Proceedings of the Sixteenth (2006) International Offshore and Polar Engineering Conference
San Francisco, California, USA, May 28-June 2, 2006

ISBN 1-880653-66-4 (Set); ISSN 1098-6189 (Set)

Mechanics of the Float Type Wave Energy Conversion

Kesayoshi Hadano(1), *Keisuke Taneura*(2), *Makoto Watanabe*(2) , *Takashi Saito*(3) ,*Kimihiko Nakano*(3)
Masami Matsuura(4) .
(1) Yamaguchi University, Dept. of Civil Engineering.
(2) Graduate School of Science and Engineering Yamaguchi University
(3) Yamaguchi University, Dept. of Mechanical Engineering.
Ube, Yamaguchi, Japan
(4) Mitsubishi Heavy Industries, LTD, Nagasaki Research & Development center.
Nagasaki, Japan

ABSTRACT

Dynamics model is presented for the wave energy conversion system which consists of pulley(s), wire(s), float(s), counterweight(s) and ratchet mechanism. In the calculation, submerged condition of the float is checked at every time to select the equations of calculation according to whether float is partly submerged, wholly submerged in the water or hung in the air. Applicability of the model was examined using the data of energy conversion obtained from the wave tank test, and a good agreement has been obtained. Next, the effect of the float submergence on the time series of the electric power and the physical quantities such as wire tensile force and torque of the shaft has been examined using the calculated results for these quantities.

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

INTRODUCTION

Wave energy is expected as one of the important sustainable energies, although the practical use has not been attained. Indeed, compared with the use of photovoltaic power or the wind power, it has more advantages on the point of stability etc. Ocean waves transfers the energy occurred by wind to the seas where there is no wind; furthermore, wind always occurs at any sea(s) and the high density of seawater enables waves to maintain relatively long term. Recently development of the utilizing technique of wave energy has again become fairly active, particularly in UK and Australia. The final version, however, does not seem to have been presented.

OWC and movable body type are expected as the system with high possibilities. At present OWC system is considered as the major one because it does not seem to have serious problems of the structural strength, however the practical use has not been attained for economical reasons. On the other hand, Hadano (2003) proposed a movable body type which transmits wave energy into rotational motion of the pulley using a pair of float and counterweight connected at either ends of a wire hung 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, made with a flexible material, enables to avoid a 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 an elliptic orbit in the wave field, a horizontal force will act on the hung 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 as conceptually indicated in Fig.1. This is achieved by utilizing the slit-type caisson shown in Fig.2. Thus, practically possible wave energy system can be constructed.

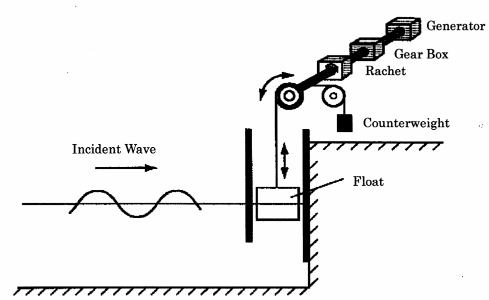


Fig.1 Conceptual figure of the present system working in front of the breakwater etc.

Fig.2 A photograph of slit-type caissons breakwater before setting.

Authors have also tried to give the evaluation of energy gain employing mechanical dynamics model. Saito et al[5] tried to examine the occurred electric power calculated by the mechanical dynamics model. However, the estimates were inadequate from the point of energy gain since the main aim was directed toward mechanical dynamics to calculate various quantities of the parts. Hadano (2003) developed the model aiming at whole system of the device. Nevertheless, they failed to give the time series of physical quantities since the model was based on the assumption that the physical quantities concerning energy conversion vary as a function of time with the frequency the same as that of water level variation. Hadano et. al. also presented dynamics model which enables to conveniently give the time series of the physical quantities directly related such as energy gain and the process.

The present paper gives experimental results to examine the above mechanical dynamics model. Calculated results of the energy conversion rate are compared with experimental results. Then the properties of the calculated time series of energy gain, wire tensile force etc. are examined considering the effect of float submergence condition.

THE MECHANICAL DYNAMICS MODEL

Here we describe the mechanical dynamics model again. As shown in Fig.3 the system consists of a float, counterweight, wire, driving pulley, rotary converter, speed changer, and generator. Rotary converter includes a ratchet mechanism. Thus, the power of the sea wave is transferred into that of a unidirectional rotational motion of the shaft.

