The research of the floating-type wave power pump composed of a slope, a curved surface reflection board and phase plates

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Abstract

A floating-type wave power pump is a device which sends air into water by using wave power. The floating-type wave power pump has the new configuration composed of a curved surface reflection board, a slope, and phase plates. As a result of a water-tank experiment, it turned out that the floating-type wave power pump with a curved surface reflection board and a slope raised power and efficiency in the wide wavelength waves. The result of a marine experiment was also preferable. The floating-type wave power pump sends air into the sea by using wave power, so it can be used for the improvement of marine environment. In addition, the floating body constituted of a curved surface reflection board, a slope, and phase plates, is effective as a device to utilize the energy of a wave. Therefore, it can be widely used for a wave power generation, pumping up deep seawater.

Keywords : Curved surface reflection board, Slope, Phase plates, Wave power, Floating-type wave power pump and efficiency

1. Introduction

If the floating-type wave power pump sends air into water by using wave power, the dirty sea where the amount of dissolved oxygen decreased can turn clean again. Photo 1 shows waves lap against the slope. Wave height becomes high, and a slope plays a role in gathering the energy of a wave near the water surface. Photo 2 shows a stroboscopic photography when waves hit a column. The column reflects waves and water moves up and down along the curved surface. Photo 3 shows a stroboscopic photography in which waves lap against the floating body with three phase plates. In this case, the waves' wavelength is twice as long as the length of the floating body. The floating body with three phase plates reflects waves, and water moves up and down in its front. [1)]

Therefore, when a slope and a curved surface reflection board are attached to the front of the phase plates and a float moves along the curved surface, strong wave power can be obtained from the oscillation of water.

Authors produced a device cosists of a slope, a curved surface reflection board, and phase plates in order to send air into the sea by using wave power. The device is called a floating-type wave power pump. Through the measurement of wave power and efficiency, the pump's engine performance has proved to be remarkable.

2. The measurement of the wave power of a floating-type wave power device

2.1 Method

Photo 4 and Fig. 1 show a floating-type wave power device consists of a slope, a curved surface reflection board and phase plates. Wave power was measured from the electric pressure produced on the piezo-electric film. The experiment was conducted by changing conditions as: (1) both the slope and the curved surface reflection board, (2) only a curved surface reflection board (3) only a slope (4) without a curved surface reflection board and a slope.

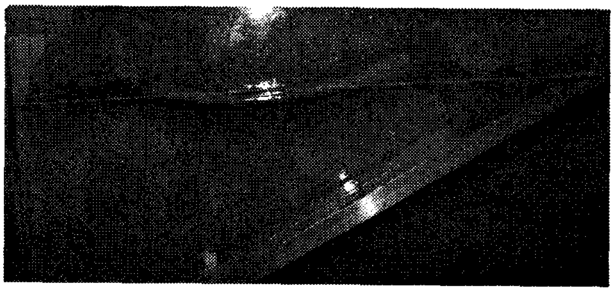


Photo 1 The wave to lap against the slope

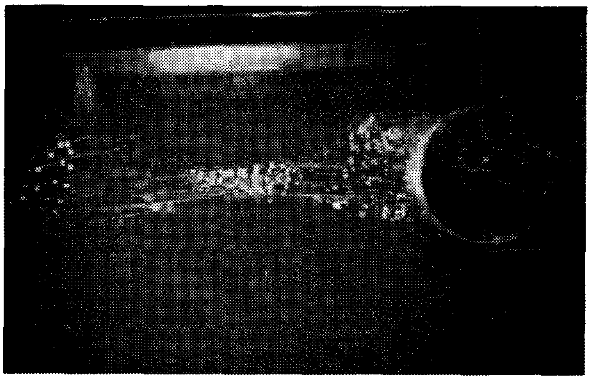


Photo 2 The waves which hit a column

Photo 3 The waves which hit 3 connection phase plates

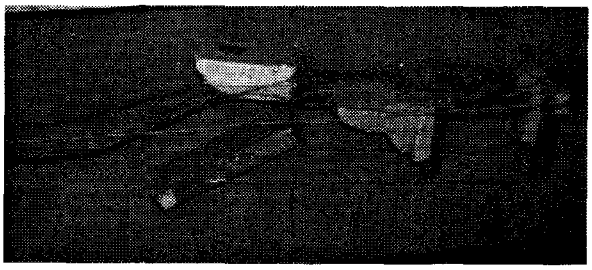


Photo 4 The floating-type wave power device

2.2 Result

Fig. 2 demonstrates the transition of wave power when wave frequency is set 1.8Hz, and only wave height is changed. The wavelength λ of 1.8Hz waves

$\lambda = g(2\pi f^2)^{-1}$,

$\lambda = 48$cm

The length L of a floating type wave power device is 30cm.

$\lambda/L = 1.6$

The higher the wave was, the stronger the wave power obtained.

