Wave Energy Converter with Wave Direction Tracking Function

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***Abstract*— If its floater is parallel to sea wave, the wave energy converter can sweep more wave energy at the same construction cost. To keep the floater parallel to wave, a self-modify design is proposed. The sea level difference of the floater will create a force to push the floater. And the force due to the rotation center will create a torque to force the wave energy converter aligned with waves. Increasing the sea level difference and the distance of the rotation center can increase the self-modify torque and the stability of the wave energy converter. After it keeps parallel to the wave, the floater will be able to collect more horizontal wave energy and extend the time which sea wave works on the wave energy converter.**

***Keywords*—** ocean energy; wave energy; wave direction; wave energy converter; horizontal wave energy; wave tracking

I. Introduction

It is not a problem to convert wave energy to electric power now. The problem of wave energy is how to reduce cost and obtain economic efficiency, especially when compared with those of wind turbines. To clear this problem, we discuss this issue from energy density to construction cost. After then this paper will introduce a design concept to reduce cost and get economic efficiency.

A. Energy density

The Beaufort scale is used to compare wind energy and sea wave energy. If we compare the wind energy and wave energy in Beaufort wind scale 4 (Moderate Breeze), the wind speed is 5.5-7.9m/s, and the wave height is 1-2m. The air density is 1.2 kg/m^3 (20°C, 1 atm), the sea water density is 1027 ~ 1070 kg/m^3 ,and the wave period is 5sec to 6sec.

The equation of air energy density :

$$\mathrm{E}_{wind} = \frac{1}{2}\rho_{air}V_{wind}^2$$

The equation of wave energy density :

$$\mathrm{E}_{wave} = \frac{\rho_{sea}g^2}{32\pi}H^2T$$

TABLE I
CALCULATIE VALUE

Item			
Beaufort scale	4	calculate value	unit
wind speed	5.5~7.9	6	m/s
air density	1.2	1.2	kg/m^3
wave height	1~2	1.2	m
wave period	5~6	5.5	sec
sea water density	1027~1070	1020	kg/m^3

TABLE II
ENERGY DENSITY

	energy density	unit
Wind energy density	129.6	w/m^2
Wave energy density	7739.59	w/m

The wave energy density is around 70 times to wind energy density. Wind energy is collected in an area which is growing in square relation of scale. And the wave energy is collected in a liner direction. When the scale is over 70 meter, wind energy will be possible to collect more energy than wave energy in Beaufort wind scale 4. However, when the scale is less than 70 meter, the wave energy converter should be able to collect more energy and get higher economic efficiency than wind turbines in Beaufort wind scale 4.

B. Construction cost

In 2014, Hiromichi Akimoto, Dr. Eng. provided a concept of the construction cost in his rotatonal wave energy converter presentation [1]. The construction cost of normal wave energy converter is squared to cubic relationship of scale. But the wave energy is related to scale, so its economical efficiency will decrease with scale. Therefore, Dr. Akimoto said the wave energy converter should be light weight and linearly extendable in the wave extend direction.

Beside, a wind turbine can collect wind energy in a big area to one power generator. When using normal wave energy converters to collect a long distance L_w (in wave extend direction) wave energy, it will need many normal wave energy converters or one big size wave energy converter to collect wave energy. If we use many normal wave energy converters, it will increase the number of power generator and increase maintenance and operation costs. If we use one big size wave energy converter, the size of wave energy converters will become L_W^2, and the cost will increase in squared to cubic relationship of scale, too.

Those reasons will also cause the cost of wave energy converter is higher than wind turbines. This limit of normal wave energy converters is due to normal wave energy converters can not extend in wave extend direction and collect wave energy to one power generator.

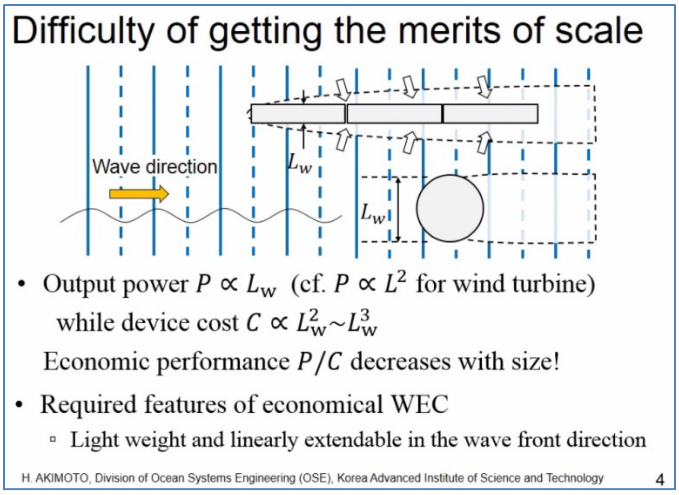


Fig. 1 the scale effect of wave energy

C. Design concept

To use the advantage of high energy density of wave energy and to avoid the disadvantage of construction cost of wave energy converter, we must reach these design target.

1) *Collect maximum wave energy in unit cost:* Let the wave energy collector parallel to wave to sweep maximum wave energy in unit cost. And try to collect not just vertical but also horizontal wave kinetic energy.

2) *Reduce maintenance and construction cost:* to reduce maintenance cost and construction cost in design stage. Even if wave energy converter is broken, it will be very easy to repair at low cost. Therefore, it is better to avoid civil work. Civil construction in the sea is difficult to repair and will increase more cost.

To achieve those design concept, it must use marine way to keep wave energy converter parallel to wave.

II. Long Floater on the Sea

The movements of long floater on the sea include linear moving (heaving , surging , swaying) and rotating (rolling , pitching , yawing). In order to discuss the parallel situation of long floater and wave, define the angle between the extend direction of long floater and the extend direction of wave as theta θ. The diagram is as Fig. 2 and Fig. 3.