In principle the system can extract energy from rising and falling motion of the float according to up/down motion of water surface. However, if we use a light counterweight to reduce the wire tensile force, its weight dose not generate enough torque to rotate the driving pulley when the water level is rising. Consequently, the wire becomes loose which poses a dangerous situation immediately after the water level starts falling as the wire will experience a sudden tensile force. So we devised the rotary converter so that the generator works only when the float is falling.

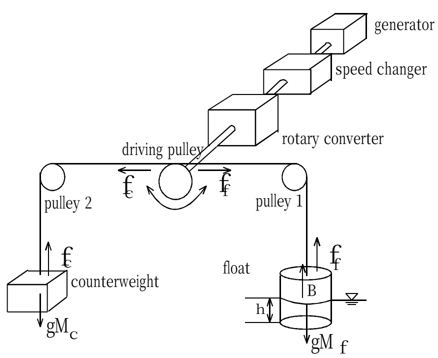


Fig. 3 Outline of the present energy conversion device

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 float motion, three patterns of float submergences: float is partly submerged, wholly submerged, and hanged in the air; are considered at every moment.

Physics of Generator We put the angle of rotation of driving pulley taken to anticlockwise direction to q , the anticlockwise torque of driving pulley receiving from generator to t , electric current in the generator to i , potential difference between the two terminals to e , angular velocity of the driving pulley to $\dot{q}$, then the following equation are given.

$$t = -Gk_t i \cdot \mathrm{sgn}(\dot{q}) \quad (1)$$

$$e = Gk_e\dot{q} \cdot \mathrm{sgn}(\dot{q}) \quad (2)$$

where, sgn(x) =1 for x >0 and –1 for x<0, G is the total gear ratio from driving pulley to generator, k_t is the torque constant, k_e is induced voltage constant. Here effect of ratchet mechanism is ignored, and minus sign in Eq. 1 indicates that if float is falling driving pulley receives anticlockwise torque from generator and vice versa. In the case of the system which converts energy only when float is rising the expression of Eq. 1 is should be modified but we use the expression of Eq. 1 in this paper for simplicity and the function of ratchet mechanism is considered in computer program.

Force Balance at Stationary Free State In this state if a circular cylinder is adopted for the float the following equation is given.

$$M_c g + \frac{1}{4} p d_f^2 r_w hg = M_f g \quad (3)$$

where, M_f :mass of float, Mc: mass of counterweight, d_f :float diameter, h :the float submergence in stationary balance, $?_w$: the density of water, g: the gravitational acceleration.

Equation of Vertical Motion of Float in Work As it is clear from Fig. 3 the float moves vertically receiving the gravity force gM_f , buoyant force B and wire tensile force f_f. Also as was mentioned before three states of float submergence should be distinguished in the calculation. We put the displacement of float and water level taken upward from the stationary free state as x_f and x_w, and the float height to H_f. Then equation of motion of the float is expressed as Eqs. 4~6.

(1) Float is partly submerged:

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

(2) Float is wholly submerged under water surface:

$$M_f \frac{d^2 x_f}{dt^2} = f_f + \frac{1}{4} p d_f^2 r_w H_f g - M_f g \quad (5)$$

(3) Float is hanged in the air:

$$M_f \frac{d^2 x_f}{dt^2} = f_f - M_f g \quad (6)$$

Equation of the Driving Pulley Motion When we put the angle of rotation of the driving pulley in anticlockwise direction to q in Fig.3, the following equation holds.

$$I \frac{d^2 q}{dt^2} + C \frac{dq}{dt} = t + (f_c - f_f) R_m \quad (7)$$

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. 3 Also f_c is evaluated as Eq. 6 considering the acceleration of the counterweight.

$$f_c = M_c (g + \ddot{x}_c) \quad (8)$$

Equation for Calculation

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

Elimination of the Wire Tensile Force Elimination of the wire tensile force f_f from Eqs. 4~6 and Eq.8 gives Eqs. 9~11.

