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Current R&D Status of Wave Energy Utilization in Japan

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Abstract- *R&D activities on wave energy utilization in Japan began in the 1970s, after oil crisis. Many open sea tests for technologies for extracting wave energy have been performed. In Japan, there have not been large research projects after the Mighty Whale offshore floating wave-power device project ended in 2003. However, recently, R&D activities on wave energy utilization in Japan started again as a consequence of recent oil price and global warming. In this paper, current R&D status of wave energy utilization in Japan and R&D activities in Saga University for two types of floating wave energy converters, namely, "Backward Bent Duct Buoy" and floating pendular type WEC are explained.*

Keywords: Wave Energy Converter, Japan, Research and Development

1. INTRODUCTION

Recently, many types of wave energy converters (WECs) based on various concepts have been proposed in the world. In Japan, a large number of R&D on wave energy conversion systems have been carried out since the oil crisis of 1973. Especially, R&D on oscillating water column (OWC) type WEC, which is safe under the extreme wave conditions such as the typhoon, has been mainly carried out. However, no system has been employed as a practical power plant due to cost of the system and fluctuation of the electric output.

Recently, R&D activities on the wave energy utilization in Japan are resumed as the consequence of recent high oil price and global warming. Ocean Energy Association – Japan (IOES-J) was also established in March, 2008 to promote the ocean energy utilization in Japan.

In this paper, 1) R&D in a past on wave energy in Japan, and 2) recent R&D on wave energy in Japan, especially, R&D activities in Saga University including two types of floating WECs, namely, "Backward Bent Duct Buoy" and floating pendular type WEC are explained.

2. PAST RESERCHES ON WAVE ENERGY

Practical R&D on a wave energy converter (WEC) in Japan is traced to that of Yoshio Masuda who is an inventor of WEC for a navigation buoy. In Japan, the researches on various WEC were carried out. Following researches were conducted in the past (JAMSTEC [1]).

2.1 Fixed OWC- type WEC

Research Development Corporation of Japan carried out the field tests for onshore fixed type wave energy device at Sanze coast in Yamagata prefecture (1983-1984) (Fig.1). About 11kW was obtained as an average power in winter season. Two wells turbines were placed.

Fig.1 Fixed OWC - type WEC "Sanze"

"Wave-activated heat-recovery system" was tested at the fishing port of Neya in Niigata Prefecture by Taisei Corporation and got the heat energy of 1-3kW/m (1986-1987) (Fig.2). Wave energy was converted into thermal energy by using Wells turbine and heat exchanger.

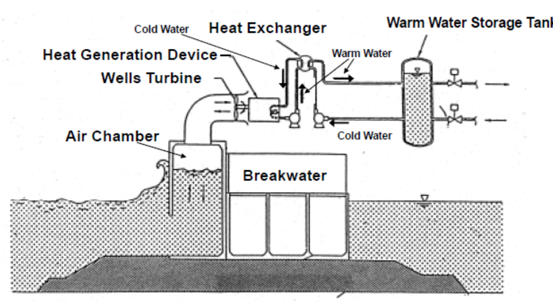


Fig.2 Wave-activated heat-recovery system

"Hydraulic-valve-integration wave power generation system” was tested on Thermal Power Plant at the Haranomachi breakwater in Fukushima Prefecture by the Tohoku Electric Power Co. The oscillating air flow by the OWC-type WEC is rectified using the hydraulic-valve sealed using water head difference.

- “Wave-breaker type wave power generation system with constant pressure tank” was used in experiments on the coast near Katagai in Chiba Prefecture by the Engineering Advancement Association of Japan (1987-1996, Fig.3). The compressed air obtained in multiple air chamber of OWC type wave energy converter is collected in the constant pressure tank and smoothed the variability.

Fig.3 Wave-breaker type wave power generation system with constant-pressure-tank

- “Wave-power-extracting caisson” was tested at the northern breakwater of the Port of Sakata in Yamagata Prefecture by the Ministry of Transport’s First District Port Construction Bureau (1988-1999) (Fig.4). The detailed research was carried out by the port and harbor research institute and the design technique of this caisson was proposed.

