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Evaluation of Energy Obtained by Float-Type Wave Generation System

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ABSTRACT

The authors are developing a movable body type wave energy converter which transfers wave energy into rotational motion of the shaft using a pulley, wire, float and counterweight [1)- 3)]. This paper gives a mechanical dynamic model convenient to estimate the obtainable energy for various conditions. Calculation of the model showed good agreement with a preliminary performance test held at a wharf using a small size apparatus. For the calculation of time series of various quantities, the effect of float submergence condition on the temporal variations of the mechanical quantities is considered. Evaluation is also made for the time average of occurred electric power and the maximum values of various forces such as the tensile force of wire for various conditions.

KEY WORDS: Wave Energy Conversion, Movable Body Type, Wire-Float-Counterweight, Mechanical Dynamic Model, Occurred Electric Power

INTRODUCTION

Wave energy is expected as one of the important sustainable energies, though the practical use has not been attained. Various system of OWC [4)-7)] and movable body types have been designed to extract wave energy. OWC system seems to be considered major one because it does not seem to have serious problem of structural strength, however the practical use has not been attained for economical reasons. On the other hand the authors have proposed a movable body type which transfers wave energy into rotational motion of the pulley using a pair of float and counterweight connected at both ends of a wire hanged from a pulley set above the sea surface. This system extracts wave energy through the weight of the float and the tensile force of the wire. The use of wire, a flexible material, enables to avoid serious structural strength problem common to most systems of movable body type. As a remaining problem, since the float on the water surface will trace elliptic orbit in wavy condition, horizontal force will act on the hanged float and therefore on the system. In order to avoid the horizontal force, the authors have proposed the system to reduce the horizontal motion and to amplify the vertical motion of water around the float This is achieved by enclosing the float using the vertical plate(s) covering the vertical region from about 2 m higher than the highest float level to about 3 m lower than the lowest float level. Thus practically possible wave generation system can be made.

The present paper gives the mechanical dynamics model to predict conveniently the obtainable energy, various forces such as wire tensile force and the displacement of the float. The calculated result for energy gain is compared with a preliminary performance test held at a wharf using a small size apparatus. Then from the calculation of the time series of energy gain, wire tensile force, torque at driving pulley and float displacement, the effect of float submergence condition on the temporal variations of the above quantities is considered. Also time-averaged value of the obtainable energy and the maximum values of the above forces is examined for various wave conditions and some speculations of the system.

THE MECHANICAL DYNAMICS MODEL

Outline of the system is given in Fig.1.

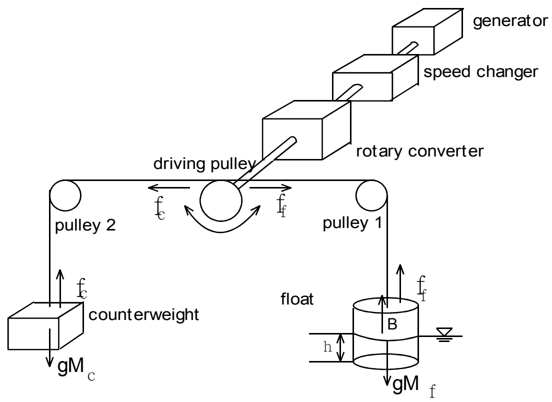

Fig.1 The power transmission device

The system is composed of a float, counterweight, wire, driving pulley, rotary converter, speed changer, and generator. Rotary converter includes a one-way clutch. Thus the power of the sea wave is transferred into a unidirectional rotational motion of the shaft. In the practical machine a flywheel is inserted after the rotary converter in order to reduce the fluctuation of the rotational velocity of the shaft and the generator.

Equations of Mechanical Dynamics Model

The mechanical dynamics model is composed of the physics of generator, stationary balance between the float and counterweight without generator's work, dynamics of the float in working, and that of the driving pulley. In the equation of the float motion three patterns of float submergences: float is partly submerged, wholly submerged, and hanged in the air; are considered at every moment. As will be shown later the system is devised so that the generator works only when the float is falling.

Physics of Generator

We put the angle of rotation of the driving pulley taken in the anticlockwise direction to θ, the torque that driving pulley receives from generator in anticlockwise direction to τ, electric current in the generator to i, potential difference between the two terminals to e, angular velocity of the driving pulley to $\dot{\theta}$, then the following equation are given.

$$\tau = -Gk_\tau i \quad (1)$$

$$e = Gk_e \dot{\theta} \quad (2)$$

where, G is the total gear ratio from driving pulley to generator, k_τ is the torque constant, k_e is induced voltage constant. Here, effect of one-way clutch is ignored, and minus sign in Eq.1 indicates that if float is falling driving pulley receives anticlockwise torque from generator and vice versa. We devised the system so that the generator works only when the float is falling using one-way clutch. In this case expression of Eq.1 should be modified but we use the expression in this paper for simplicity and the function of one-way clutch is considered in computer program.

