CHAPTER 357

FAESIBILITY TESTS OF NEW PENDULAR-TYPE WAVE ENERGY CONVERSION APPARATUS

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Abstract

In order to utilize natural energy,it is essential to develop a fully compatible system, instead of conventional power- generating systems.

The authors proposed a new pendular-type wave power generation device. Design criteria for a new rotary vane pump systems (NRVP) was studied for several years and a 5-kW-model test plant with a large displacement of 45.9 l/rev pump was established. This simplified pendular system was considered to limit the investment costs. This paper describes the new pendular-type converter and its components, and presents observation data obtained in field tests conducted at sea.

1. Introduction

As Japan is largely dependent on fossil fuels such as coal and petroleum for energy, transition to nuclear power and others non-fossil fuels is being undertaken. Efforts should be made to find energy-saving techniques or new energy sources in order to ensure future development while protecting the earth's environment. It is essential to switch to clean and natural energy sources such as solar radiation, wind power and wave power.

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However, these sources have problems regarding cost and generation capacity limitations. The biggest obstacle to the practical use of clean and natural energy sources is their generating costs compared with those of fossil fuels.

To address this problem, a new, pendular-type wave energy conversion device, named Pendulor by the authors, was developed.

In 1981, the first device[1),3)] (20 kW) was installed on a breakwater at the Port of Mashike in a collaborative development project involving the Town of Mashike, the Muroran Institute of Technology and Hitatchi Zosen corp. Full-scale feasibility tests were conducted .

Following these tests, in 1983 a research group from the Muroran Institute of Technology made the first experimental test device by improving the existing one, and conducted test plant experiments. The tests achieved the expected results and the device was proved to be efficient in wave energy conversion. But it was absolutely necessary to further reduce the power generation costs. Therefore, based on the past research and development results, a new, remarkably improved wave energy conversion device was built under a new research plan. Field tests were conducted at sea.

2. Outline of new pendulor device

Wave energy conversion devices can be largely classified into OWC(Oscillating-wave-column) and pendular-types. The principal of the device is shown Fig.1.

Horizontal standing wave motion is converted to motion of the pendular plate, which is then converted to reciprocating rotary motion of a vane -type rotary pump directly connected to the pendulum. This rotation feeds hydraulic oil to the hydraulic motor and drives the generator.

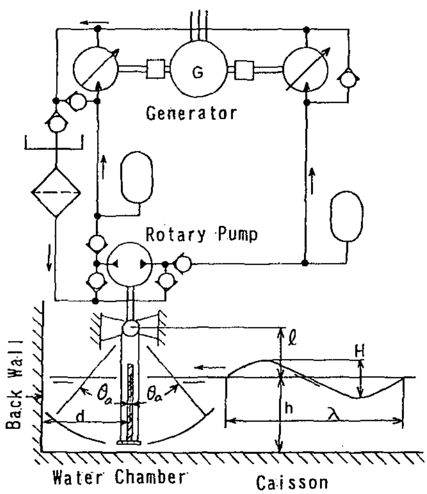

Fig. 1 Principle of the device

Figure 2 shows the original pendular device [4),8)] which had a cylinder pump. It was used to drive an oil motor-generated set.

Since the pendulum actuated the pump , both were fixed on a common bed lest the caïsson suffer from the huge reaction of the pump. When the pump and pendulum were coupled together at sea, the system became dangerous because the pendulum moved whenever incident waves exited it. A water gate as illustrated as in the figure was required.

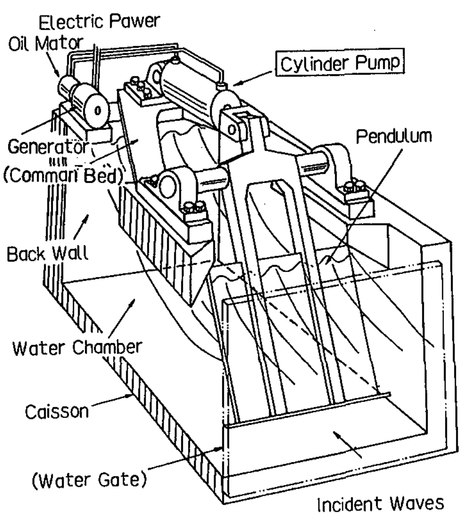

Fig.2 Original pendular device

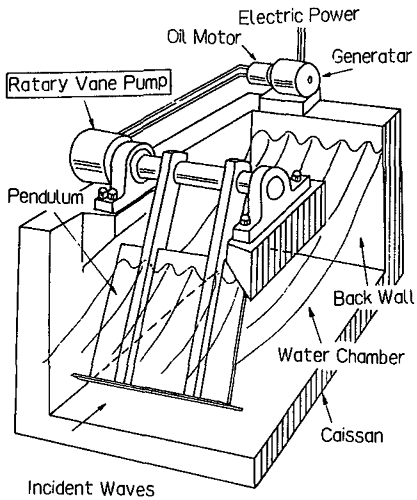

Fig.3 New pendular device

In order to improve cost efficiency, simple combined feature was invented in which a rotary vane pump was coupled with the pendulum.