(In the next demonstration sketch, the blue color is under the sea, and the green and yellow color is in the air.)

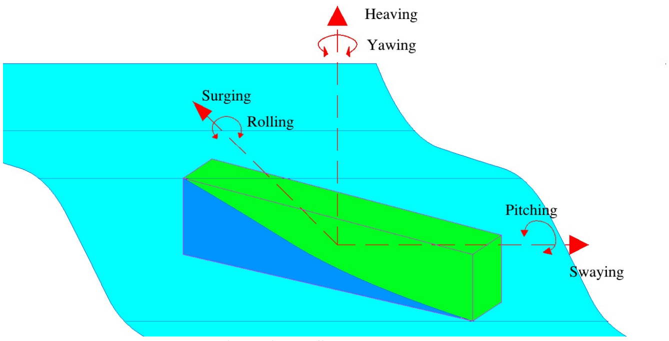


Fig. 2 long floater movement

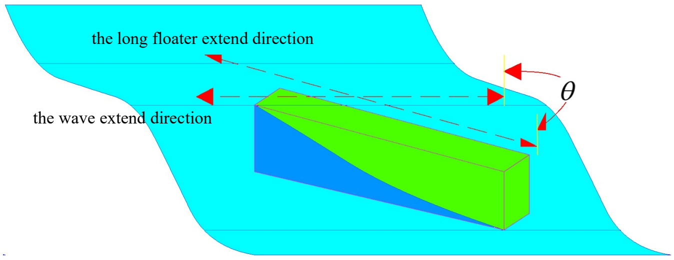


Fig. 3 the angle of theta θ

Normally, the long floater on the sea will stay in its steady conditions. The normal steady conditions θ of the long floater on the sea include 90° which is like a ship against wave. The steady conditions θ also include 45° to 90° which depend on the shape or other additional parts of the long floater. Those steady condition should cause by the sea level difference of each side of the long floater when wave passes, as fig. 4. The level difference on each long side will create a net force to push long floater to stay in steady condition. And the net force due to the rotation center of long floater will create a torque to rotate long floater. But the normal steady conditions of a pure long floater do not include θ as 0°. That means it is difficult to keep long floater parallel to wave.

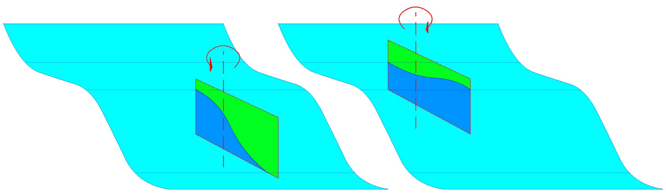


Fig. 4 wave push long floater

When we use long floater to collect wave energy, we wish the long floater to heave and to collect vertical wave energy or to surge to collect horizontal wave energy. But the floater might be only pitching but without heaving and surging, like fig. 5. Pitching situation will reduce heaving and surging moving, so pitching will reduce energy collect efficiency.

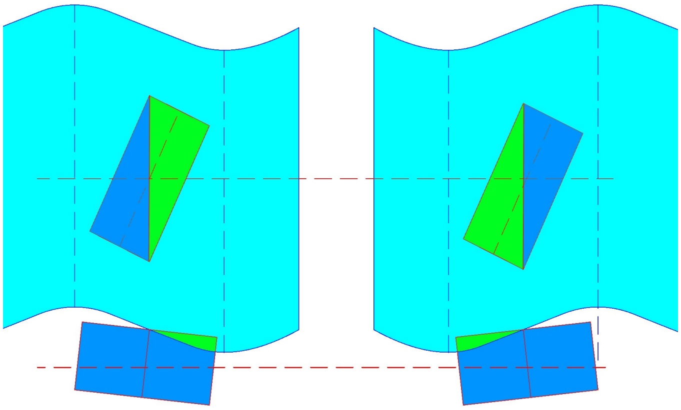


Fig. 5 pitching without heaving or surging

Adding some parts on the long floater might be able to change the steady condition or increase some other steady condition. The slow miller [2] use a sail part under the sea to produce at a steady condition. This steady condition of slow miller can keep an angle to the wave and collect wave energy.

Fig. 6 slow miller

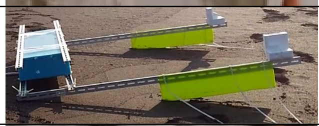
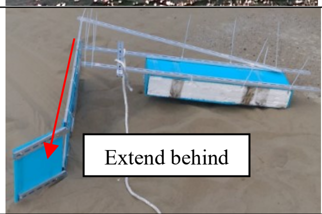
III. Test parts

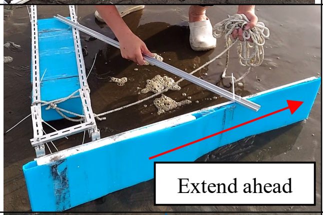
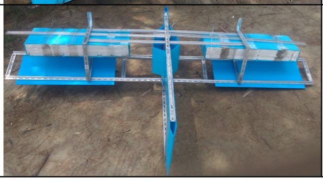
First, I tried to use the additional part to change the steady condition of long floater. In order to clear how additional parts effect the angle θ between long floater and wave, I tested a series of additional parts on long floater. After a series of tests, I found a efficiency way to keep the parallel between long floater and wave. This efficiency way will be discussed in section IV. Those no effect and small effect ways will be discussed In this section.

The no effect and small effect additional parts are listed in table III. I use two factors to survey whether it is effective or not. The two factors are : 1. the steady condition angle θ_{steady} and 2. the long floater self-modify speed V_{modify}. If the angle θ in steady condition is without 0° or even with 90°, this additional part is no effect. If the angle in steady condition (θ_{steady})is with 0° but with other degree (like 45° , 30°), this additional part is small effect. In small effect, there is a maximum modify angle (θ_{max}). Before maximum modify angle (θ_{max}) , the floater can self-modify angle θ to 0°.When self-modifying, the speed of self-modify (V_{modify}) is defined as angle/sec. If the speed is fast, it meets this floater can be very stably parallel to wave and modify the angle θ to 0° easily. The commentary of the ability of wave direction tracking and wave parallel keeping includes the angle in steady condition (θ_{steady}) , maximum modify angle (θ_{max}) , and speed of self-modify (V_{modify}).