Stationary Balance without Generator

In this state, gravity and buoyant forces are in balance. If circular cylinder is adopted for the float(s) the following equation is given.

$$M_c g + \frac{1}{4}\pi d_f^2 \rho_w h g = M_f g \quad (3)$$

where, M_f :mass of float, Mc: mass of counterweight, d_f :float diameter, h :the float submergence in stationary balance, ρ_w :

Equation of Float Motion in Work

As it is clear from Fig.1 equation of motion of the float should include the terms of the gravity force acting on float and counterweight gM_f and gMc respectively, buoyant force on the float B and wire tensile force f_f. Also as was mentioned before three patterns of float submergence should be considered in evaluation of the buoyant force. If we put the displacement of float and water level taken upward from their positions of stationary balance without work of generator as x_f, and x_w, respectively and height of the float as H_f, equation of motion of the float is expressed as Eq.4. Where, added mass is not considered since the information of it is insufficient when both fluid and water are in acceleration.

(1) Float is partly submerged:

$$M_f \frac{d^2 x_f}{dt^2} = f_f + \frac{1}{4}\pi d_f^2 \rho_w (h + x_w - x_f) g - M_f g \quad (4)\text{ a}$$

(2) Float is wholly submerged under water surface:

$$M_f \frac{d^2 x_f}{dt^2} = f_f + \frac{1}{4}\pi d_f^2 \rho_w H_f g - M_f g \quad (4)\text{ b}$$

(3) Float is hanged in the air:

$$M_f \frac{d^2 x_f}{dt^2} = f_f - M_f g \quad (4)\text{ c}$$

Equation of Tthe Driving Pulley Motion

If we put the angle of rotation of the driving pulley taken anticlockwise to θ in Fig.1, the following equation is given.

$$I\frac{d^2\theta}{dt^2} + C\frac{d\theta}{dt} = \tau + (f_c - f_f)R_m \quad (5)$$

where, I : the moment of inertia of rotating bodies, C : viscous damping coefficient, R_m : radius of driving pulley, f_c: tensile force of the wire in Fig.1. Also f_c is evaluated as Eq.6 considering the acceleration of the counterweight.

$$f_c = M_c\left(g + \ddot{x}_c\right) \quad (6)$$

Equation for Calculation

Here we sum up these equations for various quantities into the equation for some convenient quantity to consider the dynamics by eliminating other quantities.

ELIMINATION OF THE TENSILE FORCE OF WIRE

Elimination of the wire tensile force f_f from Eq.4 and Eq.5 gives Eq.7.

(1) Float is partly submerged:

$$I\frac{d^2\theta}{dt^2} + C\frac{d\theta}{dt} = \tau + f_c R_m + \left(\frac{\rho g \pi}{4} d_f^2 (h + x_w - x_f) - M_f g - M_f \frac{d^2 x_f}{dt^2}\right) R_m \quad (7)\text{ a}$$

(2) Float is wholly submerged under the water surface:

$$I\frac{d^2\theta}{dt^2} + C\frac{d\theta}{dt} = \tau + f_c R_m + \left(\frac{\rho g \pi}{4} d_f^2 H_f\right.$$

$$- M_f g - M_f \frac{d^2 x_f}{dt^2} \Bigg) R_m \quad \text{(7)b}$$

(3) Float is hanged in the air:

$$I \frac{d^2\theta}{dt^2} + C \frac{d\theta}{dt} = \tau + f_c R_m - \left(M_f g + M_f \frac{d^2 x_f}{dt^2} \right) R_m \quad \text{(7) c}$$

Since the wire is fixed at a point of the driving pulley and winds around it, displacement of the float x_f is related to the angle of rotation of the driving pulley as below.

$$x_f = R_m \theta \quad (8)$$

Thus x_f in Eq.7 can be expressed using θ.

Combination with Generator factors

Torque τ is written as Eq.9 from Eq.1, Eq.2, and $e = i \cdot r$.

$$\tau = -\frac{G^2}{r} k_\tau k_e \frac{d\theta}{dt} \quad (9)$$

where, r is the inner resistance of the generator. Therefore equations for the rotational angle of the driving pulley can be written as Eq.10 using the relations of Eq.9 in Eq.7.