A long shaft was used to support both the pump rotor and the pendulum, having no coupling component. There were 3 bearings on the shaft, 2 of which were for the pendulum. This combination makes for easier installation work than with the previous model. This system was called a new pendular device[2),5),6)] as seen in Fig.3.

This large-capacity vane -type pump offers the following advantages:

1) The features of the pendular system can be simplified through an integrated pendular plate and rotary vane-type pump.
2) Energy generation costs can be reduced through simplification of installation work at sea.
3) High-wave resistance of the pendular system is also improved.

3. Design of new rotary pump and pendulum

3.1. Rotary pump

Displacement D_P of the pump, which consists of 2 vanes, is described in the following equation, assuming it is the same as the previous pump.

where D_P displacement of the pump

$$D_P = \frac{\pi}{2}(d_1{}^2 - d_1{}^2)B = 2\pi A_P r$$

d_1 vane tip diameter
d_2 rotor cylinder diameter
B vane width
A_P piston area (cylinder pump)=$98.17\times10^{-4}m^2$
r arm radius =0.6 m

The leakage is prevented by the metal seals. As leakage is proportional to the total seal length Lp, a pump having greater value of Dp/Lp(displacement/total seal length) can operate more efficiently.
Dp/Lp is shown in the next equation[7]:

$$\frac{D_p}{L_s} = \frac{\pi\{(d_1/d_2)^2-1\}d_1{}^2}{4\left(2\frac{d_1}{d_2}+\frac{d_1}{W}\left(\pi+\frac{d_1}{d_2}-1\right)\right)}$$

where W vane width

Through the results of the research, the following equation was determined to provide the optimal profile of the pump[7]:

$$\frac{d_1}{d_2} = \sqrt{\frac{(0.36\sim0.46)(d_2/W)\tau_s}{P_{max}}+1}$$

where $d_2/W=1.0\sim1.2$, τ_s is shearing stress of the shaft, P_{max} is maximum delivery pressure of the pump.

Applying the research results, the test pump shown in Fig.4 was designed.

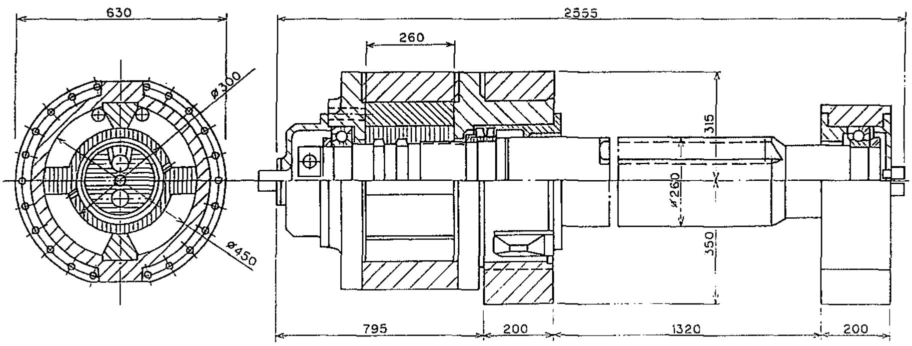

Fig.4 New rotary pump

Its specifications arc arranged in Table 1.

Table 1 Specification of the NRVP

Input: $\eta_1 E_1$=16.6kw	Displacement: Dp=0.0459m^3/rev
Vane tip diameter: d_1=0.45m	Rotor cylinder diameter: d_2=0.30m
Vane Width: W=0.26m	Shaft diameter: ds=0.232m
Movable angle: θ max=65°(both sides)	
Pressure(mean/max.): P_{mean}/P_{max}=12.8/25MPa	

3.2. Pendulum

The power E_1 produced by the pendulum can be determined with the following equation[7]:

$$E_1=1/8\times\rho\ g\ H^2 C_g B\ \eta_1$$

where H is wave height = 1.5m , ρ is density of water =1,030kg/m^3, g is acceleration of gravity =9.81 m/sec^2, C_g is group speed of the incident waves=3.46m/s(wave period 4s, water depth:h=2.75m), B is width of the pendulum in water=2m, η_1 is conversion ratio from wave power to pendular power=80%.

In this case, these parameters were adopted in the design, and then it was decided that E_1=16.6kW.

In design, amplitude of pendular motion θ a was established using the following values.

θ a=M/(ω N)=0.285rad(16.3°) at no load operation

θ a =16.30°×0.625°=10.20 at optimal load operation

where M is amplitude of exiting moment =370KNm, N is load factor by wave generation =828KNms, ω is circular frequency of wave =1.571rad/s (T=4s).