The wave power with "both a curved surface reflection board and a slope" was the strongest of all. That of "only a curved surface reflection board" was the second largest. That of "without a curved surface reflection board and a slope" was the third. That of "only slope" was the leasst.

Fig. 3 shows the transition of wave power when the wave height is set 3.5cm, and frequency is changed. The wavelength λ in each frequency of vibration and λ/L of a wave during feach number of frequency are as follows:

Wavelength of 2.4Hz waves	$\lambda = 27$cm	$\lambda/L = 27/30 = 0.90$
Wavelength of 1.8Hz waves	$\lambda = 48$cm	$\lambda/L = 48/30 = 1.6$
Wavelength of 1.6Hz waves	$\lambda = 60$cm	$\lambda/L = 60/30 = 2.0$
Wavelength of 1.2Hz waves	$\lambda = 108$cm	$\lambda/L = 108/30 = 3.6$
Wavelength of 1.0Hz waves	$\lambda = 156$cm	$\lambda/L = 156/30 = 5.2$

The wave power in the range of $\lambda/L < 2$ is higher with "only a curved surface" than in "without a curved surface reflection board and a slope." The wave power in the range of $\lambda/L > 2$ is higher with "only a slope" than in "without a curved surface reflection board and a slope." The wave power in "both a curved surface reflection board and a slope" became higher at the point of $\lambda/L > 1.6$. From these results, a curved surface reflection board increases the wave power in the range of $\lambda/L < 2$, and a slope strengthens the wave power in the range of $\lambda/L > 2$. It turned out clear that the use of a curved surface reflecting board and a slope increases wave power in the wide range of λ/L.

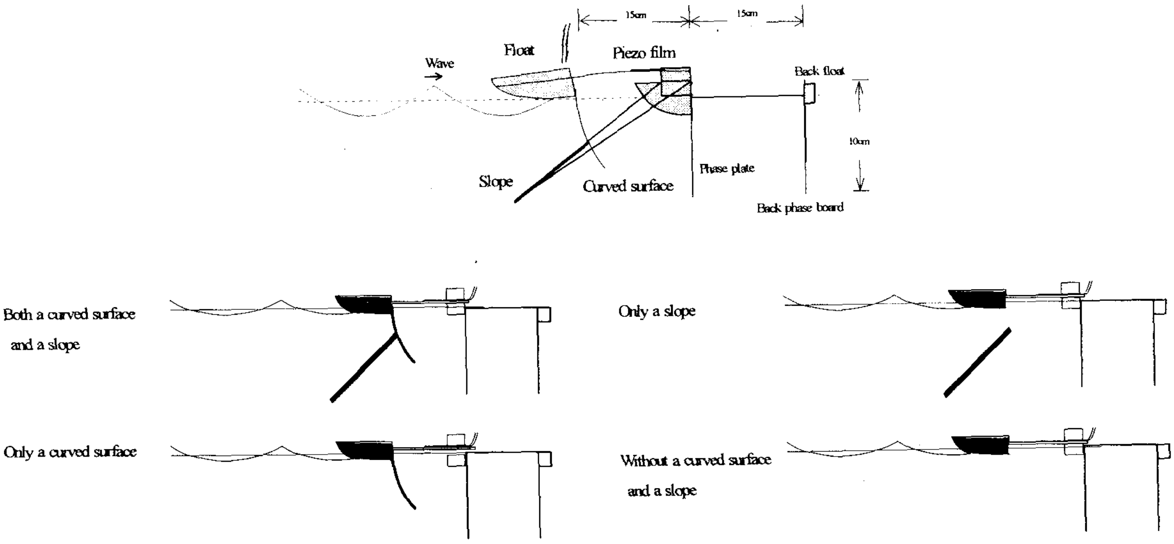
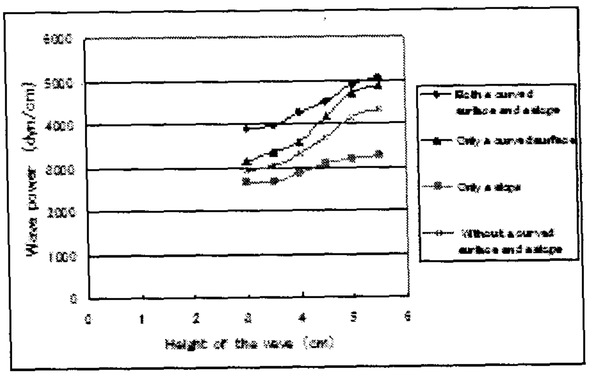


Fig.1 Floating-type wave power device
The combination of the slope and the curved surface