(1) Float is partly submerged

$$\left(\frac{I}{R_m} + (M_c + M_f) R_m\right) \frac{d^2\theta}{dt^2} + \frac{1}{R_m} \cdot \left(C + \frac{G^2}{r} k_\tau k_e \right) \frac{d\theta}{dt}$$

$$+ \frac{\rho g \pi}{4} d_f^2 R_m \theta = \frac{\rho g \pi}{4} d_f^2 x_w \quad \text{(10) a}$$

(2) Float is wholly submerged under water surface

$$\left(\frac{I}{R_m} + (M_c + M_f) R_m\right) \frac{d^2\theta}{dt^2} + \frac{1}{R_m} \cdot \left(C + \frac{G^2}{r} k_\tau k_e \right) \frac{d\theta}{dt}$$

$$= \frac{\rho g \pi}{4} d_f^2 H_f + (M_c - M_f) g \quad \text{(10) b}$$

(3) Float is hanged in the air

$$\left(\frac{I}{R_m} + (M_c + M_f) R_m\right) \frac{d^2\theta}{dt^2} + \frac{1}{R_m} \cdot \left(C + \frac{G^2}{r} k_\tau k_e \right) \frac{d\theta}{dt}$$

$$= (M_c - M_f) g \quad \text{(10) c}$$

If we give x_w as a function of time t and the initial conditions of θ and its time derivative, we can obtain the time series of them, and therefore of the tensile force of wire, torque, the displacement of the float and the occurred electric power. The occurred electric power is given as Eq.11.

$$P_G = r \cdot i^2 = r \left(\frac{-G k_e}{r} \dot{\theta} \right)^2 \quad (11)$$

Calculation conditions

As a basic problem we consider the regular water wave of a sine function of t for x_w, and consider the situation where generator is cut off from the system until the initial time of computation t=0 when water level has arrived at its peak, then it is suddenly connected and becomes in work. In this initial setting, x_w in Eq.10 is expressed as Eq.12, and the initial conditions for θ and the time derivative are given as Eq.13.

$$x_w = \frac{H}{2} \cos\left(\frac{2\pi}{T} t \right) \quad (12)$$

$$\theta(0) = \frac{H}{2R_m} \quad , \quad \dot{\theta}(0) = 0 \quad (13)$$

Examination of The Dynamics Model

In order to examine the applicability of the model, we attempted to apply the calculation to the result of a preliminary field test. Dimensions of device and generator factors are indicated in Table.1. The value of viscous damping coefficient C was determined by fitting the values of occurred electric power. The average value of viscous damping coefficient C determined from the data examined was 567N-m-s. Fig.2 shows the comparison between the experimental data of occurred electric power and the calculation using the above average value of C. This figure shows that the calculated results are relatively in good agreement with experimental data, which implies the validity of the present dynamics model.

ESTIMATION OF SOME MECHANICAL QUANTITIES FOR PROTOTYPE SYSTEM

Now we describe the behavior of time series of the various physical quantities, which seem important in considering the dynamics of the present system, focusing on the condition of float submergence. Examination is made for the case of practical use in the real sea. Table 2 indicates the calculation conditions. The float was assumed a circular cylinder. Counterweight was set so that the relative submergence of the float would become 0.6 in stationary balance without generator. The specifications of overhead units of the rotary converter and gear changer were set as the same ones as those of the device used in the present experiment. The specifications of the generator: the induced voltage coefficient k_e =0.135 (V/(rpm)), torque constant k_τ=1.2838(Nm/A) and the inner resistance r=0.26(Ω); were set to the values of the generator sold in the market.

Table.1 The dimensions of thedevice and generator factors

FLOAT DIMENSION	mass :Mf (kg)	500
	diameter :df (m)	2
	height :Hf (m)	1
COUNTERWEIGHT DIMENSION	mass :Mc (kg)	350
DRIVING PULLEY DIMENSION	radius :Rm (m)	0.14
	moment of inertia :I (kgm)	0.123
GENERATOR FACTORS	induced voltage constant :ke (V/(rpm))	0.092
	torque constant :kτ (Nm/A)	0.878
	inner resistance :r (Ω)	1.45
OTHER DIMENSION	total gear ratio :G	10
	gravity force :g (m/s2)	9.8
	density of water : ρw (kg/m3)	1025