(1)Float is partly submerged:

$$I\frac{d^2q}{dt^2}+C\frac{dq}{dt}=t+f_cR_m+\left(\frac{rgp}{4}d_f^2(h+x_w-x_f)-M_fg-M_f\frac{d^2x_f}{dt^2}\right)R_m \tag{9}$$

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

$$I\frac{d^2q}{dt^2}+C\frac{dq}{dt}=t+f_cR_m+\left(\frac{rgp}{4}d_f^2H_f-M_fg-M_f\frac{d^2x_f}{dt^2}\right)R_m \tag{10}$$

(3)Float is hanged in the air:

$$I\frac{d^2q}{dt^2}+C\frac{dq}{dt}=t+f_cR_m-\left(M_fg+M_f\frac{d^2x_f}{dt^2}\right)R_m \tag{11}$$

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.

$$x_f=R_mq \tag{12}$$

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

Combination with Generator Factors Torque t is written as Eq. 13 from Eq. 1~2, and the relationship $e=i\cdot r$.

$$t=-\frac{G^2}{r}k_tk_e\frac{dq}{dt} \tag{13}$$

where, r is the internal resistance of the generator. Therefore equations for the rotational angle of the driving pulley can be written as Eqs. 14~16 using the relationship of Eq.13 in Eqs. 9~11.

(1) Float is partly submerged

$$\left(\frac{I}{R_m}+(M_c+M_f)R_m^2\right)\frac{d^2q}{dt^2}+\frac{1}{R_m}\cdot\left(C+\frac{G^2}{r}k_tk_e\right)\frac{dq}{dt}+\frac{rgp}{4}d_f^2R_mq=t+\frac{rgp}{4}d_f^2x_w \tag{14}$$

(2) Float is wholly submerged under water surface

$$\left(\frac{I}{R_m}+(M_c+M_f)R_m^2\right)\frac{d^2q}{dt^2}+\frac{1}{R_m}\cdot\left(C+\frac{G^2}{r}k_tk_e\right)\frac{dq}{dt}=\frac{rgp}{4}d_f^2H_f+(M_c-M_f)g \tag{15}$$

(3) Float is hung in the air

$$\left(\frac{I}{R_m}+(M_c+M_f)R_m^2\right)\frac{d^2q}{dt^2}+\frac{1}{R_m}\cdot\left(C+\frac{G^2}{r}k_tk_e\right)\frac{dq}{dt}=(M_c-M_f)g \tag{16}$$

If we take x_w as a function of time t and the initial conditions of q and its time derivative, we can obtain the time series of these, 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. 17.

$$P_G=r\cdot i^2=r\left(\frac{-Gk_e}{r}\dot{q}\right)^2 \tag{17}$$

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 the clutch of transmission is cut off until the initial time of computation t=0 when water level has arrived at its peak, then it is suddenly connected and starts to work. In this initial setting, x_w in Eqs. 14~16 is expressed as Eq. 18, and the initial conditions for q and its time derivative are given as Eq. 19.

$$x_w=\frac{H}{2}\cos\left(\frac{2p}{T}t\right) \tag{18}$$

$$q(0)=\frac{H}{2R_m}\quad,\qquad \dot{q}(0)=0 \tag{19}$$

EXPERIMENT TO EXAMINE THE MODEL

Experimental Apparatus and Method

In order to examine the applicability of the model, we produced a large-sized model and made experiments in a wave tank. Fig. 4 illustrates the panorama of the devise with 4 pairs of floats and counterweights which have shafts connecting to 4 driving pulleys.The shaft rotates at the same speed at every position but accumulates the torque at individual positions where the driving pulleys are connected. In the experiment the model with 2 pairs of float and counterweight was used.The dimension of the apparatus is as follows: float diameter is 2m, float mass is 1680Kg, float height is 0.7m, float's specific weight is 0.7457, float submergence at stationary free state is 0.5714, mass of counterweight is 150Kg, radius of driving pulley is 0.14m, gear ratio is 41.36.

The wave tank used is 3.2m deep, 30m wide and effectively 160m long set at Research and Development center of Mitsubishi Heavy Industries LTD in Nagasaki city in Japan. At one side of the longitudinal direction is a wave maker and the model was set at the opposite side so that the float receives wave directly. Figure 5 indicates the model set in the wave tank. Floats were supported by idler pulleys mounted at intermediate position of the beam member supported by the vertical column.