When θ_{steady} is without 0°, it is no effect. If θ_{steady} is with 0°, θ_{max} exists, and V_{modify} is slow, the effect is small. If θ can stably keep 0°, the effect is enough.

TABLE III
TEST LIST of SMALL EFFECT

No	Floater with additional part	Test date	θ	Effect
1		2017/04 /16	θ_{steady} : 90°	No
2		2017/04 /23	θ_{steady} : 90°	No
3		2017/04 /23	θ_{steady} : 90°	No
4		201704/ 30	θ_{steady} : 90°, 45°	No
5		201704/ 30	θ_{steady} : 45°	No
6		2017/05 /06	θ_{steady} : 90°	No
7		2017/05 /06	θ_{steady} : 90°, 30°	No
8		2017/05 /14	θ_{steady} : 90°, 70°	No
9		2017/05 /14	θ_{steady} : 90°, 45°, 0°	small
10		2017/05 /21	θ_{steady} : 90°, 45°, 0°	small

11		2017/06 /11	θ_{steady} : 45°, 0°	small
12		2017/06 /11	θ_{steady} : 45°, 0°	small
13		2017/06 /25	θ_{steady} : 0° ~ 30° swaying	Small
14		2017/07 /09	θ_{steady} : 0° ~ 15° θ_{max}: 45°	Small / enough

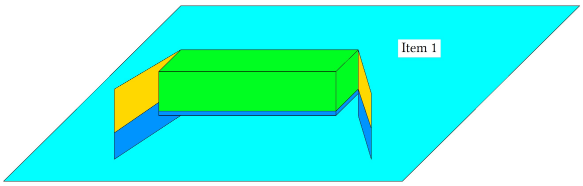
To analyze these result, I classify these additional parts as three kinds: with under water panel, multihull, and with extend guide panel. The under water panel kinds are as fig. 7. The multihull kinds are as fig. 10. The extend guide panel kinds are as fig. 11.

The under water panel kinds should create vortexes behind the long floater. The vortex should cause a force to rotate the long floater and control the θ, like the air plane control. But in fact, those are almost no effect. The reasons for this no effect might be about two condition: 1. the sea flow under the wave is different direction with depth, and 2. the vortex caused by panel is not obvious. These factors should reduce the force of vortex and make the no effect.

The under water panel kinds are test item 1 to item 5. The item 1 to item 5 are as fig. 7. In item 1, I tried to use guide panel on each end side of long floater. Sometimes, it might be parallel to wave as fig. 8, but the steady condition θ_{steady} of test item 1 is 90° like fig. 9.

The test item 2 used a guide panel in the middle and after the long floater, like a rudder of air plane. But the steady condition θ_{steady} of test item 2 is 90°. Near the beach, the sea flow direction on the surface and under the sea are different. The guide panel of test item 2 was effected by the different flow direction with depth. The different flow direction should offset the force and make the guide panel no effect. And the guide panel even makes the steady condition θ_{steady} of 90° become more stable. So the additional parts should be not too deep.

The test item 3 to 5, I tried to used shallow guide panel. The θ_{steady} became 45° to 90° but still not 0°.



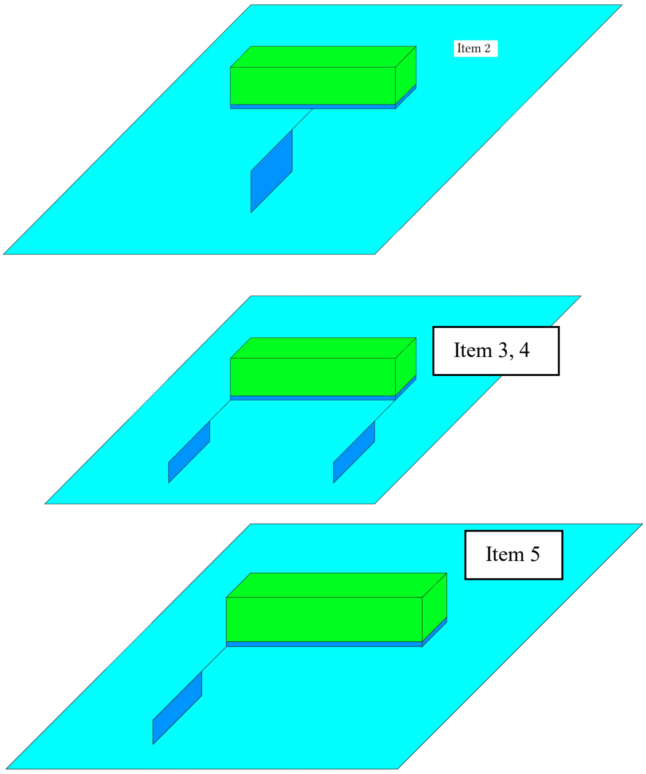


Fig. 7 additional parts of under water panel kinds

Fig. 8 test item 1 parallel moving

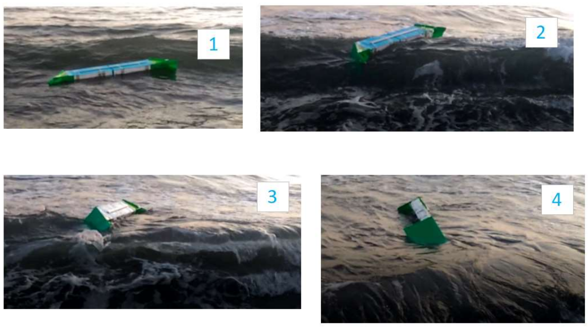


Fig. 9 test item 1 θ_{steady} 90°

The multihull kinds are as item 6 to 14, like fig. 9. In test item 6, I added a guide panel on each end side of long floater to create multihull: guide panel - long floater - guide panel. But the steady condition θ_{steady} is 90° in test item 6. And test item 7 only use one end side of guide panel: long floater -

guide panel. In test item 7, the steady condition θ_{steady} is 90° and 30°. Test item 7 is better than test item 6. The two end side guide panel could create different direction torque to offset each other and then reduce the ability of keeping parallel to wave. But the ability to keep parallel to wave in test item 7 is still not enough.