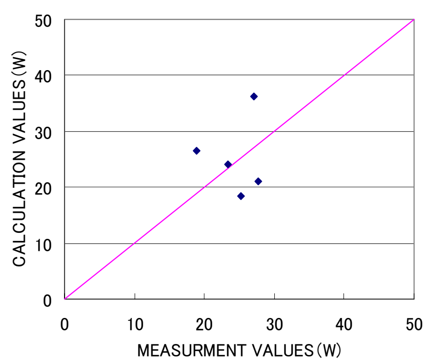

Fig.2 Measured and computed occurred electric power

Table.2 Calculation conditions

CONDITION	specific weight	M_f (t)	Mc (t)	wave height (m)	wave period (s)
1)	1.1	10.367	4.571	3	6
2)	1.1	10.367	4.571	3	7

The results of the calculations are shown in Fig.3&4. Fig.3 indicates the results of the calculation for condition 1). Fig.3 (a) indicates the time series of the occurred electric power and the tensile force, and (b) indicates the time series of the torque and displacement of the float. These figures show that the occurred electric power, tensile force and torque sharply change and that the speed of float's descending falls off at time around 3 seconds after the start of generator's work. Also wire's tensile force begins to increase after it reduced the same value of weight of counterweight. From check of the values of x_w, w_f and h it proved that these indicate the situations that the float is hanged above water surface. At time around 12 seconds, the wire tensile force suddenly shifts from the decreasing state to increasing state. And after it reached the value the same as the weight of counterweight it again begins to decrease, then it behaves like normal state. After that this irregular pattern of wire's tensile force repeated every 6 seconds. It proved that float is wholly submerged under the water surface when this irregularity arises.

These sudden changes in the various forces arising (tensile force etc.) seem to have disadvantage for the durability of the system. Therefore it is thought that these irregular states should be avoided during the work of the system. Fig.4 shows an example of the results for the case in which the above sudden change in various forces does not occur. The only difference from condition1) is that the wave period is 7 seconds instead of 6seconds. All mechanical quantities indicated in Fig.4 change gently and regularly. It proved that float is always partly submerged in this condition. Therefore it is considered that this system will work without trouble in the condition2) in Table 2. Fig.4 (a) indicates that the tensile force varies around the value of the weight of the counterweight, that the displacement of the float does not vary symmetrically with 0m but it varies between about 1.5m of the initial condition and about –0.8m, and that time average value of the occurred electric power is about 6.3kW. This electric power is bigger than the value of the condition 1). Thus the occurrence of the situations other than that the float is always partly submerged is not desirable also from the point of view of the electric power.

ESTIMATION OF MECHANICAL QUANTITIES

Here the mechanical quantities important in designing the prototype apparatus to be used in the real sea will be evaluated. Specifications of the apparatus examined are given in Table 3. Condition No.1 has the same specification with the one examined in the previous chapter. Condition No.2 has the radius twice that of the condition No.1 and the float dimension is a little changed. Condition No.3 has the gear ratio twice that of Condition No.2. Condition No.4 has the radius of float one and a half times that of Condition No.3. First the wave conditions, wave height and wave period, in which the situation that the float is always partly submerged and the electric power for the wave conditions were examined for these 4 conditions of apparatus.

The Occurred Electric Power

Table 4 indicates the occurred electric power calculated for various wave conditions and for conditions No.1~No.4 in Table 3. The number written in the columns for various combinations of wave height and wave period indicates the occurred electric power in kW unit for the individual combinations. The blank columns indicate the occurrence of conditions in which the float is not always partly submerged.

Table.3 Change in device dimension

CONDITION	Dimension of Float				Dimension of driving pulley		Dimension of speed changer
	specific weight	ratio of submerged depth (in stationary & free state)	diameter(m)	height (m)	radius (m)	mass (kg)	total gear ratio
No.1	1.1	0.6	2	3	0.14	12.6	10
	mass of Float : 10.37 (t) mass of Counterweight : 4.57 (t)						
No.2	0.9	0.6	2	3	0.28	50.4	10
	mass of Float : 8.48 (t) mass of Counterweight : 2.69 (t)						
No.3	0.9	0.6	2	3	0.28	50.4	20
	mass of Float : 8.48 (t) mass of Counterweight : 2.69 (t)						
No.4	0.9	0.6	3	3	0.28	50.4	20
	mass of Float : 19.09 (t) mass of Counterweight : 6.04 (t)						