In the experiment, regular waves were produced and the clutch was turned on at some proper time when wave crest reached the floats. The water level, displacement of float, wire tensile force, torque etc. were simultaneously measured. Wave condition: wave period/wave height; at which experiments were performed is as follows: 1.8sec/0.32m, 2.0sec/0.25m, 3.0sec/0.14m, 3.5sec/0.24m, 4.0sec/0.27m, 4.5sec/0.15m, 5.0sec/0.10m.

Fig.4 A Photograph of the Apparatus used

Fig.5 A Photograph of the experiment

RESULTS OF EXPERIMENT

As the results of experiments, when the wave period was shorter than 3 seconds, the device could not convert energy significantly because of the noticeable rolling motion of the floats caused by water wave. The conditions at which the devise could convert energy in the present experimental conditions are as follows: 3.5sec/0.24m(No.1), and 4.0sec/0.27m(No.2). Fig.6 illustrates the time series of the displacement of float and wire tensile force obtained from experiment No.1, where the data for the initial three periods of waves with somewhat unsteady patterns of time series has been removed for the benefits of explanation of the fundamental patterns and benefit of the determination of C value. It is shown that immediately after float displacement reached its top wire tensile force become nonzero and it becomes zero displacement of the float reached its bottom, these corresponds to the times at which energy conversion starts and ends respectively.

Next, we determined the value of viscous damping coefficient C from the time average of energy conversion rate evaluated as the product of wire tensile force and float descending speed. Fig. 7 shows the results of the determination of C, where data is indicated for experiments No.1 and 2 with C plausible value and the around values. From the figure the value of C is approximately 1580 (N s/m).

Figs. 8~9 show the time series of the experimental and computational values of energy conversion rate. It is found that the calculated time series is relatively in good agreement with the experimental ones. Consequently, it can be said that the present dynamics model is applicable to the system.