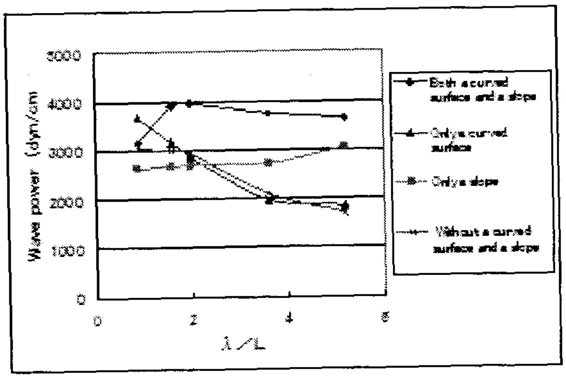


Fig.2 Wave power of the floating-type
λ/L=1.6 1.8Hz

Fig.3 Wave power of the floating-type
Wave height 3.5cm

3. The measurement of the power and efficiency of the floating-type wave power pump

3.1 Method

Photo 5 shows a floating-type wave power pump which consists of a slope, a curved surface reflection board, phase plates and a pump like bellows. The angle of a slope is 30 degrees.

Fig. 4 indicates the method which is used to measure the amount of air from the floating-type wave power pump and the depth of water D which the air reaches. From air in the wave of 20 periodic times, we calculated the amount of air V(cc/s/cm) which indicates how much air is sent in 1cm width of the float per second. Fig. 5 shows the size of the floating-type wave power pump, and all the four patterns conducted in the experiment.

The power W (erg/s/cm) and the efficiency Q (%) per cm width of the float were calculated by making use of the following formula:

$$W=\rho gVD$$

(ρ is Density of water g is Acceleration due to gravity)

$$Q=100W/E$$

Here, E is the amount of energy transmitted from waves (the wave height is H, the wavelength is λ, the velocity of wave v).

$$E = 1/8\ \rho g H^2 v$$

The graph of power and efficiency became the form of a convex parabola like the parabola of the depth of water. The MAX efficiency Q_{max} and the MAX power W_{max} are calculated by the following formula.

$$W_{max} = V_{max} D_{max}\ /4$$

V_{max} The amount of air in the sea level of 0cm

D_{max} The max depth of water which the pump was able to send air

$$Q_{max} = 100 W_{max} / E$$

E The amount of energy transmitted from the wave in unit time

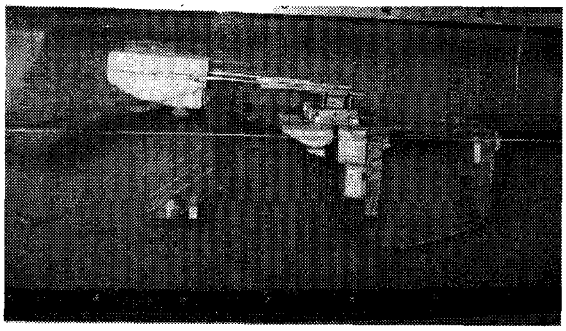


Photo 5 The floating-type wave power pump

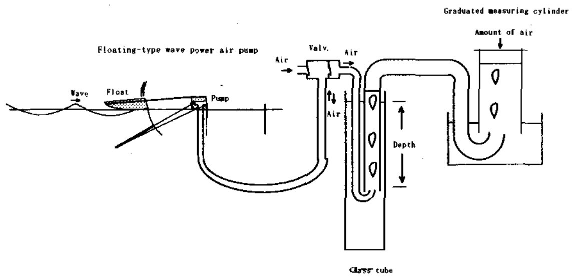


Fig. 4 The mensuration of the amount of air

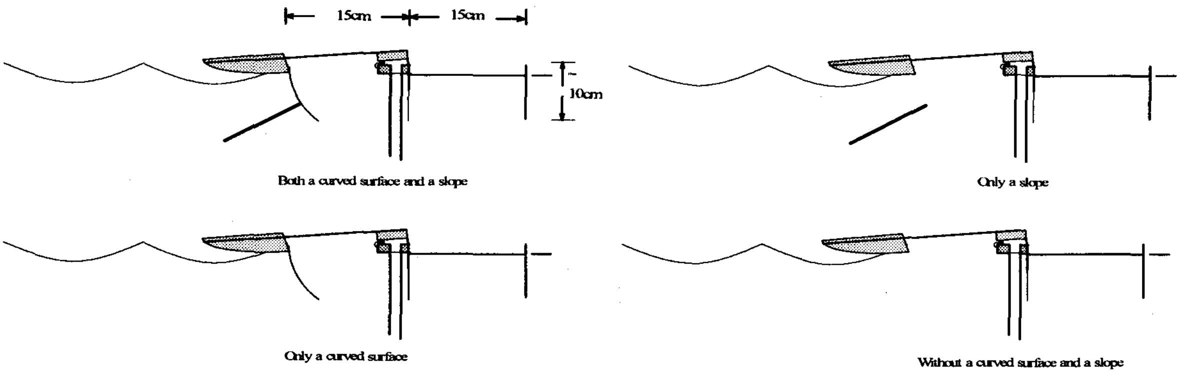


Fig.5 Floating-type wave power pump
The combination of the slope and the curved surface