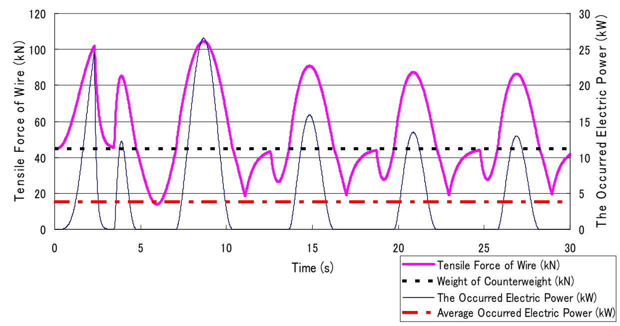

Fig.3 (a) The time series of the occurred electric power (P_G) & the wire tensile force (f_f)

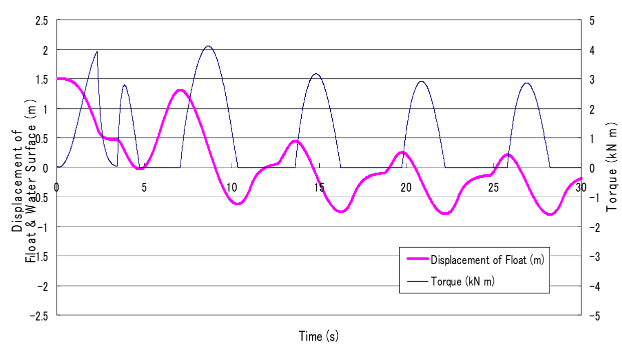

Fig.3 (b) The time series of the displacement of the float (x_f)& the torque (τ)

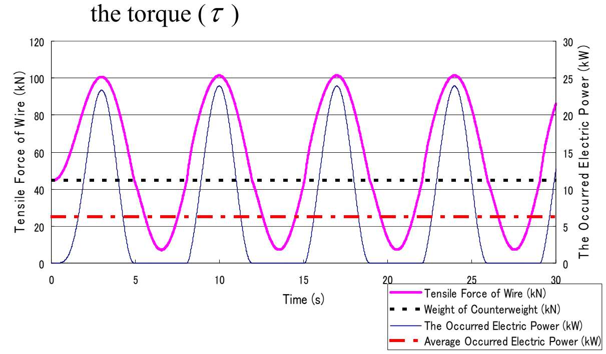

Fig.4 (a) The time series of P_G & f_f

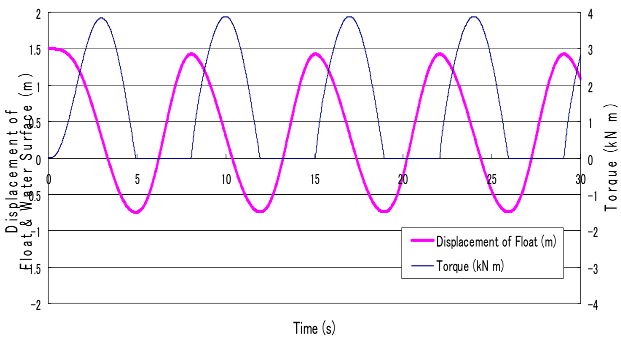

Fig.4 (b) The time series of x_f & τ

It is shown that the maximum wave height at which the system can work in the desirable condition of float submergence for each wave period gradually increases with increase of wave period for condition No.1, while for condition No.2 to 4 the above maximum wave height has the minimum value at wave periods around 3 to 5 seconds and that the occurred electric power at these wave periods is the greatest among the values for various wave periods with wave height fixed. Therefore it is thought that these wave periods are the resonance periods of the system. The plausible resonance period is 4- to 5seconds for No.1, 3 to 4seconds for No.2, 4 to 5seconds for No.3, and 3 to 4seconds for No.4.

From the comparison between Table4 (a) and (b), increase of the radius of the driving pulley brings about the occurrence of the submergence conditions other than that the floats is always partly submerged at relatively short wave period. Also at the longer wave periods, the maximum value of wave height at which the float is always partly submerged becomes greater than for condition No.1. The occurred electric power for condition No.2 near the resonance period is greater than that for condition No.1, however it is smaller at long periods near 10seconds and low wave height than that for condition No.1. The occurred electric power is evaluated as about 1kW and 2 kW for conditions No.1 and 2 respectively at wave height 1.13m and wave period 5.5s, typical wave condition.

Comparison between Table 4 (b) and (c) shows that the incr ease of gear ratio increases the maximum value of available wave height for wave period shorter than 5seconds and decreases it for wave period longer than 7 seconds. Also the occurred electric power is increased for every combination of wave height and wave period. But the value for condition No.3 is not twice that of condition No.2. It is about 3.5 kW for wave height 1.13m and wave period 5.5seconds.