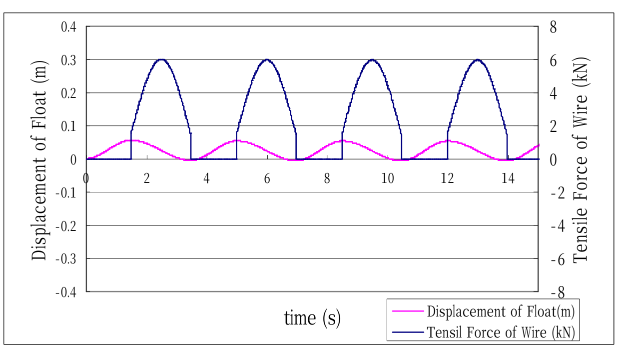


Fig.6 Time Series of the float displacement and wire tensile force

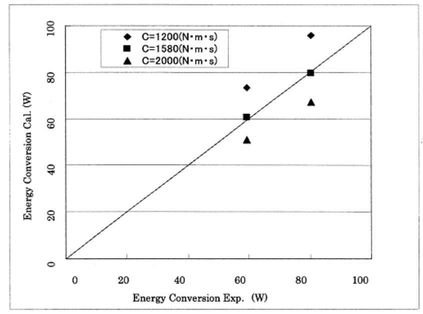


Fig. 7 Determination of the damping coefficient C

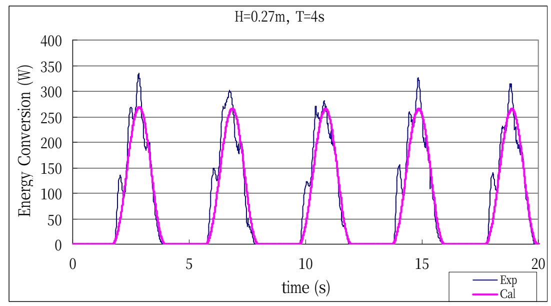


Fig.8 Time Series of energy conversion rate for experiment No. 1

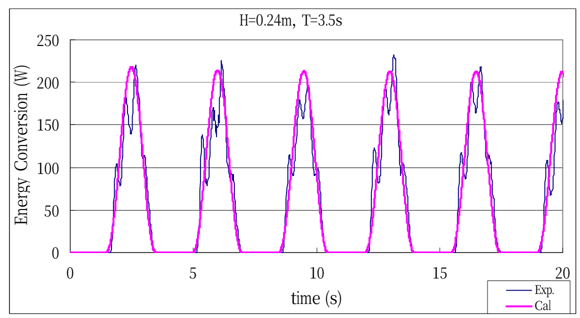


Fig.9 Time Series of energy conversion rate for experiment No. 2

EXAMINATION OF THE PROPERTIES OF THE SYSTEM

Here we examine the time series of the physical quantities related to the design of the system from the calculation. Time series was examined for the displacement of the float, wire tensile force, input torque, and energy conversion rate of the system. Specifications of the system was set is as follows: mass of float M_f=6911Kg, diameter of float D_f =2m, height of float=2m, specific weight of float=1.1, float submergence ratio at stationary free state = 0.5, mass of counterweight Mc =3691kg, radius of the driving pulley Rm=0.14m, moment of inertia I=0.123kg-m, damping coefficient C=567N-s/m, torque constant k_t =1.2838N-m/A, induced voltage constant k_e =0.135V/rpm, internal resistance r = 0.26Ohm. The value of C was set at smaller one than evaluated in the present experiment referring to the results of the previous experiment[6] made using the rotary converter shown in Fig.9 which gave relatively small value of C since all gears are set in the closed space and it is hard for stain to emerge. In this rotary converter there are a pair of ratchet mechanism each of which is mounted to gear and sprocket and set in opposite direction each other. This constitution enables to transmit both sides rotational power, and it is easy to modify so that it transmits only one directional rotational power. Wave conditions examined are given in Table 1. Only the wave height is different in two conditions. Calculation was made for the situation that the clutch was cut off until the time t=0 when water level becomes its peak, then it is turned on at t=0.

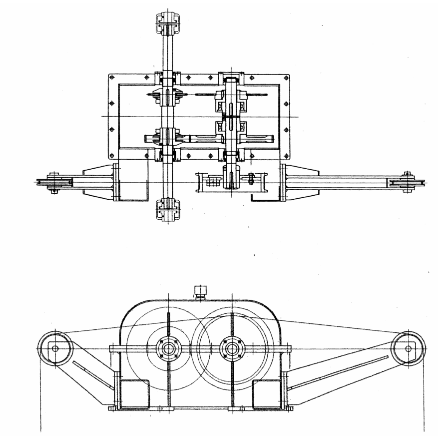
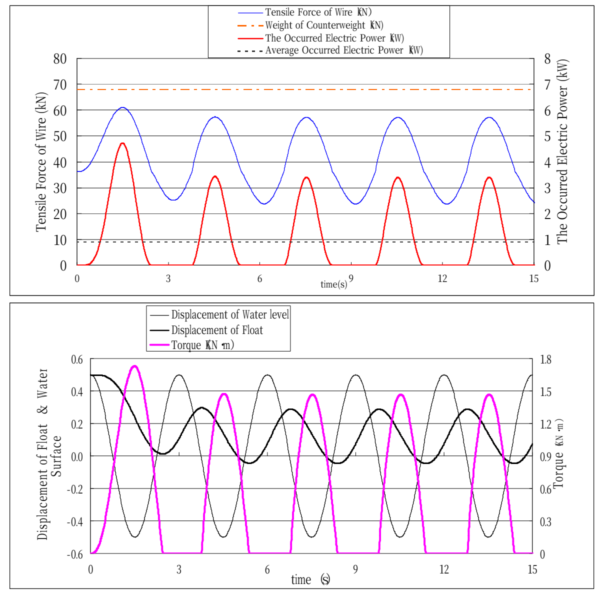


Fig. 10 Rotary converter used in the former experiment

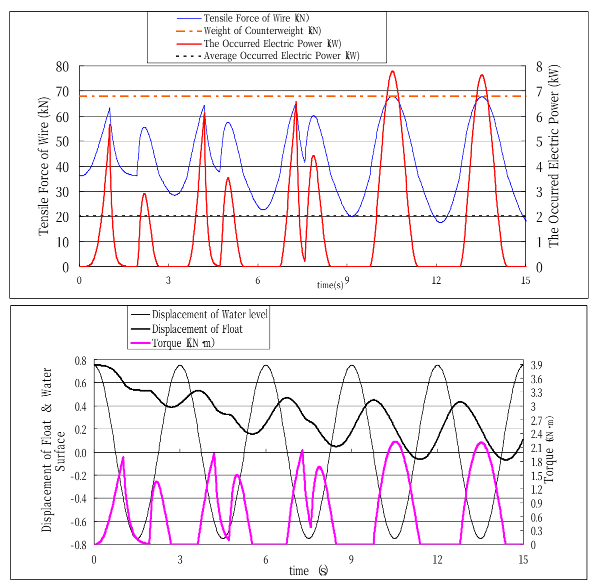
Table 1 condition at which time series of the physical quantities are examined by calculation