3.2 Result

Fig. 5 indicates the amount of air, power, efficiency and Max power and Max efficiency when the frequency of waves is set at 1.8Hz and only wave height was changed. The amount of air linearly decreased along with the depth of water. Power and efficiency changed in the same way as the depth of water. The Max power increased in proportion to wave height. The Max efficiency slightly decreased with wave height. It was in the case of "both a curved surface reflection board and a

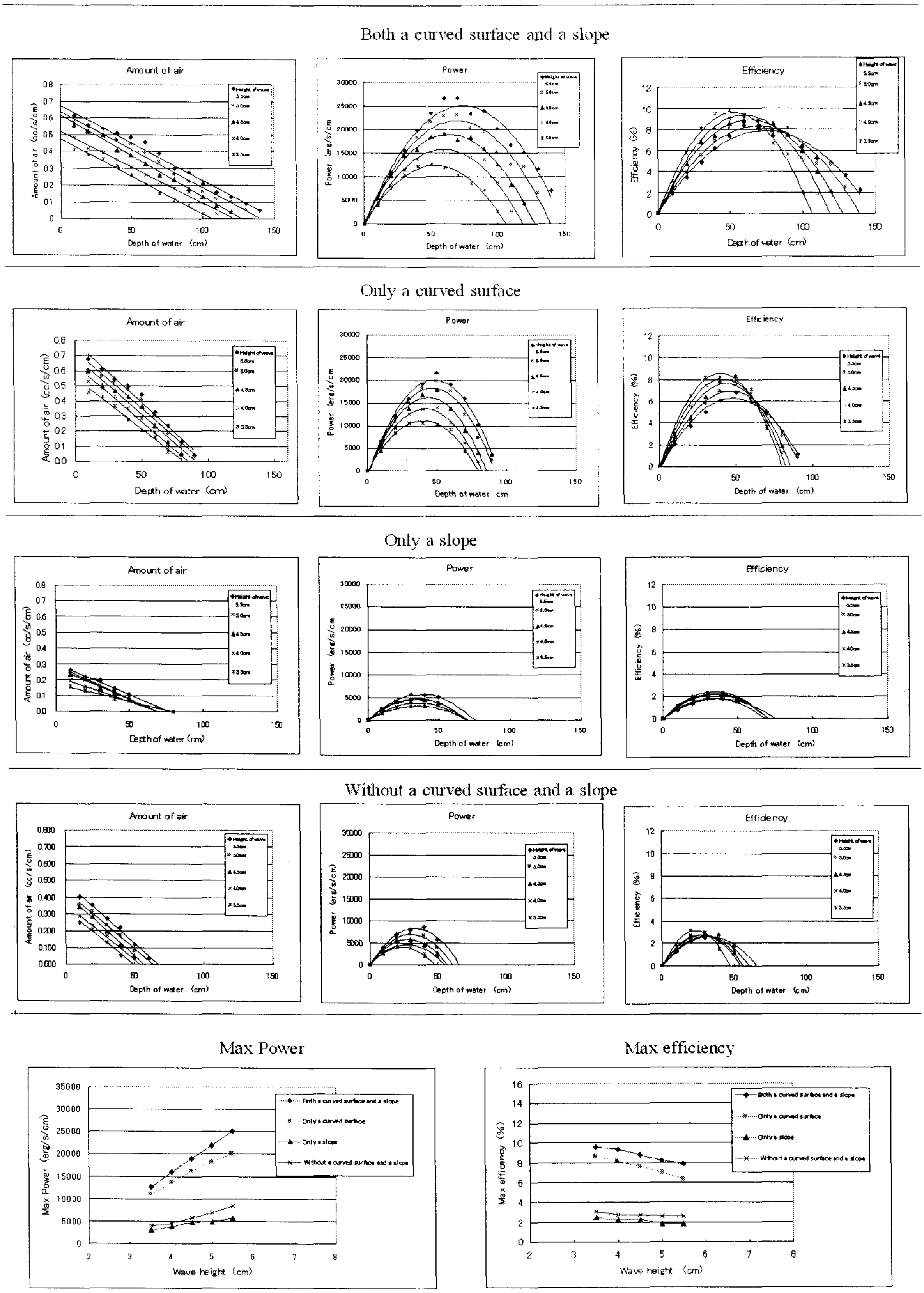


Fig. 6 The amount of air Power Efficiency (Wave 1.8Hz)