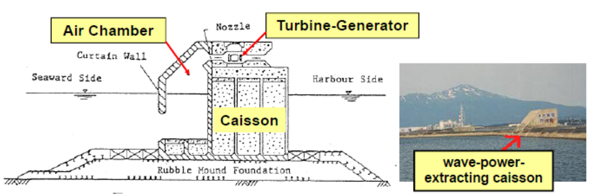


Fig.4 Wave-power-extracting caisson

2.2 Floating OWC- type WEC

- ”Navigation buoy” invented by Masuda has a cylinder in the center where the water surface oscillates compressing and expanding the air in the above the water and rotated the turbine (Fig.5). The air flow is rectified by air valves. More than 1000 navigation buoys of this type were employed in the world since 1965 although the power output is small, 10 to 500w each.
- “Kaimei” which had a vessel-shaped floating structure, was tested by JAMSTEC off the coast of Yura in Yamagata Prefecture (1978-1980, 1985-1986) (Fig.6). 13 air chambers were installed in a ship of 80m long and 12m wide.
- “Mighty Whale” which was a offshore floating OWC, was tested off Gokasyo Bay in Mie Prefecture by JAMSTEC (1998~2003) (Fig.7) .

Fig.5 Navigation buoy Fig.6 Kaimei

Fig.7 Mighty Whale

2.3 Moving body-type WEC

- ”Fixed Pendular-type WEC” was tested off the breakwater of Port Muroran by the Muroran Institute of Technology (1983 ~2000, Fig.8).

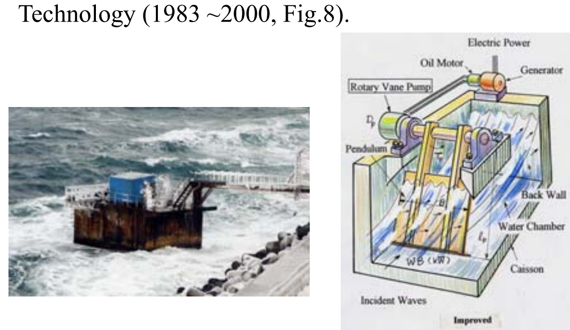


Fig.8 Fixed Pendular-type WEC

- “Kaiyo” which was a floating-type WEC using the actuator and oil pressure, was tested off Iriomotejima Island in Okinawa Prefecture by the Japan Shipbuilding Industry Foundation (1984~1986)

3. RECENT R&D ON WAVE ENERGY IN JAPAN

Recently, the following researches on WEC have been done.

3.1 OWC type WEC

(1) Air turbine for OWC-type WEC

Matsue National College of Technology, Saga University and Ministry of Land, Infrastructure and Transport carried out a sea trial of the fixed OWC-type wave power plant using impulse turbine with coreless generator at the breakwater of Niigata-nishi Port in Japan (Takao et al. [2], Fig.9). As shown in Fig.10, this impulse turbine has fixed guide vanes both upstream and downstream. The tests for Wells turbine were also done. It was concluded that the impulse turbine is superior to Wells turbine as the air turbine for wave energy conversion and a coreless generator generates the electricity at lower rotational speed in comparison with the conventional generator.

Fig.9 Fixed OWC-type WEC plant

(a) Impulse turbine with guide vanes (b) Wells turbine

Fig. 10 Two types of air turbines

(2) Multi-resonance, fixed OWC-type WEC

JAMSTEC and Nihon University proposed muti-resonance, fixed OWC type WEC with side walls (Fig.11) and showed that the side walls are effectiveness very much in order to enhance the primary conversion efficiency (Fig.12, Ikoma et al. [3]). In Fig.12, η is the primary conversion efficiency which is defined as a ratio of the air power to incident wave power,λwavelength, L overall length of model. In this figure, 1/200 and 1/300 show the open ratio of the nozzle.

