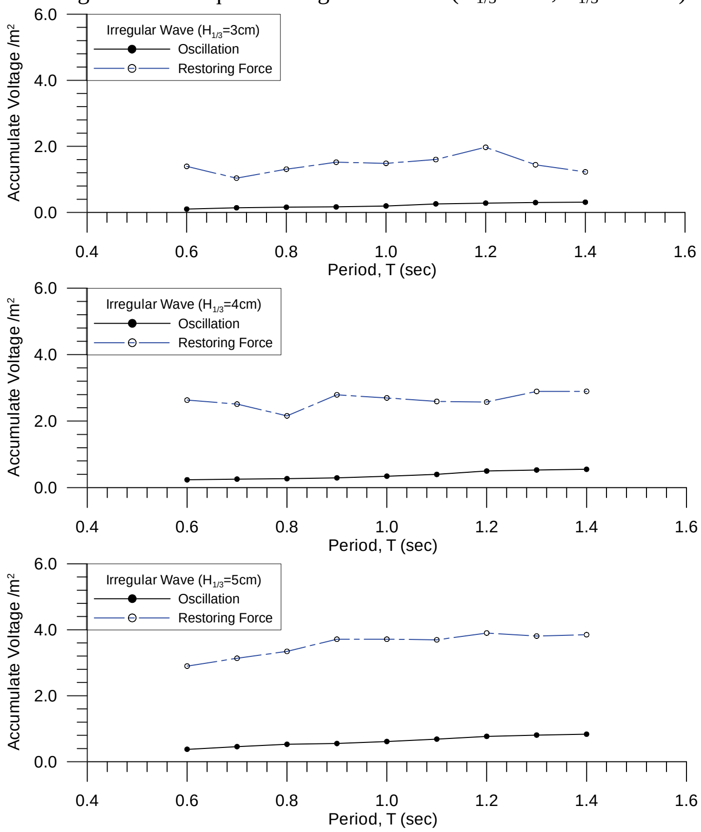

Fig.17 Comparison of accumulative voltage between varied wave properties and power device for irregular waves.

CONCLUSIONS

The application of restoring force through elastic spring to wave power device was an enlightenment of "pull-back car", which may create a greatly ongoing high speed action function for power generation with only a slightly pull back and/or fluctuations. How to make the best used of waves under limited fluctuations by the accumulation of wave with feeble energy to great potential are studied in this paper, an improvement by applying a concept of restoring force technique to present a high performance wave power device, besides, power output may be too small to support commercial installation of single unit, but a great quantity of units arrayed in order can overcome this problem. this can be further discuss by using wave farms and thereby may become an supplementary earning of renewable energy in actual operation of wave power generations, i.e. the majority of ocean wave fluctuations are worth exploitable by applicable processing. Some conclusions may be drawn from the present results as follows:

The feasibility of the restoring device has been rudimentary confirmed by hydraulic model test using a small-scale motor, tentatively, with a maximum efficiency of nearly 2190%, which simply represents that the voltage output is enhanced 21 times as much as oscillating design, and even the minimum improvement accrues at least twice power as much as original manner, yet, larger scale model test would be proceed prospectively with greater precision instruments and equipments to obtain a higher performance evaluation.

The experiments would be carrying out prospectively with elastic bodies of various elasticity coefficients under different wave conditions to investigate over the corresponding wave power and optimizations, moreover, the influence and beneficial results of submerged obstacles will be studied as well. Results can also proceed to the investigations utilizing multi-directional wave basin, prospectively. The feasibility of the technique is applicable in practical applications to the development of existing wave power device.

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