So I tried to extend the guide panel on multihull to increase self-modify ability. In test item 8, 9, 10, 11 and 12, I extended the guide panel in behind direction which is in nearing beach direction. These result is better than test item 7, but these still can not keep parallel with wave and have other steady condition θ_{steady}.

In test item 13, I tried to extend the guide panel in ahead direction which is in away beach direction. In test item 6 and 7 experiment, one end side guide panel is better, so I extended one end side guide panel ahead. The result of test item 13 is better than test item 10, 11 and 12, but I found the long floater of test item 13 was swaying. This swaying should was caused by unbalance force to long floater, so I replaced the ahead extend guide panel in the middle of long floater as test item 14.

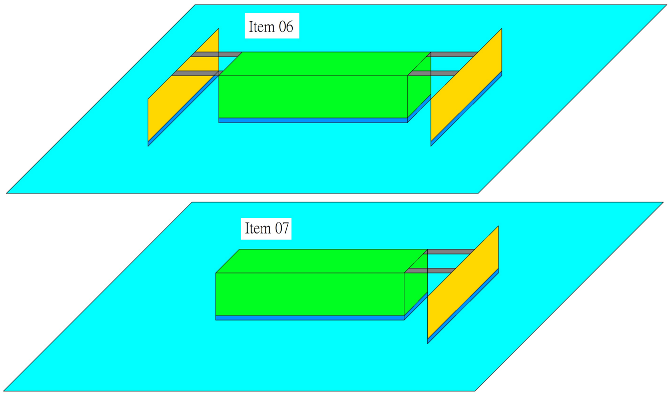


Fig. 10 additional parts of multihull kinds

In test item 14, the guide panel was in the middle of the long floater and extended in wave coming direction.The long floater in test item 14 can keep parallel to wave more stably than test item 13. And the maximum modify angle θ_{max} in test item 14 is around 45°. If the angle θ is 45° or over 45°, it can not self-modify to parallel with wave.

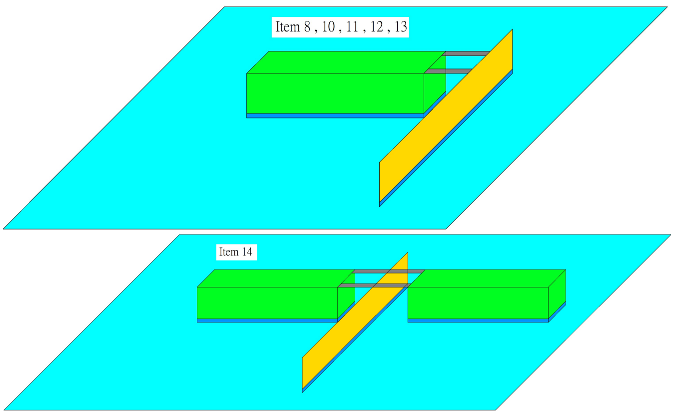


Fig. 11 multihull with guide panel kind test item

By observing the movement in test item 14 as fig. 12, the ahead extend guide panel can rotate floater more earlier and increase the time which wave acts on the guide panel. Besides, the ahead extend guide panel separates the area before long floater to two half sides. And the ahead extend guide panel also increases the sea level difference of the two half sides. The level difference will form a hydraulic pressure to act on the guide panel and long floater and cause a force to modify the long floater.

The longer guide panel can increase longer time to keep level difference to make self-modification. And the net force will create a torque to rotate the guide panel and long floater as fig. 13.