calculation condition	specific weight	Mf (kg)	Mc (kg)	wave height (m)	wave period (s)
1)	1.1	6911.5	3691.4	1	3
2)	1.1	6911.5	3691.4	1.5	3

Fig. 11 shows the time series of the calculated various physical quantities for conditions 1) and 2) given in Table 1. First we describe the result for condition 1): wave height is 1m. In this case evaluated values of occurred electric power, torque, wire tensile force and displacement of the float vary relatively large amount at the first and second wave cycles from the "clutch on" of the system then they indicate the variations of relatively steady patterns. The value of the occurred electric power shows positive and zero alternately both with duration times of about a half wave period. The time at which the occurred electric power becomes the maximum is a little later than the time at which the velocity of water surface falling is the maximum. In this case time averaged occurred electric power is evaluated as about 0.994kW. Float displacement varies nearly sinusoidal around the level a little higher than the water surface level at stationary condition. The stroke of the float motion is smaller than that of wave motion in this case. The wire tensile force varies around the value of the weight of the counterweight, it seems that the value is the sum of the weight of the counterweight and a sinusoidal function. In this system the quantity: wire tensile force minus weight of counterweight; is the power of energy conversion. Also wire tensile force becomes smaller than the weight of counterweight even for the system in which energy conversion is performed only when water surface is falling. This phenomenon seems to reflect the situation that float ascending velocity become inferior to that of the water level since the weight of the counterweight is not enough to accelerate the float upward and accelerate the counterweight downward. Variation of the torque is proportional to that of the electric power.
Next we describe the result of the case of the condition 2) where wave height is changed to 1.5m. In this case the occurred electric power, wire tensile force and torque show abrupt changes in the first 3 periods of water surface oscillation, then the variations become relatively regular patterns. Float is hanged in the air at about 1- 2 seconds in the first cycle, at about 4-- 5seconds in the second cycle, and at about 7 seconds in the third cycle of the wave. The situation that the wire tensile force varies abruptly is undesirable since it is directly related to the lifetime of the apparatus. So we have to check the condition for this phenomenon to occur.



(a) Calculation condition 1) in Table 1



(b) Calculation condition 2) in Table 1

Fig.11 Time series of various physical quantities evaluated

EXAMPLE OF THE ENERGY CONVERSION RATE

Here we will present the condition at which the system works with float always partly submerged from the sample calculation. Specification of the generator and the value of C were set at the same values as those of the previous chapter. Calculation was made for 4 apparatus whose speculation of the apparatus calculated are indicated in Table 2. Table 3 shows the time averaged value of energy conversion rate for various pairs of wave height and wave period for each apparatus, where blanc columns indicate the wave condition in which float submergences other than partly submerged have occurred. Yellow columns in the table indicate the wave conditions in 2000 at the Fukaura[8] wave observation stations where wave conditions were the most severe in all of the observation stations. From the table apparatus B or D will be desired from the point of severe wave condition. However, the apparatus has only to endure the wave at the station where the apparatus will be set. So the calculation to make the tables like Table 3 is required for the position where construction of the wave energy conversion is planned.

Table 2 Specifications of apparatus calculated

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)						

Table 3 Time averaged energy conversion rate

(a) Apparatus A

H(m) \ T(s)	1.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5
9.5									
8.5									
7.5									
6.75									
6.25									
5.75									
5.25									
4.75									
4.25									
3.75								7.344	5.755
3.25							5.566	5.516	4.322
2.75				6.508	5.754	5.355	3.985	3.949	3.095
2.25		4.775	5.071	4.357	3.852	3.585	2.668	2.644	2.072
1.88	1.384	3.334	3.54	3.042	2.689	2.503	1.863	1.846	1.446
1.63	1.040	2.506	2.661	2.287	2.022	1.882	1.400	1.387	1.087
1.38	0.745	1.796	1.908	1.639	1.449	1.349	1.004	0.994	0.779
1.13	0.500	1.204	1.279	1.099	0.972	0.904	0.673	0.667	0.523
0.88	0.303	0.730	0.776	0.666	0.589	0.548	0.408	0.404	0.317
0.63	0.155	0.374	0.398	0.342	0.302	0.281	0.209	0.207	0.162
0.38	0.057	0.136	0.145	0.124	0.110	0.102	0.076	0.075	0.059
0.13	0.007	0.016	0.017	0.015	0.013	0.012	0.009	0.009	0.007