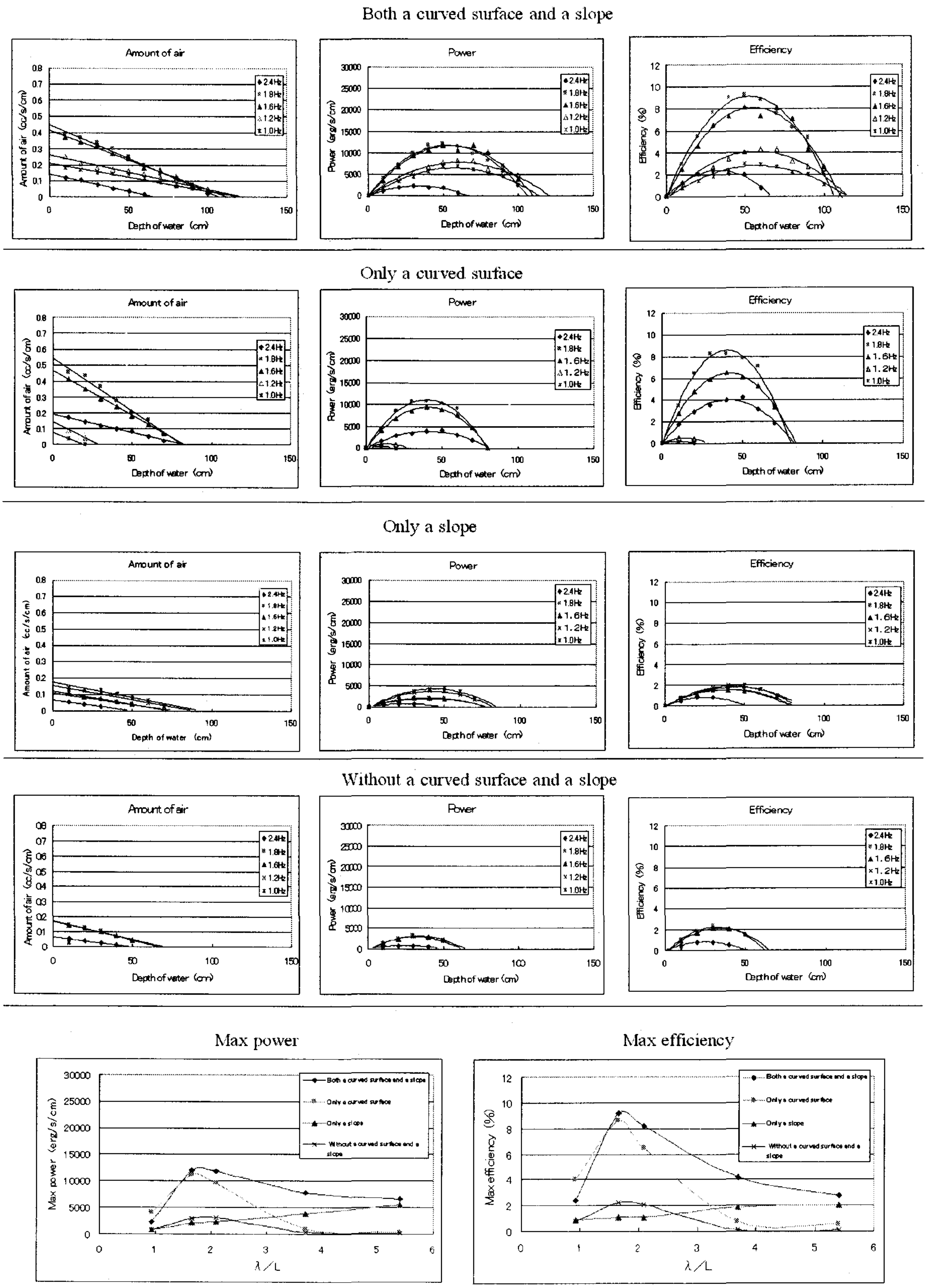


Fig. 7 The amount of air Power Efficiency (Height of the wave 3.5cm)

slope" that Max power and Max efficiency were the highest. They were the second highest in the case of "only a curved surface reflection board," and the next was in the case of "without a curved surface reflection board and a slope." It was in the case of "only a slope" that they were the lowest.

Fig. 6 indicates the amount of air, power, efficiency and the Max power and Max efficiency when the wave height was set 3.5cm and only the frequency was changed. Compared with "without a curved surface reflection board and a slope," "only a curved surface reflection board" increases in Max power and MAX efficiency. Compared with "without a curved surface reflection board and a slope," "only a slope" increases in Max power and Max in the range of $\lambda/L>2$. MAX power and Max efficiency became the highest in the range of $\lambda/L>1.6$ in the case of "both a curved surface reflection board and a slope." "Both a curved surface reflection board and a slope" became the highest in the Max power and Max efficiency of all.

From these results, we concluded as follows:

A curved surface reflecting board has an effect to raise the power and efficiency in a short wavelength of $\lambda/L<2$.

A slope has an effect to raise the power and efficiency in a long wavelength of $\lambda/L>2$.

The combination of a slope and curved surface is the mot useful for enhancing the power and efficiency in a wide range of $\lambda/L>1.6$ of all the patterns.

