International Conference on Renewable Energies and Power Quality (ICREPQ'13)
Bilbao (Spain), 20th to 22th March, 2013
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.11, March 2013

Guide Vanes for Darrieus Water Turbine in Tidal Current

Koju Hiraki*, Kohei Nishida*,Ryo Wakita*,Manabu Takao**, Toshiaki Watanabe***
*Kyushu Institute of Technology
1-1 Sensui, Tobata, Kitakyushu, Fukuoka 804-8550, JAPAN
**Matsue College of Technology
14-4 Nishiikuma, Matsue, Tottori, Shimane 690-8518, JAPAN
***National Fisheries University
2-7-1 Nagata-Honmachi, Shimonoseki 759-6595, JAPAN

Contact Information: Koju Hiraki, Associate Professor
E-mail: hiraki@mech.kyutech.ac.jp
TEL: +81 93 884 3154
FAX: +81 93 871 8591

ABSTRACT

On purpose to enhance the performance of a Darrieus-type water turbine for the power generation using a tidal current, the technique with guide vanes were applied. The guide vanes placed in front of the turbine, were expected to allow the turbine to rotate with higher speed by turning the direction of the current partially. The device was tested in both the wind and water tunnels, and its effect was recognized at both tests. Since the configuration with the twin turbines in parallel was considered advantageous especially under the weaker tidal current, the guide vanes suitable for the twin-turbine configuration were investigated using the wind tunnel, based on the previous results obtained in the single-turbine configuration. The experimental results showed that the guide vanes placed on the center line increased the rotational speed in the regions of lower tip-speed ratio.

KEY WORDS

Tidal Current; Power Generation; Vertical Axis Water Turbine; Darrieus Turbine; Guide Vane

NOMENCALTURE

A Projected area
C Chord length of rotor blade
R Radius of rotor
V Flow velocity
C_p Power coefficient = $P/(\rho AV^3/2)$
C_t Torque coefficient = $T/(\rho AV^3R/2)$
H Rotor blade height
ρ Angular velocity of rotor
U Circumferential velocity of rotor
λ Tip speed ratio = U/V

INTRODUCTION

Tidal current

Considering to stabilize energy supply and to protect the earth-environment, the importance of the technologies of natural energies is getting higher on these days. Among them, ocean energy has received greater attention in natural energies because Japan is surrounded by the sea. The methods of power generation using ocean energy include tidal current, ocean current, tidal, wave and thermal difference. Above all, the tidal current power generation is regarded as a method of power generation suitable for Japan because there are number of straits where the strong tidal current exits.

A tidal current is a flow of seawater characterized by the strong regularity. The tidal current reverses its direction every six hours, and the current velocity varies like a sine wave(1). The tidal current energy is regarded as the stable energy source, because the velocity changes are predictable to some extent from the positions of Earth, Moon and Sun. Furthermore, as a density of seawater is more than 800 times greater than that of air, the current velocity of 1 m/s corresponds to the wind speed of 9 m/s in air because the energy of a fluid is proportional to the density and the cube of the stream velocity. Thus, the tidal power generation is expected as a promising way of utilizing the renewable energy.

Water turbine

The water turbines used in tidal power generation can be divided into two styles, a horizontal axis water turbine (HAWT) and a vertical axis water turbine (VAWT) (2), as shown in Fig.1. The HAWT has advantages of the higher power coefficient and good self-starting characteristics. However, it has the disadvantages of the directional control requirement and the stiff column structures due to the large bending moment. In contrast, for VAWT there is no need of directional control of the turbine, and no such large bending moment is generated on the structure. But, the power coefficient and the self-starting characteristic of

VAWT are poorer than those of HAWT. Currently, HAWT is used mainly in the tidal power generation. However, there is the problem that the HAWT would block the ship course in a narrow strait when the projected area is increased for larger power. In contrast, VAWT can achieve higher output by the multiple-stage system in the depth direction, as shown in Fig.2.