Finally, we examined the case of condition No.4. The difference between condition No.3 and No.4 is only in the radius of the float. Comparison between Table (c) and (d) shows that the increase of the cross-sectional area of the float will bring about the increase of the occurred electric power and that the change will increase the maximum value of the wave height to which the system works in the desirable condition of float submergence except the wave period close to the resonance period. The occurred electric power is estimated about 8.7kW at wave height 1.13m and wave period 5.5seconds.

By the inspection of data of the wave observation [8] in the waters around Japan, the possible wave height is restricted by the wave period. The wave height does not exceed 0.5m, 1.25m and 1.75m under the wave periods 3, 4, and 5 seconds respectively. Therefore condition No.3 and No. 4 in Table 4 will be recommended for the specification of the present system.

Average Occurred Electric Power, Maximum Values of Wire Tensile Force and Driving Pulley Torque

Next, we evaluated the physical quantities needed in planning and designing the prototype system. Here we report and inspect the average value of the occurred electric power and the maximum values of the wire tensile force and the torque for the various wave conditions examined for condition No.4 in the pervious section. Fig.5, 6 and 7 are the results: the average occurred electric power, maximum tensile force of wire and maximum torque at various wave conditions, wave heights and wave periods using for condition No.4. The horizontal axis in these figures indicates wave height and the wave period are distinguished by the symbols in the plots. Note that all plots are the results of the case in which the system works in the desirable condition of float submergence that it is always partly submerged.

In Fig.5 the average occurred electric power is plotted against the wave height for various wave periods for condition

Table.4 (a) The electric power at several wave conditions (Change dimension No.1)

H (m) \ T (s)	～3	3～4	4～5	5～6	6～7	7～8	8～9	9～10	10～11	11～12	12～13
9.01～10											
8.01～9											
7.01～8											
6.51～7											
6.01～6.5											
5.51～6											
5.01～5.5											
4.51～5											
4.01～4.5										6.443	6.435
3.51～4								7.35	5.759	5.016	5.01
3.01～3.5							5.572	5.521	4.326	3.768	3.763
2.51～3				6.513	5.759	5.361	3.989	3.953	3.097	2.698	2.694
2.01～2.5	1.978	4.772	5.072	4.36	3.855	3.589	2.671	2.646	2.073	1.806	1.804
1.76～2	1.377	3.331	3.541	3.044	2.692	2.506	1.864	1.847	1.447	1.261	1.259
1.51～1.75	1.035	2.504	2.662	2.288	2.202	1.884	1.402	1.389	1.088	0.948	0.947
1.26～1.5	0.742	1.795	1.908	1.64	1.45	1.35	1.005	0.995	0.78	0.679	0.678
1.01～1.25	0.497	1.204	1.279	1.01	0.972	0.905	0.674	0.667	0.523	0.456	0.455
0.76～1	0.302	0.73	0.776	0.667	0.59	0.549	0.409	0.405	0.317	0.276	0.276
0.51～0.75	0.155	0.374	0.398	0.342	0.302	0.281	0.209	0.207	0.163	0.142	0.141
0.26～0.5	0.056	0.136	0.145	0.124	0.11	0.102	0.076	0.075	0.059	0.052	0.051
～0.25	0.007	0.016	0.017	0.015	0.013	0.012	0.009	0.009	0.007	0.006	0.006

Table.4 (b) The electric power at several wave conditions (Change dimension No.2)

H (m) \ T (s)	～3	3～4	4～5	5～6	6～7	7～8	8～9	9～10	10～11	11～12	12～13
9.01～10											
8.01～9											9.272
7.01～8										7.762	7.212
6.51～7									8.984	6.287	5.847
6.01～6.5									7.702	5.390	5.013
5.51～6								8.432	6.519	4.562	4.243
5.01～5.5							8.316	7.029	5.435	3.803	3.537
4.51～5							6.807	5.754	4.487	3.113	2.895
4.01～4.5						8.996	5.449	4.606	3.561	2.492	2.318
3.51～4						7.004	4.243	3.586	2.773	1.940	1.805
3.01～3.5					8.715	5.261	3.187	2.694	2.083	1.457	1.355
2.51～3					6.240	3.766	2.282	1.929	1.491	1.044	0.971
2.01～2.5				7.654	4.177	2.521	1.573	1.291	0.998	0.699	0.650
1.76～2				5.343	2.916	1.760	1.066	0.901	0.697	0.488	0.454
1.51～1.75	0.774		8.175	4.017	2.192	1.323	0.802	0.678	0.524	0.367	0.341
1.26～1.5	0.555		5.860	2.879	1.571	0.948	0.575	0.486	0.375	0.263	0.244
1.01～1.25	0.372	4.864	3.929	1.930	1.054	0.636	0.385	0.326	0.252	0.176	0.164
0.76～1	0.226	2.950	2.383	1.171	0.639	0.386	0.234	0.197	0.153	0.107	0.099
0.51～0.75	0.116	1.512	1.221	0.600	0.327	0.198	0.120	0.101	0.078	0.055	0.051
0.26～0.5	0.042	0.550	0.444	0.218	0.119	0.072	0.044	0.037	0.028	0.020	0.019
～0.25	0.005	0.064	0.052	0.026	0.014	0.008	0.005	0.004	0.003	0.002	0.002