(b) Apparatus B

H(m) \ T(s)	1.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5
9.5									
8.5									
7.5									
6.75									8.950
6.25								9.911	7.673
5.75								8.389	6.495
5.25							8.252	6.993	5.414
4.75							6.755	5.725	4.432
4.25						8.882	5.408	4.583	3.548
3.75						6.915	4.210	3.568	2.762
3.25					8.547	5.194	3.162	2.680	2.075
2.75					6.119	3.719	2.264	1.919	1.486
2.25				7.479	4.096	2.489	1.516	1.284	0.994
1.88				5.221	2.860	1.738	1.058	0.897	0.694
1.63	0.807		7.986	3.925	2.150	1.306	0.795	0.674	0.522
1.38	0.578		5.724	2.813	1.541	0.936	0.570	0.483	0.374
1.13	0.388	4.929	3.838	1.886	1.033	0.628	0.382	0.324	0.251
0.88	0.235	2.989	2.328	1.144	0.627	0.381	0.232	0.196	0.152
0.63	0.121	1.532	1.193	0.586	0.321	0.195	0.119	0.101	0.078
0.38	0.044	0.557	0.434	0.213	0.117	0.071	0.043	0.037	0.028
0.13	0.005	0.065	0.051	0.025	0.014	0.008	0.005	0.004	0.003

(c) Apparatus C

H(m) \ T(s)	1.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5
9.5									
8.5									
7.5									
6.75									
6.25									
5.75									
5.25									15.132
4.75								16.588	12.387
4.25							15.524	13.279	9.916
3.75						19.296	12.087	10.339	7.720
3.25					20.452	14.494	9.078	7.765	5.799
2.75					14.643	10.377	6.500	5.560	4.152
2.25				13.926	9.803	6.947	4.351	3.722	2.779
1.88	3.274	12.921	13.19	9.724	6.844	4.850	3.038	2.598	1.940
1.63	2.461	9.713	9.915	7.310	5.154	3.646	2.284	1.953	1.459
1.38	1.764	6.962	7.107	5.239	3.688	2.613	1.637	1.400	1.046
1.13	1.183	4.668	4.765	3.513	2.472	1.752	1.097	0.939	0.701
0.88	0.717	2.831	2.890	2.131	1.499	1.063	0.666	0.569	0.425
0.63	0.368	1.451	1.481	1.092	0.769	0.545	0.341	0.292	0.218
0.38	0.134	0.528	0.539	0.397	0.280	0.198	0.124	0.106	0.079
0.13	0.016	0.062	0.063	0.046	0.033	0.023	0.015	0.012	0.009

(d) Apparatus D

H(m) \ T(s)	1.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5
9.5									
8.5									53.651
7.5								53.661	41.770
6.75								43.465	33.834
6.25							44.512	37.265	29.007
5.75							37.675	31.541	24.551
5.25							31.408	26.294	20.467
4.75						43.672	25.710	21.524	16.754
4.25						34.961	20.582	17.231	13.413
3.75					48.493	27.219	16.024	13.415	10.442
3.25					36.424	20.445	12.036	10.076	7.843
2.75				50.741	26.078	14.638	8.618	7.214	5.616
2.25				33.967	17.457	9.799	5.769	4.829	3.759
1.88	4.324			23.714	12.188	6.841	4.027	3.372	2.625
1.63	3.251		37.658	17.827	9.162	5.143	3.028	2.535	1.973
1.38	2.330		26.992	12.778	6.567	3.686	2.170	1.817	1.414
1.13	1.562	22.660	18.098	8.568	4.403	2.472	1.455	1.218	0.948
0.88	0.947	13.743	10.976	5.196	2.670	1.499	0.882	0.739	0.575
0.63	0.486	7.043	5.626	2.663	1.369	0.768	0.452	0.379	0.295
0.38	0.177	2.563	2.047	0.969	0.498	0.279	0.165	0.138	0.107
0.13	0.021	0.300	0.240	0.113	0.058	0.033	0.019	0.016	0.013