4. A marine experiment of a floating type wave power pump

Authors carried out a marine experiment with the students of Miyagi Onagawa high school science club from 1993 to 1994, when subsidy was received from the Japanese Institute of Technology on Fishing Ports and Communities. The result of the experiment was worth reporting. [2] At that time, they didn't come up with an idea of using a slope. Therefore, the marine experiment was conducted by using a 3 connection phase plates floating type wave power pump which had 3 connection phase plates with a float and a wave power pump which had a curved surface reflection board with a float.

4.1 The method of a marine experiment with 3 connection phase plates wave power pump

3 connection phase plate wave power pump has a structure where a float jutted from the upper part of the floating body with three phase plates. The size is 8m in full length, 1m in width and 1.5m in depth. Thedistance between the float and the axis of rotation is 1m. The compressor turned by wave power and air was sent into the sea. The compressor had 1000 cc displacement (Fig. 8).

E is regarded as the average amount of energy per unit time to unit area of waves (the wave length is H, the velocity of waves is v, the group velocity of waves is u).

$$E=1/8\,\rho g H^2 u$$

When we consider the depth of water as h, the group velocity u is calculated in the following formula.

$$u=vn$$

Only, $n=1/2+2\pi/\lambda\cdot\mathrm{cosech}(4\pi h/\lambda)$

$h/\lambda>1/2$ $\quad n=1/2$ one half. [3]

Therefore, efficiency Q in the power W of the 3 connection phase plates wave power pump can be obtained from the next formula:

$$Q=100\ W/E$$

Only, $E=1/16\,\rho g H^2 v$

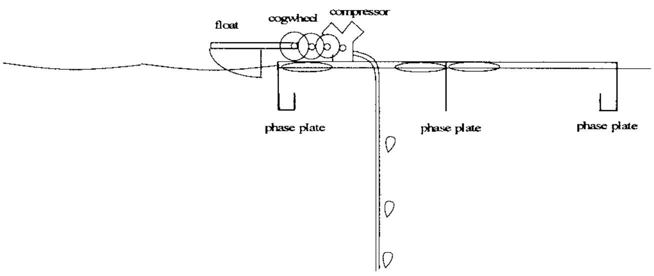


Fig. 8 Curved surface reflecting-plate wave power pump

For eight days on April 17 to 25 in 1993, one of authors and his students carried out the marine experiment, mooring one kilometer away from Kirigasaki in Onagawa-Cho, Miyagi Prefecture. (Photo 6, Photo 7).

The result of an experiment is shown in Fig. 9. The amount of air decreased linearly as the depth of water became deeper. When the 3 connection phase plates wave power pump faced southeast, and waves [the average wavelength 0.40 Hz and wave height 0.4 meter] from west (almost from the back) hit the pump, Max power was 6.7 j/s/m and Max efficiency was 2.0%. Judging from Fig. 9, Max depth of water could be 21 meter. When waves from south [the average wavelength 0.30Hz and wave height 0.2 meter] hit the pump, Max power was 8.7 j/s/m and Max efficiency was 5.6%. From Fig. 9, Max depth of water was 17 meter.

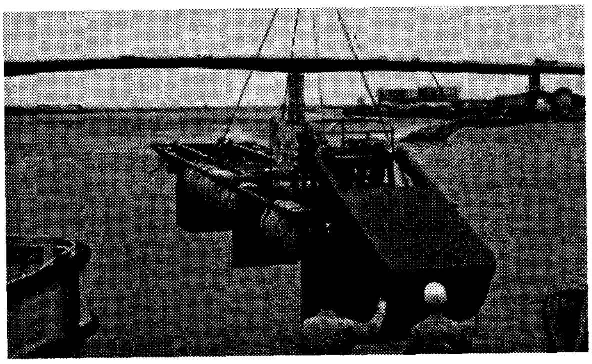


Photo 6 3 connection phase plates wave power pump

Photo 7 Marine experiment

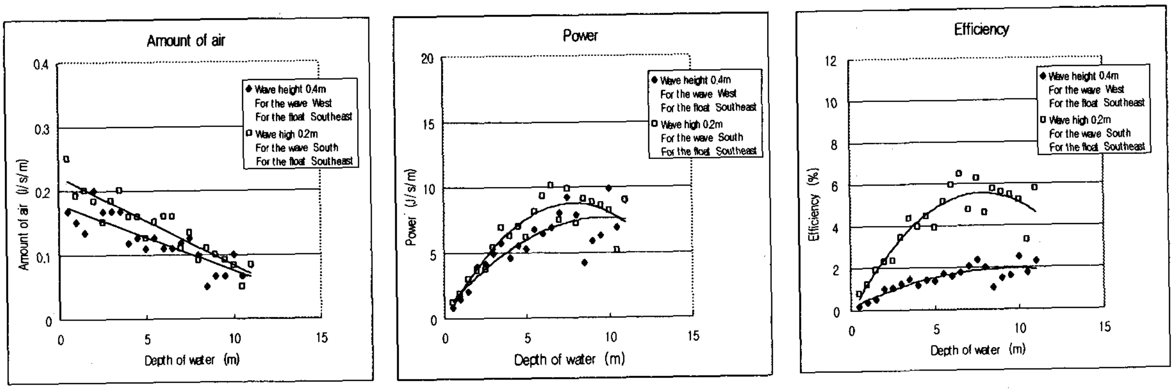


Fig. 9 Marine experiment 3 connection phase plate s wave power pump Kirigasaki,Onagawa,Miyagi,Japan