Table.4 (c) The electric power at several wave conditions (Change dimension No.3)

H (m) \ T (s)	～3	3～4	4～5	5～6	6～7	7～8	8～9	9～10	10～11	11～12	12～13
9.01～10											
8.01～9											
7.01～8											
6.51～7											
6.01～6.5											
5.51～6										14.458	14.154
5.01～5.5									15.205	12.053	11.8
4.51～5								16.714	12.447	9.866	9.659
4.01～4.5							15.692	13.38	9.964	7.898	7.7326
3.51～4						19.545	12.217	10.417	7.758	6.1493	6.0202
3.01～3.5					20.73	14.68	9.176	7.825	5.827	4.619	4.5218
2.51～3					14.842	10.511	6.57	5.602	4.172	3.307	3.2375
2.01～2.5	4.5292			14.082	9.9358	7.036	4.398	3.75	2.793	2.214	2.1673
1.76～2	3.1658	12.854	13.265	9.8311	6.9367	4.912	3.071	2.618	1.95	1.5455	1.5131
1.51～1.75	2.3798	9.6626	9.9717	7.3903	5.2145	3.693	2.308	1.968	1.466	1.1618	1.1374
1.26～1.5	1.7058	6.9259	7.1474	5.2972	3.7376	2.647	1.654	1.411	1.051	0.8328	0.8153
1.01～1.25	1.1437	4.6438	4.7924	3.5517	2.5061	1.775	1.109	0.946	0.704	0.5584	0.5466
0.76～1	0.6936	2.8163	2.9064	2.154	1.5199	1.076	0.673	0.574	0.427	0.3386	0.3315
0.51～0.75	0.3555	1.4435	1.4896	1.104	0.779	0.552	0.345	0.294	0.219	0.1736	0.1699
0.26～0.5	0.1293	0.5252	0.542	0.4017	0.2834	0.201	0.125	0.107	0.08	0.0631	0.0618
～0.25	0.0151	0.0615	0.0634	0.047	0.0332	0.023	0.015	0.013	0.009	0.0074	0.0072

Table.4 (d) The electric power at several wave conditions (Change dimension No.4)

H (m) \ T (s)	～3	3～4	4～5	5～6	6～7	7～8	8～9	9～10	10～11	11～12	12～13
9.01～10										48.688	45.844
8.01～9									53.693	38.978	36.700
7.01～8								53.773	41.803	30.346	28.573
6.51～7								43.556	33.860	24.580	23.144
6.01～6.5								37.343	29.030	21.074	19.842
5.51～6								31.607	24.571	17.837	16.794
5.01～5.5							31.549	26.349	20.483	14.870	14.001
4.51～5						44.000	25.826	21.569	16.767	12.172	11.461
4.01～4.5						35.224	20.675	17.267	13.423	9.744	9.175
3.51～4					49.002	27.424	16.097	13.443	10.451	7.586	7.143
3.01～3.5					36.806	20.598	12.090	10.097	7.850	5.698	5.365
2.51～3					26.352	14.748	8.656	7.230	5.620	4.080	3.841
2.01～2.5				34.344	17.641	9.873	5.795	4.840	3.762	2.731	2.572
1.76～2	4.244			23.977	12.316	6.893	4.046	3.379	2.627	1.907	1.795
1.51～1.75	3.190		38.069	18.024	9.258	5.181	3.041	2.540	1.974	1.433	1.350
1.26～1.5	2.287	29.542	27.287	12.919	6.636	3.714	2.180	1.821	1.415	1.027	0.967
1.01～1.25	1.533	22.491	18.296	8.662	4.449	2.490	1.462	1.221	0.949	0.689	0.649
0.76～1	0.930	13.640	11.096	5.253	2.698	1.510	0.886	0.740	0.576	0.418	0.393
0.51～0.75	0.477	6.991	5.687	2.693	1.383	0.774	0.454	0.379	0.295	0.214	0.202
0.26～0.5	0.173	2.543	2.069	0.980	0.503	0.282	0.165	0.138	0.107	0.078	0.073
～0.25	0.020	0.298	0.242	0.115	0.059	0.033	0.019	0.016	0.013	0.009	0.009