As seen in the pendular device shown in Fig.5, the basic style was not changed significantly, though the pendulum is more durable in storms with its rubber tires of heavy track's, it can swing wider

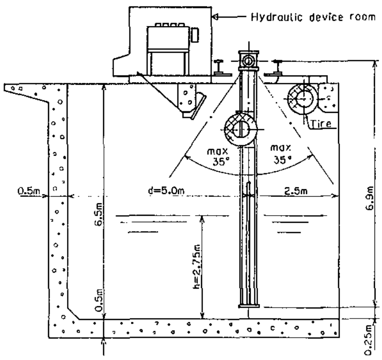

Fig.5 Test pendular device

and more reliable to absorbing shock loads.It is expecting to be relatively maintenance free.

In order to prevent electro-chemical corrosion, the shaft was connected to the earth through brushes and zinc plate were fixed to the pendulum surface and incorporated into the vane- type rotary pump.

3.3.Installation

The device was installed using a large crane in August 1994,on the caisson of the Muroran Institute of Technology around the exterior of the south breakwater in the Etomo area of Muroran. The installation was completed within 2 hours, not included preparation of a gate.

Muroran is centrally located on the middle of Hokkaido and faces the Pacific Ocean. The water in front of the breakwater is approximately 4.0 m in depth. Because of the port's location in a bay, incoming waves are small. The largest significant wave was 2.7 m high and its period was 5.4 second. The mean wave direction was west northwest. Photo 1 shows the installation of the device. Fig.6 shows the location of the port of Muroran.

Photo 1 Installation work

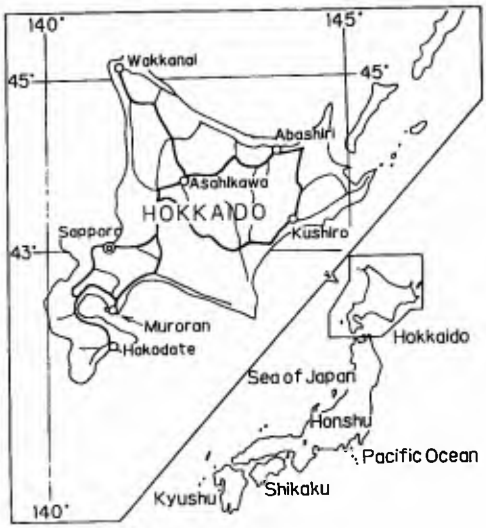

Fig. 6 Location of Muroran port

4. Measurement of the new pendular-type wave conversion device

Measurement were made at 8 points: ① Pump pressure (4 points). ② Motor axis torque (1 point), ③ Motor axis rotation speed (1 point), ④ Pendulum gradient (1 point), ⑤ Wave recorder (1 point).

Eight patterns were successively measured, with load condition changed every 20 minutes .The data was stored on a CVS-type disk. Figure 7 shows the interior structure of the observation system.

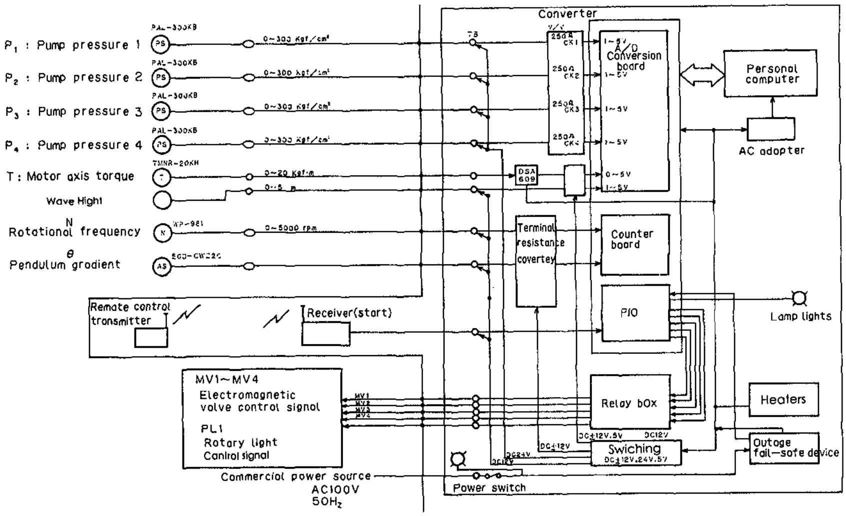

Fig.7 Observation instruments and wiring diagram

5. Observation of the new pendulor-type wave energy conversion device

The new pendulor-type wave energy conversion device was produced and tested in accordance with the development schedule shown in Fig.8.

The device was produced in 1993 and 1994. It was installed at the site, along with observation instruments, and ancillary electrical work was carried out before conducting observations.