4.2 The marine experiment of a curved surface reflection board wave power pump

A curved surface reflection board wave power pump attaches a curved surface reflection board to the rear of the float, and turns the compressor of 50 cc displacement, and sends air into the sea(Fig. 10).

The size of the pump is 1 meter in width, 3.2 meter in length, and the distance between the axis of rotation and a float is 1.7meter. The curvature radius is 1.7 meter, and it jutted 0.7 meter below the lower part of the float.

On August 20, 1994, the workout of the floating-type wave power pump was conducted in the preserve for silver salmon which was 1 kilometer out in Kirigasaki. It was a quite calm day and waves were running very low. The curved surface reflection board wave power pump without any load moved along with waves caused by the ships sailing near. The float repeatedly sprang up and sank into the sea (Photo 8).

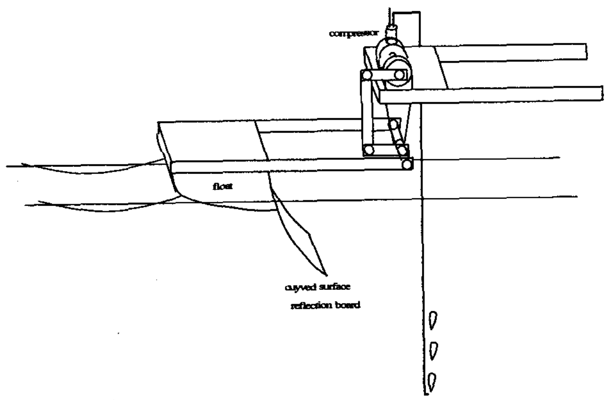


Fig. 10 Curved surface reflection board wave power pump

On September 3, 1994, an experiment was done 5 kilometer out in the Ishinomaki new fishing port by attaching the pump to the rear of the ship (8 kilogram in length and 20 ton in width).

The results of the experiment are in Fig. 11. The amount of air decreased linearly as the depth of water increases. When the average wavelength is 0.33Hz and the wave height is 0.2 meter, Max power was 10.4 J/s/m , MAX efficiency was 9.0% and Max depth of water was 20.0m. When the average is 0.38Hz and wave height is 0.4 meter, MAX power was 16.0 J/s/m, MAX efficiency was 4.0% and MAX depth of water 20.5m.

Photo 8 The movement of a curved surface reflection board wave power pump

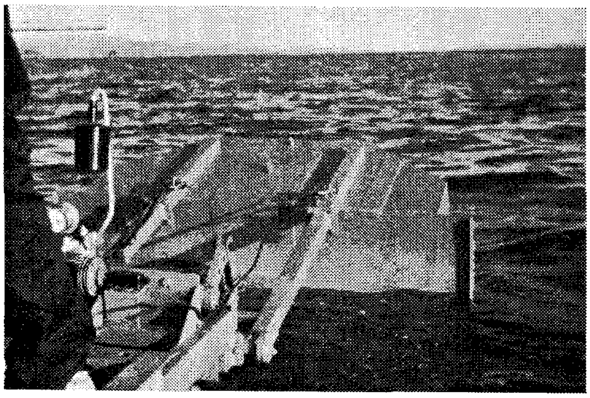


Photo 9 The curved surface reflection board wave power pump attached to the stern