No.4, where it should be noted that the vertical axis is graduated in logarithm scale. The average value of occurred electric power is evaluated as 0.17kW, 22.4kW, 38kW and 8kW at the combinations of wave height & wave period for wave with the greatest wave steepness in the coast around Japan of 0.5m and 3s, 1.25m and 4s, and 1.75m and 5s, respectively. These values overestimate the wave height corresponding to the wave period and the occurred electric power. We have to evaluate the mean value of the electric power obtained using the data of the relative frequency of the combination of wave periods and heights. In this process the following situation can be supposed: if the wall is set in front of the breakwater 3 or 4 m from the front surface of it, vertical motion of the water is amplified and the horizontal motion is reduced. As was described before, combination of the present system with this structure seems the most reasonable constitution.

Fig.6 indicates the maximum value of the wire tensile force against the wave height for various wave periods for condition No.4. It is shown that the maximum value of the wire tensile force increases proportional to the wave height from the value of the weight of counterweight. The increasing rate falls off with increase of the wave period, which corresponds to the slow motion of the pulley.

Fig.7 indicates the maximum torque arising against the wave height for various values of the wave periods. It is shown that the torque itself is proportional to the wave height and that the increasing rate falls off with increase of the wave period.

CONCLUSION

So far we described the mechanical dynamics model to conveniently evaluate the obtainable energy and the various mechanical quantities needed for designing and checked applicability with a preliminary field test. Then the various mechanical quantities needed for the design was examined for various wave conditions. The main results of this study are as follows:

(1) Mechanical dynamics model showed good agreement with the result of a preliminary field test.
(2) The desirable condition of the float submergence is that the float is always partly submerged.
(3) The radius of driving pulley is the key factor for the quantity of the obtainable energy. Large value of this quantity would be recommended.

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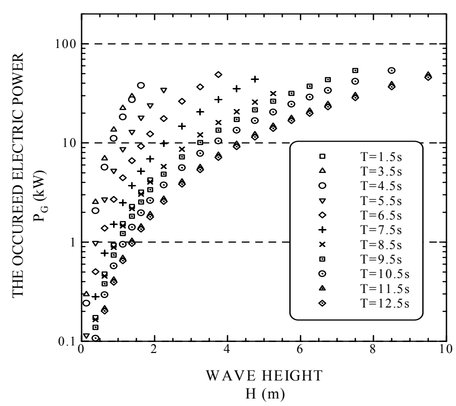

Fig.5 Evaluated average occurred electric power for prototype system of condition No.4

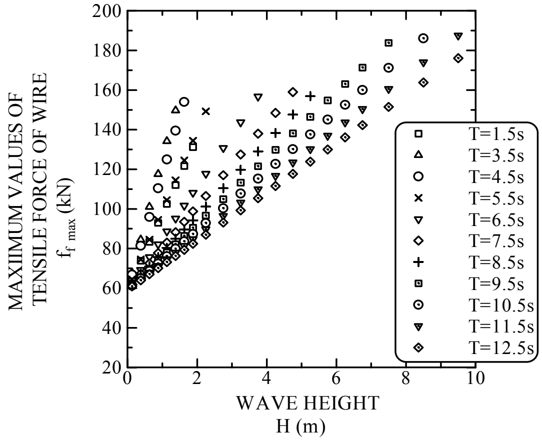

Fig.6 Evaluated maximum tensile force of wire for prototype system of condition No.4

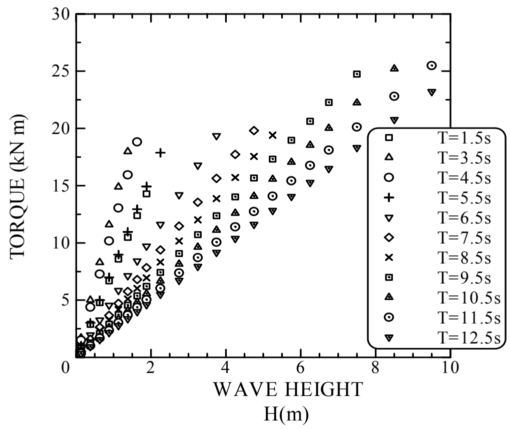

Fig.7 Evaluated maximum torque for prototype system of condition No.4