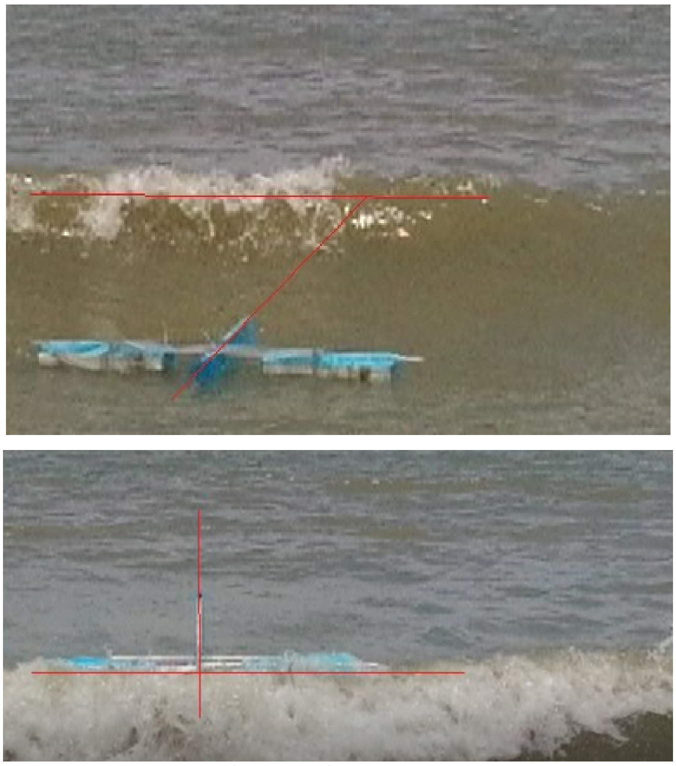


Fig. 12 test item 14 movement

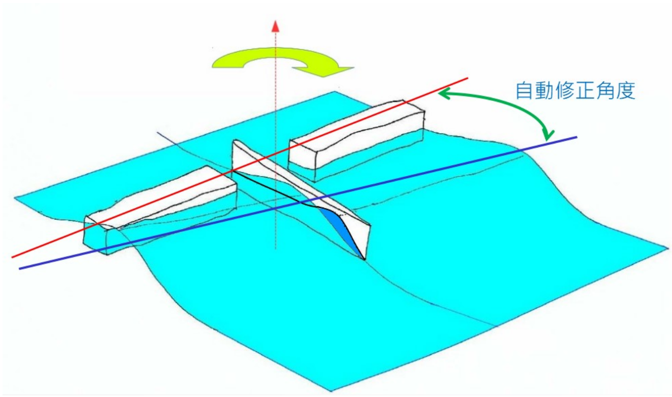


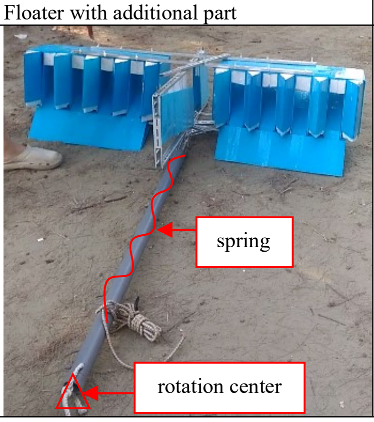
Fig. 13 test item 14 modify rotation by level difference

The multihull kind is only small effect. Those ways are not the best way to design a long float wave energy converter.

There should be at least two reasons of this phenomenon. The first reason: the torque to modify floater is not big enough. The second reason: there are other steady condition. In order to overcome these two problems, I use a long guide panel to increase the self-modify torque and increase the stability of steady condition θ_{steady} as 0°. But the speed of self-modify (V_{modify}) is still not fast enough. And the maximum modify angle (θ_{max}) is limited around 45°. To overcome these two problems, I must use another way.

IV. Efficient Design

The effective way to reach design target is the test item 14. From the test item 14, I wish to get more fast self-modify speed (V_{modify}). The effect of self-modify is caused by the torque to create rotation movement. The torque is create by forces and their lever arm. From the previous test, the force by level difference is bigger and more efficient than vortex force, so it is the best way to use level difference to create the rotating force. The lever arm of self-modify torque is from the net force to the rotation center, so I have to try to increase the distance of the net force to rotation center. Under this concept, I design a long indented floater with a guide panel and a beam with spring. Use the beam to extend the rotation center. Use the indented floater to absorb more sea water to test whether absorbing more sea water can increase the net force and wave energy collection or not. The beam is also combined with a spring to absorb the wave energy, and we can observe wave energy collection by the spring movement. The test item 15 as below.

No.	Floater with additional part	Test date	Effect
15		2017/09/17	Stable & fast

Define θ_1 as the begin angle before wave coming, θ_2 as the final angle in one wave period, T as the time which wave act on the floater. By the angle change of θ_1 - θ_2 and the T, we can calculate the modify rotate speed V_{modify}. The result data of test item 15 is as the table IV. The result is very stable. The self-modify speed can finish self-modify in two wave period. And more, the time which wave act on the floater can be increased (compare with test item 14). This increased not only the stability but also the force which wave act on the floater. By increasing the wave acting time, the spring absorbed wave energy over the spring's limit. So it increased the level difference, rotation center distance, and the wave acting time.

TABLE IV
TEST DATA of TEST ITEM 15

No.	Hour:min:sec	θ_1 (deg)	θ_2 (deg)	T (sec)	V_{modify} (deg/sec)
1	16:46:48	0	0	2	
2	16:46:56	45	30	2	7.5
3	16:46:58	30	20	1	10
4	16:47:02	0	0	2	
5	16:47:20	10	0	3	
6	16:47:28	0	0	2	
7	16:47:42	0	0	6	
8	16:47:53	10	0	5	2
9	16:48:20	0	0	8	
10	16:48:42	0	0	3	
11	16:48:47	10	0	5	2

Fig. 14 Example 1 of the level difference of the floater

Fig. 15 Example of the level difference of the floater

By observing test item 15, I found some useful phenomenon. When wave passed, there was a back flow under the sea. And this back flow can push the long floater back, so we can use the back flow period to push long floater back and collect this kind of wave energy. In other words, we can use wave to push long floater forward and use the back flow to push long floater back. We can also use springs to store coming wave energy and release this energy to pull long floater back after the wave passed. Combining the back flow and springs will make the energy converter more efficient.

In test item 14 and test item 15, I placed gaps between floater and the guide panel to let wave act on guide panel more. As I found the force by level difference, these gap seems no necessary. The time of level difference should be able to keep longer by no gap design.

In test item 15, The wave height of coming wave and passed wave are not too much different. As the wave energy is square relationship of wave height. So there are much wave energy which was not absorbed in test item 15. The reason of low wave energy absorption might be due to the limit of spring’s energy content. Sometimes, the spring reached its limit extension. Additionally, the space of the indented long floater might be not deep or big enough to absorb wave water, so wave water could pass the indented floater to make wave energy pass. If we use enough springs to absorb wave energy and enough indented space to keep wave water, I believe this way will collect more wave energy and reduce wave height between coming wave and passed wave. The small wave height reduction of coming wave and passed wave might be also caused by diffraction effect. The diffraction effect will make the nearby wave fill up the wave height. This diffraction effect might be less if the long floater becomes more longer.

From test item 15, I organize the mechanism as fig. 16. The level difference of long floater and guide panel will cause a net force. The net force due to the rotation center will form a torque. This torque will rotate the wave energy converter to modify itself to keep parallel with wave.When long floater is parallel to wave, the level difference will be 0 or very small, so there will be no torque to rotate the wave energy converter. When wave keeps an big angle θ to long floater, the level difference will increase to cause a torque to rotate the wave energy converter until long floater aligned with the wave.