	1993	1994	1995	1996	97~98
Development of device					
Testing					
Data analysis					
Other					

Fig.8 Research and development schedule

The device was installed in August 1994 in front of the port of Muroran shown fig-6. Since then, tests have been conducted for 20 months. In order to analyze efficiency , measurements were conducted at 8 points during operation. The data is presented in Table1. Figure 9 shows spectrum response of the system . Two spectrums, wave and angular displacement of the pendulum, showed a close correlation.

Year / Date	95 11.8	95 11.8	96 1.04	96 1.07
$H_{\frac{1}{3}}$ (m)	2.52	2.53	2.36	2.63
$T_{\frac{1}{3}}$ (sec)	6.45	6.57	6.04	5.93
Wave Power (kw)	14.426	14.727	14.125	18.401
Primary Conversion Efficiency (%)	61.71	56.0	53.55	42.16

$H_{\frac{1}{3}}$ Wave Height, $T_{\frac{1}{3}}$ Wave Perid

Table 1 Observation data

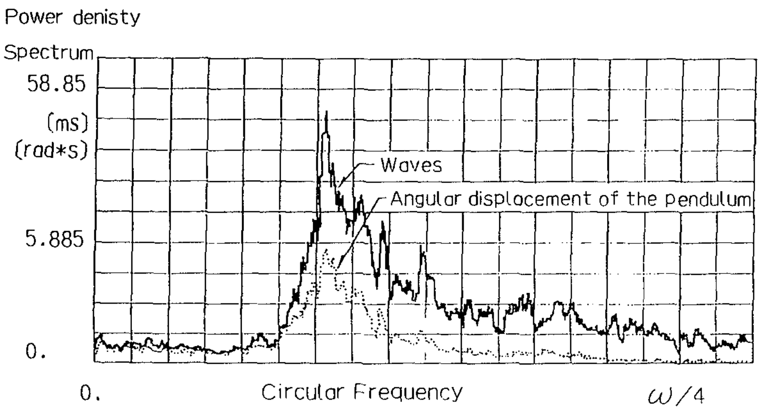

Fig.9 Responsiveness of the system

Figure 10 shows the efficiency of the new pendulor. The efficiency η_1 is shown in relation to wave period,$T_{1/3}$. It can be seen that η_1 =0.5～0.9, and it reaches peak value at approximately $T_{1/3}$ =4.5～5.2second.

During the field test ,the pump operated without a breakdown, but pump efficiency was only 27-37%.

No contamination of the oil has been observed, so it is presumed the cause of low efficiency may be malfunction of the seal .

Besides the power conversion test, remarkable durability of the pump has been proved .There were no troubles around the pendulum or the pump such as loosening of bolts , leaking of oil or wear of sliding parts.

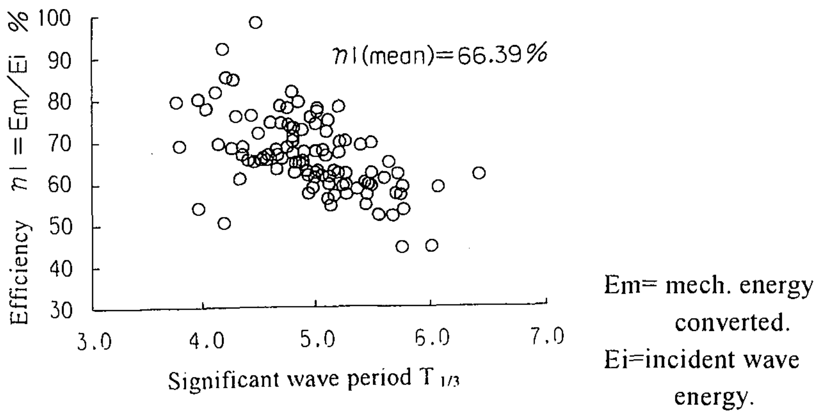

Fig.10 Efficiency of the new pendulor

6.Conclusions

Through testing of the new pendular device , the following conclusions were obtained.

1) The new rotary-vane pump system proposed for the pendulor makes installation easier, without the need for a water gate. It can lower energy costs.
2) The new pendular system improves durability not only for the pump, but also for the pendulor.
3) Efficiency of the new pendular was approximately 50~70 %(It was the same as the old pendulor coupled with a cylinder pump.)
4) Pump efficiency did not achieve the predicted value, as derived in the indoor test.

Therefore, there is still the need to solve the problems regarding pump efficiency and the seals on the pump unit. Further research to this end is expected .

After a great deal of research and development, the new pendular system was realized. It employed unique technique developed in Hokkaido, and which must be further developed. To put the device to practical use, we must continue field tests. Observation data, particularly that for durability and efficiency versus load, will be collected for application in design.

Acknowledgments

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