Fig.11 Fixed OWC-type WEC with side walls

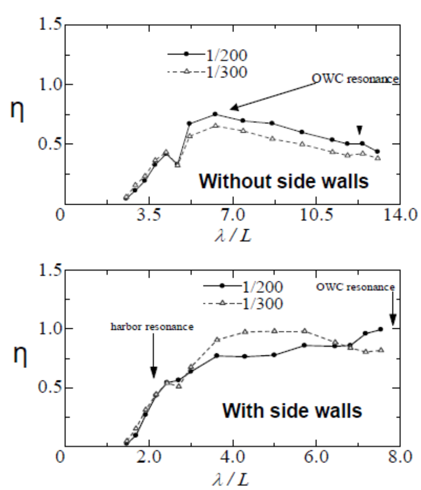


Fig.12 Effect of side walls on primary conversion efficiency

(3) Research of floating OWC-type WEC “BBDB” in Saga University

In Saga University, fundamental research of floating OWC-type WEC “Backward Bent Duct Buoy (BBDB, Fig.13)” proposed by Masuda is being carried out, such as conversion efficiency and drift force acting on BBDB. This device has some advantages, that is, i) the primary conversion efficiency is higher than other floating OWCs, ii) as the wavelength λ that the primary conversion efficiency is maximum is about four times length L of the BBDB, a longer floating structure is not required, iii) as the BBDB slowly advances against wave propagation direction in particular wave frequency range, the mooring force and mooring cost are reduced in irregular sea.

Toyota el al. [4] carried out tank tests for the primary conversion efficiency η for a small scale BBDB model as shown in Fig.14. Fig.15 shows the 2D and 3D experimental results for primary conversion efficiency in head seas. The primary conversion efficiency in 3D test, whose maximum value is about 1.0, is larger than that of the 2D test because of the wave diffraction from the corners of BBDB.

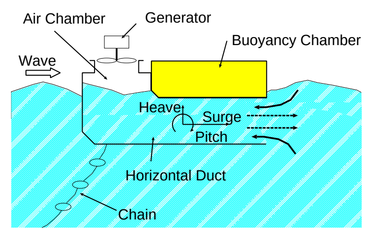


Fig.13 Schematic diagram of floating OWC-type wave energy converter “BBDB”

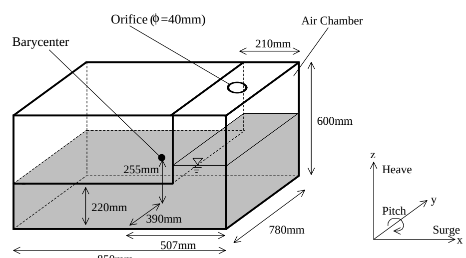


Fig.14 BBDB model used in wave tank test

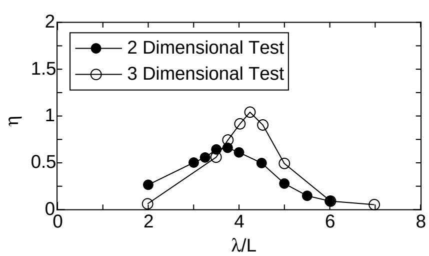


Fig.15 Primary conversion efficiency

Saga University, Matsue National College of Technology carried out the generating test of medium scale BBDB model with impulse turbine in wave tank at Kyusyu University (Imai et al. [5]). The size of this model is 2.5m long, 2.3m wide and 1.8m tall (Fig.16). An impulse turbine with guide vanes, which is developed by Saga University and Matsue National College of Technology, and generator are mounted in this model. Fig.17 shows the generating efficiency η_e which is defined as a ratio of the generating power to incident wave power.

(a) Medium scale BBDB model

(b) Impulse turbine with guide vanes

Fig.16 Generating test of medium scale BBDB model

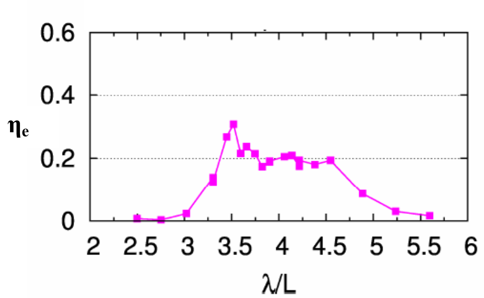
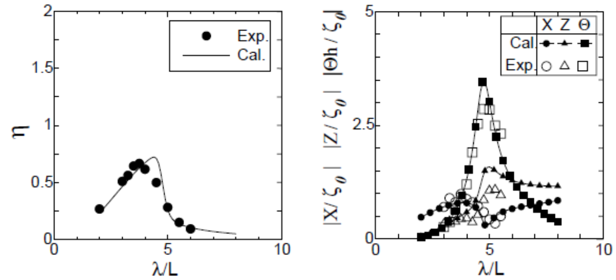