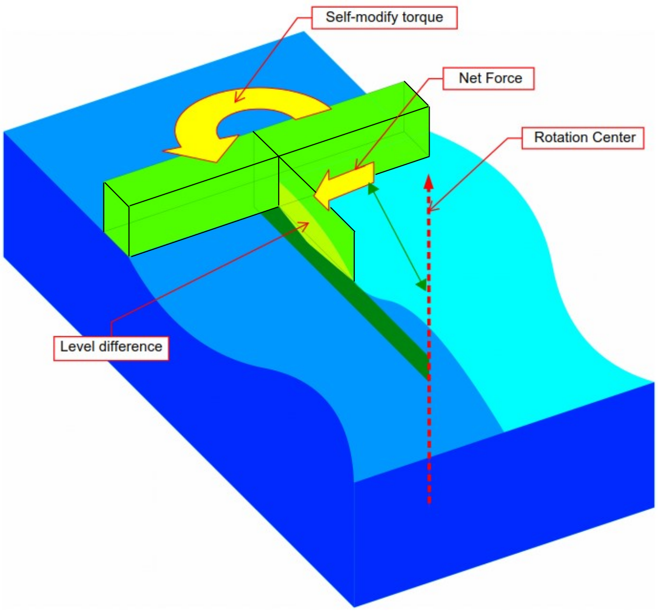


Fig. 16 Example 1 of the self-modify torque

In order to test this mechanism, I arranged a series of test with different guide panel and rotation center as table V and fig. 17. The different guide panels are A: long floater, center guide panel, side guide panels and rotation beam; B: long floater, center guide panel and rotation beam; and C: only long floater and rotation beam. The different rotation center are 2L: rotating point fixed on the end of double length of center guide panel; L: rotating point fixed on the end of center guide panel; 0L: no rotating point fixed on rotation beam.

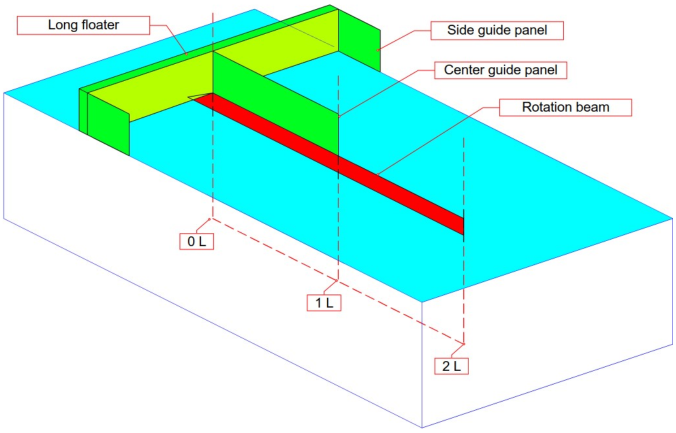


Fig. 17 illustration of mechanism test

TABLE V
MECHANISM TEST NAMES TABLE

	Rotation center position		
Guide panel type	0 L	1 L	2 L
 A	A0L	A1L	A2L
 B	B0L	B1L	B2L
 C	C0L	C1L	C2L

The different guide panels (A, B, C) and rotation centers (0L, 1L, 2L) form a test names table as the table V. The test results include 9 data tables are as table VI to table XIV. Comparison of the test result in steady condition θ_{steady} is as table XV.

TABLE VI
TEST DATA of A2L

No.	Hour:min:sec	θ_1 (deg)	θ_2 (deg)	T (sec)	V_{modify} (deg/sec)
1	10:57:28	0	0	1.5	0
2	10:57:39	30	0	2.5	12
3	10:57:46	30	10	2	10
4	10:57:58	90	70	1	20
5	10:58:05	90	30	2	30
6	10:58:10	30	10	1	20
7	10:58:20	90	0	3	30
8	10:58:30	30	10	2	10
9	10:58:35	0	0	1	0
10	10:58:45	45	20	2	12.5
11	10:58:56	90	45	3	15
12	10:59:02	45	0	2	22.5
13	10:59:06	0	0	1	0
14	10:59:19	45	10	1	35
15	10:59:26	45	10	2	17.5
16	10:59:32	0	0	1	0
17	10:59:41	45	10	2	17.5
18	11:00:05	180	90	6	15
19	11:00:15	90	0	4	22.5

TABLE VII
TEST DATA of A1L

No.	Hour:min:sec	θ_1 (deg)	θ_2 (deg)	T (sec)	V_{modify} (deg/sec)
1	11:02:19	10	0	1	10
2	11:02:25	0	0	1	0
3	11:02:37	80	0	2	40
4	11:02:50	120	80	2	20
5	11:03:02	180	110	4	17.5
6	11:03:10	150	80	5	14
7	11:03:17	90	0	9	10
8	11:03:32	45	30	2	7.5
9	11:03:42	90	60	2	15
10	11:03:52	180	150	3	10
11	11:04:04	180	30	7	21.4
12	11:04:12	45	0	4	11.25
13	11:04:25	150	120	2	15

TABLE VIII
TEST DATA of A0L

No.	Hour:min:sec	θ_1 (deg)	θ_2 (deg)	T (sec)	V_{modify} (deg/sec)
1	11:05:11	45	45	1	0
2	11:05:20	60	80	1	-20
3	11:05:23	80	80	1	0
4	11:05:34	45	30	1	15
5	11:05:41	30	0	3	10
6	11:05:53	0	0	1	0
7	11:05:55	10	0	1	10
8	11:06:09	0	0	5	0