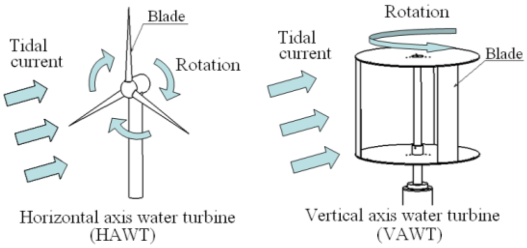

Fig.1 Classification of water turbines

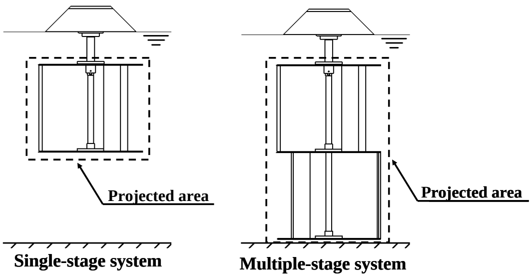

Fig.2 Multiple-stage VAWT concept

DARRIEUS WATER TURBINE

In the present study a Darrieus-type water turbine was selected in the VAWT. It has the three straight blades in the rotor, as shown in Fig.3. The blade-section profile is NACA0018. The specifications of this water turbine is listed in Table 1. The solidity of the rotor was 0.179.

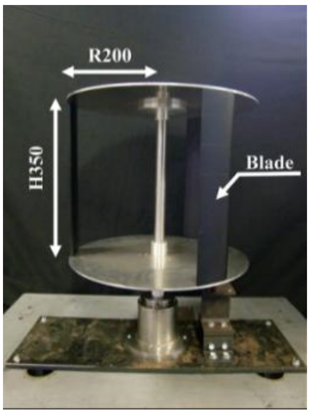

Fig.3 Darrieus Water Turbine

Table 1 Specifications of Darrieus Water Turbine

Section profile	NACA0018
Radius R [mm]	200
Height H [mm]	350
Chord length C [mm]	75
Number of blades Z	1,3
Solidity $\sigma = ZC/(2\pi R)$	0.179

GUIDE VANE

Experiment in wind tunnel

The guide vane technique is known effective to enhance the performance of a straight-bladed Darrieus turbine in the wind power generation[4]. It is also expected that the guide vane is effective in tidal current power generating.

First, in order to verify the effectiveness of the guide vane it was tested in the wind tunnel. The experimental setups of the testing apparatus were shown in Fig.4. The arc shaped guide vane was placed with a certain distance from the center of the turbine, and its position measured as the angles from the center of the turbine was varied.

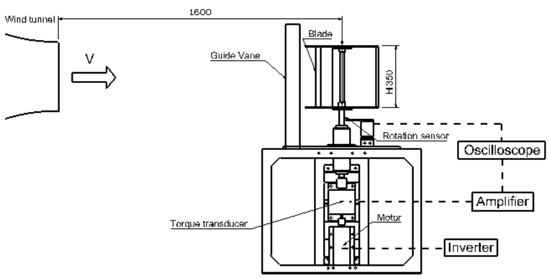

Fig.4 Test apparatus for guide vane in wind tunnel

The typical result of the experiment was shown in Fig.5, which was the most effective position of the guide vane. The power coefficient of the turbine with the guide vane achieved 0.25 at the tip speed ratio over 2, whereas that of the turbine without the guide vane was 0.225. It is clear from the figure that the performance of the turbine was improved when the guide vane was added to the turbine.

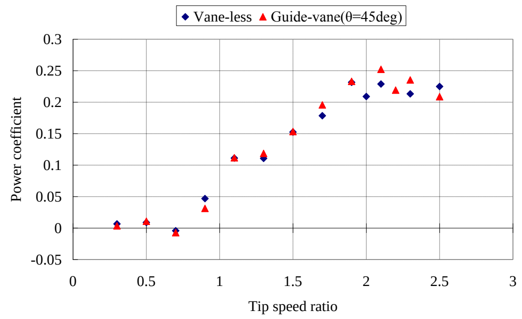

Fig.5 Power coefficient vs. tip speed ratio

Power Generation by water flow

In order to confirm the effectiveness of the guide vane, the power generation tests of the Darrieus turbine were carried out in the water tunnel. Fig.6 shows the setup of the water tunnel experiment test. As was shown, the electric generator was connected directly to the shaft of the turbine. The angle between the guide vane and turbine was 45° which was proposed as the most effective angle[5].