Fig.17 Generating efficiency

A vast number of tests are needed to find an optimal hull shape experimentally. So, this requires a numerical analysis code to estimate the motions of the floating body and mooring system, the fluctuation of air pressure in the air chamber and the rotational speed of the turbine in waves. Nagata et al. [6] proposed a two-dimensional numerical method to estimate the primary conversion efficiency of a floating OWC-type wave energy converter with arbitrary cross section in frequency domain. The fluid force by water waves is calculated by using boundary element method based on velocity potential theory. For the air flow in air chamber, equation of state and the conservation of mass and energy with the assumption of air being the perfect gas are used. They showed that calculated results for the transmission coefficient, air pressure and free surface elevation in the air chamber, motions of BBDB and primary conversion efficiency are good agreement with the experimental results. Fig.18 shows comparison between numerical and measured primary conversion efficiency and motions of the BBDB model in regular waves. In Fig.18, X, Z and Θ denote the complex amplitude of surge, heave and pitch motions of the BBDB, respectively. ζ_0 is the amplitude of incident wave, L the length of BBDB.

Nagata et al. [7] showed the equations of motion of a floating OWC-type WEC in time domain using the impulse response matrix by body velocity and air pressure in air chamber. The retardation functions for the air pressure in these equations of motion are expressed by the hydrodynamic coefficients for air pressure and its derivatives in frequency domain. Numerical results on exciting forces and radiation forces by boundary element method which are base of this time domain calculation were compared with experimental results.



(a) Primary conversion efficiency

(b) Motions of BBDB

Fig.18 Comparison between numerical and experimental results for BBDB model

Imai et al. [8] carried out two-dimensional wave tank tests in regular waves to clarify characteristics of drift force acting on the BBDB and discussed the mechanism of generation of horizontal negative drift force (Fig.19).

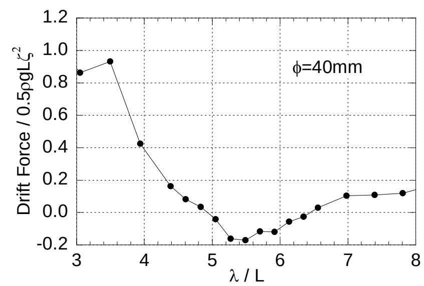


Fig.19 Drift force acting on BBDB

3.2 Moving-body type WEC

(1) Wave power generation by using gyroscopic moment

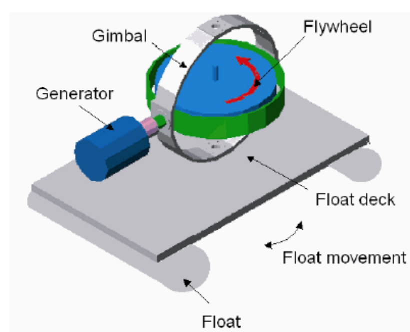


Fig.20 Principle of gyro wave power generation system

Gyrodynamics Co., Tottori University and Kobe University are developing a floating gyro wave power generation system (Kanki et al. [9]). Fig.20 shows the concept of this device. This device consists of a float and a gyroscope. In the gyroscope, a flywheel supported by a gimbal rotates at high speed and the gimbal is directly connected to a generator. The rolling of the float caused by waves generates gyroscopic moment at the flywheel. The gyroscopic moment rotates the gimbal and generator. As the results, wave energy is converted into electric energy. 45kw prototype system was tested at Susami port in Wakayama prefecture in Japan as shown in Fig.21 and the output power of max. 30kW (Wave height: 2.5m, Wave period: 5sec.) was obtained.

Fig.21 Open sea test of 45kW prototype

(2) Float-counterweight type WEC

Yamaguchi University is developing the float-counterweight type wave energy converter as shown in Fig.22 (Hadano et al. [10]). This device consists of a float, counterweight, cable, driving pulley, ratchet, gearbox and generator. The mechanism of energy transfer is basically the conversion of the heaving of the float mass into a rotational motion of the shaft connected to the electric generator. The ratchet mechanism converts the bi-directional rotation of the driving pulley into a unidirectional rotation of the shaft which is then accelerated by gearbox. Tank tests for the circular cylinder float with a diameter of 2m were carried out as shown in Fig.23. The numerical model to calculate the power output of this device was also proposed.