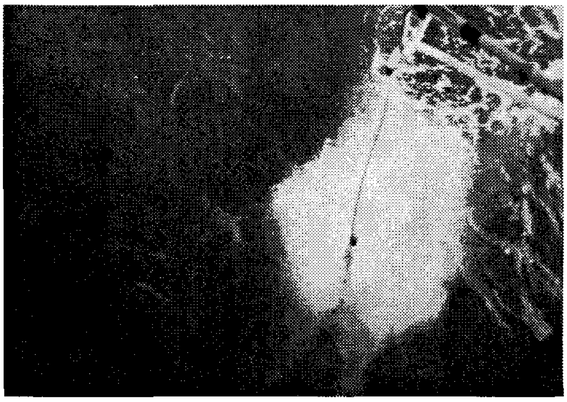


Photo 10 Signs that air comes out

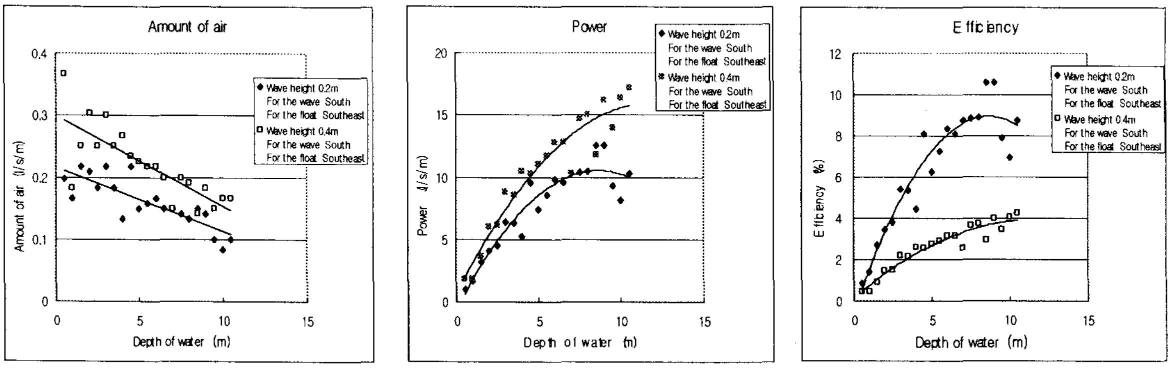


Fig. 11 Marine experiment Curved surface reflecting-plate wave power pump Isinomaki,Miyagi,Japan

5. Consideration

The curved surface reflection plate increased wave power, power, and efficiency in the short wavelengths, λ/L <2. on the other hand, it didn't work well in the case of the long wavelength, λ/L >2 and wave power, power and efficiency rapidly decreased. In the range of λ/L <2, the phase difference was so big that the phase plate pitched. In addition, wave was reflected and water pitched along the curved surface. On the other hand, in the range of λ/L >2, the phase difference between both ends of the device was small. Therefore, the device move in accordance with the movement of wave and water didn't oscillate up and down. From results of the marine experiment, when the height of wave is 2 meter and the frequency of wave is 0.30Hz and 0.33Hz, Max efficiency of 3connection phase plate floating type wave power pump was 5.6%, and that of the curved surface wave power pump was 9.0%. In the case of curved surface wave power pump, the float and the phase plate adhered to each other, so the oscillation of wave along the curved surface traveled to the float without any waste. In the 3 connection phase plates wave power pump, there is a gag between the float and the phase plates, so the oscillation didn't travel well.

The slope lowered the wave power, power and efficiency in the range of $\lambda/L < 2$, but unexpectedly raised them in the range of $\lambda/L > 2$. In general, a floating body can hardly reflect wave. Then we observed the movement of the wave power pump with the slope. Though we changed the wavelength, the phase plate didn't move up and down and the wave power pump was stable. This fact proved that the slope prevented the phase plate from moving up and down in the long wavelength waves and kept the device from synchronizing in the long wavelength waves. As a result of that, wave power, power and efficiency becomes lower in the range of $\lambda/L < 2$, but they were improved in the range of $\lambda/L > 2$. Besides, when the slope is attached to the pump, wave power, power and efficiency was low. That was because there was a gag between the slope and the float and the energy of wave gathered by the slope went out of the gap.

The combination of the slope and the curved surface reflection board raised the wave power, power and efficiency in the wide range of wavelength, $\lambda/L > 1.6$. In this combination, the slope gathered the energy of wave near the surface of water and the curved surface reflection board moved the float by the oscillation of wave. This enabled the pump to function in sending air effectively into the sea.

6. Conclusion

These experiments proved that:

(1) The curved surface reflection board attached to a phase plate played a role in increasing the power of wave in the range of $\lambda/L < 2$, enhancing power and efficiency.

(2) The slope attached to the phase plate played a role in increasing the power of wave in the range of $\lambda/L > 2$, and enhancing power and efficiency.

(3) The combination of the slope and the reflection board increases the power of wave in the range of $\lambda/L > 1.6$, and enhances power and efficiency more than any other pattern.

(4) From the results of marine experiments with the floating type wave power pump, we demonstrated that the pump could function as a device to send air into the sea with wave power and improve marine environment.

In this research, we measured wave power by using the floating type wave power device. Moreover, power and efficiency also calculated by making the floating type wave power pump sending air into the sea. The measurement proved how effective the use of the curved surface reflection board and the slope is. In addition to that, it also proved that the combination of the slope and the reflection board and the phase plate the effect of curved surface enabled us to utilize the power of wave in wider range than before. Moreover, the results of the marine experiment demonstrated that the floating type wave power pump could send air into the sea and it also could function as a fish preserve for cultivation and a device to increase the amount of dissolved oxygen.

We would like to more closely analyze the effect of using the slope, the curved surface reflection board, and the phase plate by finely dividing the wavelength. We also hope to make it possible to use the floating type wave power pump for pumping up and power generation.

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