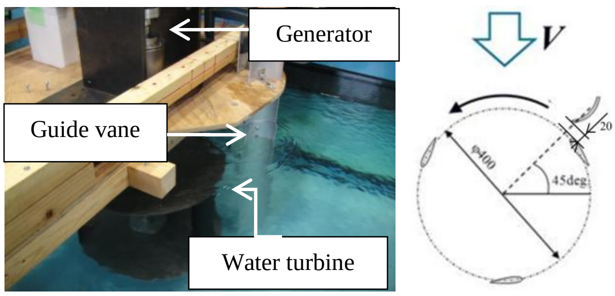

Fig.6 Power generation test in water tunnel

The obtained electrical power was plotted against the flow velocity of water in Fig.7. The output increased by 5% at any water velocity. From these results obtained in both the wind and water tunnels, the guide vane technique was proved to be effective to enhance the performance of the Darrieus water turbine.

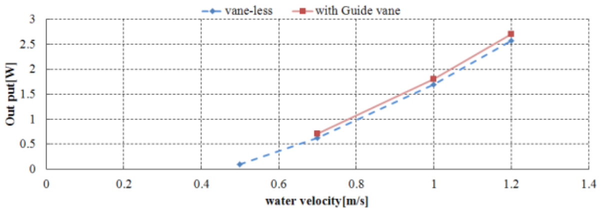

Fig.7 Generated power vs. water velocity

TWIN-TURBINE CONFIGURATION

The turbine with a larger diameter should generate the higher electrical power. However, the tidal current stagnates when it changes the direction. The increase of a turbine diameter should prevent the rotor from rotating under the weak tidal current, since the moment of inertia of the turbine also increases. Thus, it should be advantageous to place the two turbines in parallel, instead of increasing a diameter of a single turbine. Therefore, the twin-turbine configuration was tested in the water tunnel. The schematic of the twin-turbine configuration was presented in Fig.8, and the test conditions were listed in Table 2. The current velocity was set constant at 0.5 m/s. The gap between the twin turbines was varied, and the rotating directions of the turbines were also varied in three cases.

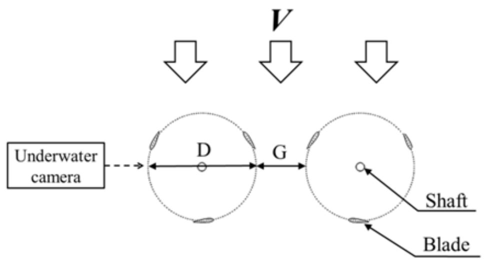

Fig.8 A schematic of twin-turbine configuration

Table2 Test conditions in twin-turbine configuration

Diameter, *D*	180mm
Distance between each turbine, *G*	5 - 50mm
Rotational Direction	3 cases
Tip speed ratio	1.4 - 1.8

The test results were shown in Fig.9. The rotational number of the single turbine was 87 rpm. In all cases of the twin-turbine configuration, the rotational numbers of the turbines were larger than 87 rpm. Moreover, the rotational directions with the type 1, as specified in the figure, achieved the highest revolutions all over the gap between the twin turbines. Based on this, the counter rotations like type 1 was advantageous for a weaker tidal current condition. In terms of the gap D, the best result was obtained at D= 0.18.

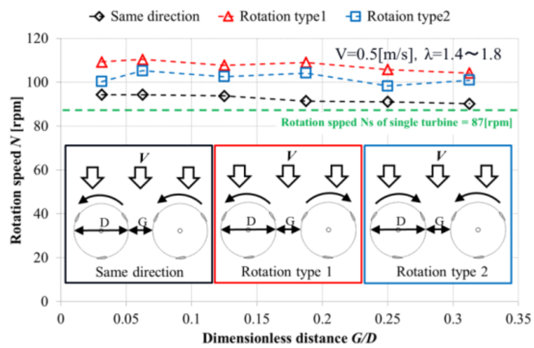

Fig.9 Rotational numbers vs. gap between twin turbines

GUIDE VANES FOR TWIN TURBINES

Experiment in wind tunnel

Since the twin-turbine configuration was preferred in the tidal current power generation than the single turbine, the suitable form of the guide vanes should be pursued. In order to find out the suitable guide vanes for the twin turbines, the wind tunnel experiments were performed. As shown in Fig.10, the positions of the guide vanes were varied. In the figure the right turbine rotates clockwise, and the left one does counterclockwise. The wind velocity was varied.