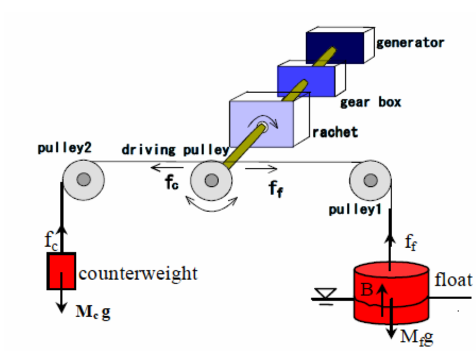


Fig.22 Schematic diagram of float-counterweight type wave energy converter

Fig.23 Experimental setup

(3) Wave energy device using electroactive polymer artificial muscle

Chiba et al. [11] proposed a single buoy type WEC using Electroactive Polymer Artificial Muscle (EPAM) which is a rubbery material that can generate electricity by simply being stretched and allowed to return to its original shape. They carried out the sea trials off the coast of Florida and showed that this device were able to generate a peak power of 1.2W with an average power of 0.25W using EPAM of 300g.

Fig.24 EPAM generator system on the test buoy

(4) Research of floating pendular-type WEC in Saga University

In Saga University, fundamental research of floating pendular type WEC proposed by Watabe as shown in Fig.25 (Watabe [12]), such as motions of floating body and conversion efficiency is being carried out.

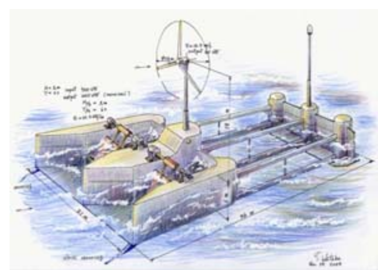


Fig.25 Floating pendular-type WEC proposed by Watabe

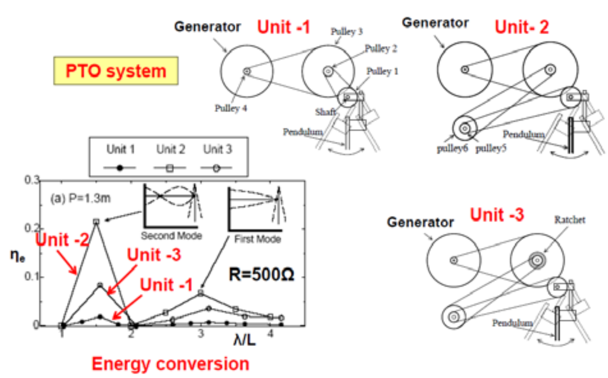


Fig.26 3 kind of PTO system and generating efficiency

Watabe proposed a rotary vane pump as power take-off system. However, as it is difficult to make its model, we used systems using pulley and belt. Fig.26 shows the three kinds of PTO systems (Unit-1, Unit-2 and Unit-3) and generating efficiency in the case of electric resistance R=500 Ω (Toyota et al. [13]). From the result of free oscillation tests for Unit-2 PTO system, it is found that the secondary conversion efficiency is about 0.5 (=50%). Therefore, from the generating efficiency on Unit-2 PTO system in Fig.26, the primary conversion efficiency η as shown in Fig.27 is obtained. In order to find an optimal shape of this device, a numerical analysis code to estimate the motions of the floating body and pendulum, the energy absorption of the PTO system in waves is required.

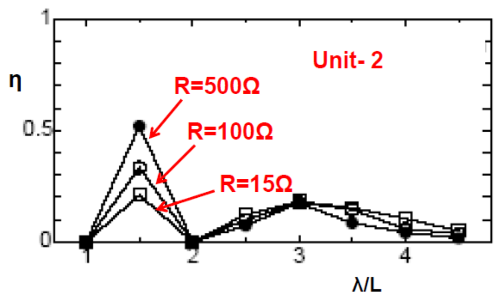


Fig.27 Influence of electric resistance on primary conversion efficiency

3.3 Overtopping type WEC

Taiyo Plant Co., Ltd and Tokai University proposed a conical floating overtopping-type wave energy converter called "Floating Beach". They conducted a tank test regarding the water flow characteristics of this device with wave-absorbing and water-flow features (Tanaka et al. [14]). The field test for a conical floating body with a diameter of 2.7m was also carried out in port of Yokohama.

Fig.28 Overtopping-type WEC "Floating Beach"

4. CONCLUSION

In this paper, current R&D status of wave energy utilization in Japan is explained. Since it has been recognized that ocean wave has a big energy, it seems that R&D on wave energy in Japan will become active more and more in the future.

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