EFFICIENT UTILIZATION OF WAVE ENERGY

Now a day energy resource has become a sincere problem all over the world, and the interest of many people has concentrated on sustainable energy as new energy source, and the energy saving technique and the public system. Wave energy is expected as a new energy that has not become practical use, but it has high potential in its amount and stable supply among natural energy. However as the restriction of the natural energy the unstable supply is inevitable. Therefore, at present, to sell the electricity generated from ocean waves to the system of electricity is not necessary the most realistic way. Thus engineers engaged in the wave energy development have always to consider the efficient utilization of the energy that they have produced from the waves as well as the development of reasonable system of wave energy conversion. As the realistic methods to utilize wave energy, which do not necessarily require the stable supply, energies for desalinization of seawater and pumping up the ground water for drink and other use for supporting various industries and daily life are considered. Also wave energy is expected to be as the one for various water qualification projects developed in and near the sea area. Moreover, hybrid with electricity system or diesel power generation may be reasonable method for various use in littoral district from the viewpoint of reducing CO2 and cost. As another problem, hydrogen is considered as the major future energy. It is expected that the hydrogen obtained by electrolysis of the water will become a useful material which storages the natural energy with unstable supply potential. We wish to establish wave energy conversion technique in the near future so that wave energy technique would stand by the combination with the electrolysis of the water that leads to storage technology of hydrogen.

CONCLUSION

So far the authors have described the wave energy conversion system that they are developing with the setting preferable. Outline of the mechanical dynamics model to conveniently evaluate the energy gain and the various mechanical quantities needed in designing the apparatus was given, then the applicability of the dynamics model was checked thorough the water pool experiments. Time series of the various physical quantities are examined by calculation. Then the method for efficient utilization considering the unstable feature of natural energy has been considered. The main results of this paper are as below.

(1) It is desired that float-type wave energy system consist of driving pulley, wire, float and counterweight is set in the water space in front of the coastal structure such as slit caisson type breakwater.
(2) Dynamics model to evaluate the energy conversion rate showed relatively good agreement with water pool experiment.
(3) Though float can take 3 patterns of float submergences, condition that float is always partly submerged is the most desirable.
(4) Energies for desalinization of seawater etc. for drink and other use for supporting various industries and daily life are considered as that utilized which does not need stable energy supply.

In the future, this project, with the aid of engineers involved, will focus on the practical use of the system described in this paper overcoming the problems encountered in the real seas

REFERENCES

http://www.greenpeace.org.uk

http://www.energetech.com.au

Hadano, K, Saito,T, Kawano, S, Hashida, M, and Ozaki, T(1998). "A Proposal of Multi-Floats Type Wave Energy Conversion System." *Proc 8th Int Offshore and Polar Eng. Conf*, Montreal, pp 100-105.

Hadano, K, Hashida, M, and Sato, M (2002). "An Attempt to make High Performance Wave Energy System." *Proc 12th Int Offshore and Polar Eng Conf*, Kitakyushu, pp. 556- 561.

Saito, T, Hadano, K, and Ueno, I (1999). "Research on Fundamental Performance of Muti-Floats Type Wave Energy Conversion System." *Proc 8th Int Offshore and Polar Eng Conf*, Breast, pp 150-155.

Hadano, K, Nakano, K, Taneura, K, Ohgi, K, and Koirala, P (2002). "On the Occurred Electric Power." Proc Techno-Ocean 2002, Int Symp. CD-ROM.

Hadano, K, Taneura, K, Saito, T, and Nakano, K (2004). "Evaluation of Energy Obtained by Float-Type Wave Energy Generation System." *Proc 14th Int Offshore and Polar Eng Conf*, Toulon, pp 246-252,CD-ROM.

Nagai, N, Sato, K, and Sugawara, K (2002). "Technical Note of the Port and Airport Research Institute No.1017." *Independent Administrative Institution, Port and Airport Research Institute*, Japan. pp 79-331.