TABLE IX
TEST DATA of B2L

No.	Hour:min:sec	θ_1 (deg)	θ_2 (deg)	T (sec)	V_{modify} (deg/sec)
1	11:12:31	0	0	1	0
2	11:12:42	45	15	1	30
3	11:12:54	0	0	1	0
4	11:13:05	90	45	5	9
5	11:13:18	90	30	2	30
6	11:13:26	75	10	3	21.67
7	11:13:37	60	0	4	15
8	11:12:54	90	60	3	10
9	11:14:03	80	15	1	65
10	11:14:15	15	0	1	15
11	11:14:25	90	15	2	37.5
12	11:14:30	0	0	1	0
13	11:14:43	90	15	3	25
14	11:14:53	45	10	1	35
15	11:15:00	45	15	1	30
16	11:15:06	0	0	1	0
17	11:15:13	15	0	2	7.5
18	11:15:27	90	45	2	22.5
19	11:15:40	180	150	2	15
20	11:15:49	90	15	5	15
21	11:16:04	60	45	2	7.5
22	11:16:10	75	45	2	15

TABLE X
TEST DATA of B1L

No.	Hour:min:sec	θ_1 (deg)	θ_2 (deg)	T (sec)	V_{modify} (deg/sec)
1	11:16:47	90	45	4	11.25
2	11:16:55	0	15	2	-7.5
3	11:17:03	90	30	1	60
4	11:17:13	90	0	3	30
5	11:17:22	30	15	1	15
6	11:17:30	0	15	2	-7.5
7	11:17:38	45	0	1	45
8	11:01:47	45	15	1	30
9	11:17:56	80	0	2	40
10	11:18:07	75	30	2	22.5
11	11:18:17	80	0	2	40
12	11:18:33	120	80	3	13.3
13	11:18:40	90	0	4	22.5
14	11:18:53	0	0	1	0
15	11:18:58	15	10	1	5
16	11:19:05	0	45	2	-22.5
18	11:19:23	0	0	1	0
19	11:19:30	180	90	10	9
20	11:19:42	90	15	3	25
21	11:19:55	120	45	5	15
22	11:20:03	45	0	2	22.5
23	11:20:10	0	0	1	0

TABLE XI
TEST DATA of B0L

No.	Hour:min:sec	θ_1 (deg)	θ_2 (deg)	T (sec)	V_{modify} (deg/sec)
1	11:20:50	15	10	2	2.5
2	11:21:00	10	0	2	5
3	11:21:08	10	0	2	5
4	11:21:10	0	0	4	0
5	11:21:45	90	75	2	7.5
6	11:21:49	45	15	2	15
7	11:21:53	0	10	1	-10
8	11:22:45	75	0	3	25
9	11:22:57	30	15	2	7.5
10	11:23:05	0	10	2	-5
11	11:23:18	10	0	2	5
12	11:23:28	0	0	2	0

TABLE XII
TEST DATA of C2L

No.	Hour:min:sec	θ_1 (deg)	θ_2 (deg)	T (sec)	V_{modify} (deg/sec)
1	11:31:54	90	30	2	30
2	11:32:01	90	75	3	5
3	11:32:07	75	0	3	25
4	11:32:21	0	0	1	0
5	11:32:30	Long floater was overturned			
6	11:41:09	0	0	1	0
7	11:41:15	15	0	2	7.5
8	23:41:28	45	30	2	7.5
9	11:41:34	90	45	2	22.5
10	11:41:40	75	30	1	45
11	11:41:42	0	0	1	0
12	11:41:44	0	0	1	0
13	11:41:56	30	0	1	30
14	11:42:05	30	10	2	10
15	11:42:25	170	120	2	25
16	11:42:29	170	150	2	10
17	11:42:42	150	120	2	15
15	11:42:47	150	120	2	15
16	11:42:50	100	80	2	10

TABLE XIII
TEST DATA of C1L

No.	Hour:min:sec	θ_1 (deg)	θ_2 (deg)	T (sec)	V_{modify} (deg/sec)
1	11:44:26	90	90	2	0
2	11:44:37	170	150	2	10
3	11:44:49	80	45	2	17.5
4	11:45:00	0	0	2	0
5	11:45:05	45	0	2	22.5
6	11:45:10	30	0	4	7.5
7	11:45:27	90	90	2	0
8	11:45:37	120	90	2	15
9	11:45:44	90	75	2	7.5
10	11:45:57	90	90	2	0
11	11:46:01	90	45	3	15
12	11:46:14	90	75	1	15
13	11:46:25	90	90	2	0
14	11:46:33	120	90	2	15
15	11:46:38	90	75	1	15
16	11:46:43	0	0	1	0
17	11:46:50	90	75	2	7.5

TABLE XIV
TEST DATA of C0L

No.	Hour:min:sec	θ_1 (deg)	θ_2 (deg)	T (sec)	V_{modify} (deg/sec)
1	11:48:40	170	120	2	25
2	11:48:48	80	45	2	17.5
3	11:49:02	75	45	2	15
4	On beach				
5	11:50:44	75	90	1	-15
6	11:50:50	60	60	1	0
7	11:50:52	60	30	2	15
8	11:51:09	60	45	2	7.5
9	On beach				
10	11:52:37	90	90	2	0
11	11:52:42	90	90	2	0
12	11:52:50	90	75	3	5
13	11:53:03	30	80	2	-25
14	11:53:23	60	90	3	-10
15	11:53:36	30	75	2	-22.5
16	11:53:40	90	90	2	0
17	On beach				
18	11:55:31	60	60	3	0
19	11:55:57	75	60	2	7.5

TABLE XV
STEADY CONDITION of MECHANISM TEST

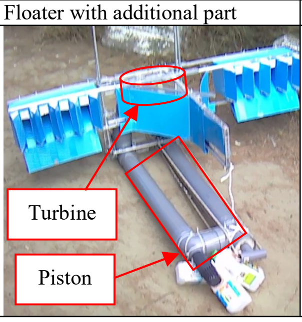
Guide pane	Rotation center position		
	0 L	1 L	2 L
A	θ_{steady} : 0°	θ_{steady} : 0°	θ_{steady} : 0°~10°
B	θ_{steady} : 0°	θ_{steady} : 0°	θ_{steady} : 0°~15°
C	θ_{steady} :45°~90 °	θ_{steady} : 0°, 90°	θ_{steady} : 0°, 30°

From the mechanism test result, The longer rotation center position can make long floater keeping parallel with wave more stably. And the center guide panel can make this parallel ability more stably,too. The back flow rushed the long floater, so the θ_1 was easy to over 90°. By absorbing back flow energy, it might be able to reduce θ_1. In big θ_1 (around 45°), V_{modify} of type B is faster than type A. The side guide panel (A type) might obstruct wave energy collection in big θ_1, so the A type will absorb less wave energy than B type in big θ_1. Compare A, B and C type, the guide panel can extend the time T. This will make wave act on floater longer and increase wave energy absorption.

V. Conclusions

As long floater parallel with wave is not a problem, we can use wave direction tracking function to get more wave energy in the same cost than before. Moreover, if we add bottom panels between the long floater and guide panels, we will collect more wave water and get the vertical and horizontal wave kinetic energy, like test item 15.

When we start to add piston or turbine to convert wave energy in this wave direction tracking design, the weight arrangement will effect the rotation center and floater surging speed. I used test item 15 to combine piston and water turbine with long floater as test item 16. The rotation center was closed to long floater, and the long floater moving speed became slower, so the result is not good. Therefore, we need to make the wave energy collector become lighter and to make the weight center close to rotation center.

No.	Floater with additional part	Test date	Effect
16		2017/11/26	Small. Floater moving slow.

When we start to combine this wave tracking design with wave energy converter, we need to reduce the mass and the drag of wave energy collector and increase the wave force acting on wave energy collector. In this way, it makes more wave energy convert to machine energy but not lost in wave energy collector's mass movement and drag.

When wave hits the long floater, the wave height will become higher to increase more hydraulic pressure on long floater, as fig. 18. If we add a bottom panel ahead the long floater, the wave height might increase more to induce more hydraulic pressure to push long floater.

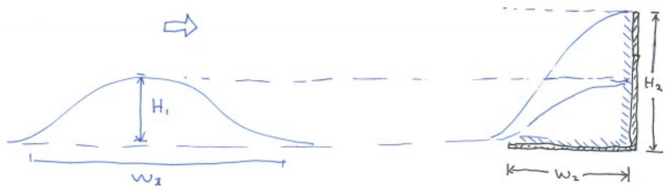


Fig. 18 wave hits long floater and becomes higher

If we can extend the time and working distance which wave act on the wave energy collector, we will collect more wave energy. But in those test, wave can pass long floater easily. There are two ways to extend the wave acting time: 1. make the long floater move with wave, and 2. keep wave water or level difference before long floater to make hydraulic power keep acting on long floater. When we use the bottom panel before long floater, the more wave water will be capture to keep the level difference, and more higher level difference will push the long floater to move with wave, too. By capturing the wave water, the bottom panel will make wave energy collector be able to collect vertical and horizontal kinetic wave energy in once.

The benefits of this design are: 1. wave energy collector extends in wave extend direction at low coast; 2. wave energy is collected and transferred to one power generator. The extend limit of this design should depend on the wave tracking ability existing or not. Define each wave's extend width as W and the extend length of long floater as L. We only tested L as 0.5m ~ 2m length and W around 10 ~ 20m width which is as $L << W$. And the results are as previous tests. I guess the other two situations (as fig. 19): 1. when $L \approx W$, waves might often hit half of the long floater and rotate the long floater; 2. when $L >> W$, the long floater can regard the waves as a continuous wave and should be able to keep wave tracking ability.

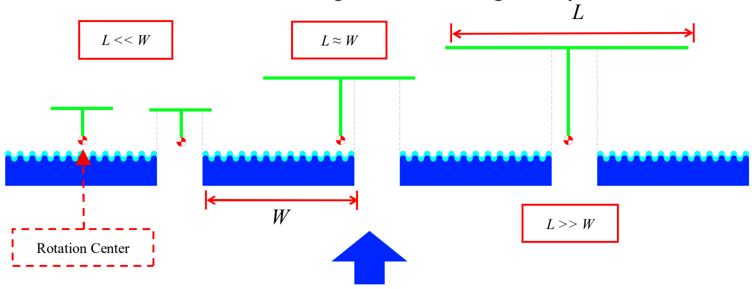


Fig. 19 the situation of $L<<W$, $L\approx W$, and $L>>W$.

The other cost reduction issues are: anchor, transfer wave energy to other power, and protection from big waves or adverse weather. Some ideals (as fig. 20) are 1. combine a pile and anchors to fix on sea bed; 2. use thread spools to transfer reciprocating motion to rotating motion; 3. open the long floater to release wave water.

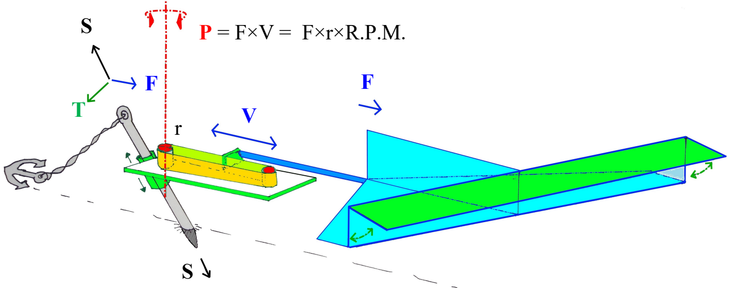


Fig. 20 other cost reduction ideals

After those efforts, I believe the cost of wave energy will be able to lower than wind energy, and we will get more cheaper renewable energy in the near future.

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