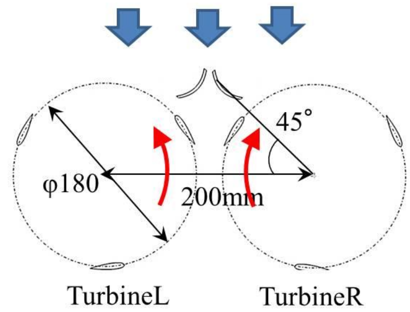

Fig.10 Guide vanes for twin-turbine configuration

The measured rotation number of the turbines was converted to the tip speed ratio, and it was plotted against the wind speed in Fig.11. At the right turbine, designated as turbineR, the difference in tip speed ratio gradually decreased as the wind speed increased. Regarding the left turbine, designated as turbineL, the difference in tip speed ratio between the turbine with and without the guide vane was about 0.06 over the gamut of wind velocity. In addition, the wind velocity at which the turbineL terminated the rotation was 3.3 m/s with the vane and 5.3 m/s without the vane, respectively. For turbineR, it was 4.0m/s with the vane and 5.8m/s without the vane, respectively. These facts also indicated that the addition of the guide vanes at the central position enhanced the performance of the twin turbines.

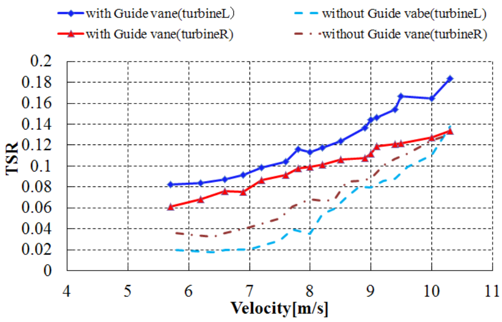

Fig.11 Effect of guide vanes for twin-turbine configuration in terms of the achieved tip speed ratio

GUIDE VANES RELATIVE TO CURRENT DIRECTION

Experiment in low-current water tunnel

Since the tidal current reverses its direction regulary, the relationship between a position of the guide vanes and the current direction should be considered. Four patterns of the relationship were tested in a water tunnel, as were shown in Fig.12. The direction of the water flow remained frontal, however, the rotational direction of the twin turbine was varied in the figure. The central placement of the guide vanes, which was described in the previous section, was considered nominal, and the lateral placement was also tested for comparison. The increment of the rotational numbers of the turbines to those without the vanes were compared under a current speed of 0.18m/s.

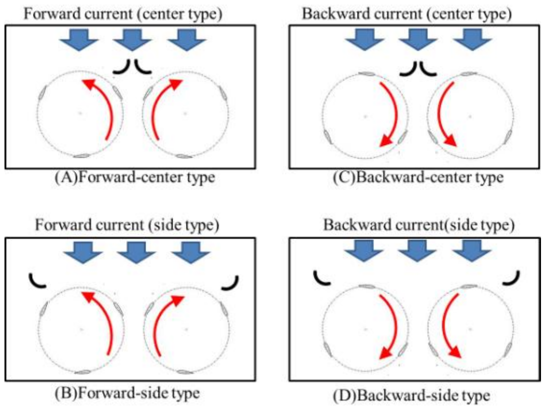

Fig.12 Tested configurations of the guide vanes relative to the current directions

The obtained results were listed in Table3. In the configuration of (A) and (B), the turbines without guide vanes did not rotate. The turbines at (A) achieved the tip-speed ratio of 0.55, whereas those at (B) stayed unrotated. In the configuration of (C) and (D), the turbines without guide vanes rotated with a tip-speed ratio of 0.66. The turbines at (C) could not even rotate, and those at (D) achieved the tip-speed ratio of 0.77. Thus, the configurations (A) and (D) were succesful to increase the rotational numbers of the twin turbines. The configuration (A) is corresponding to the case in Fig.10. Noting the left turbine at (A), the relative position of the guide vane to the turbine is similar to that shown in Fig.6. Similarly, noting the right turbine at (D), the relative position of the guide vane to the turbine is similar to that in Fig.6. This enhancing effect can be explained by the drag reduction on the rotating blade against the flow [5]. The guide vane changes the flow direction of the current in the viscnity of the vane, and the less flow is induced to the rotating blade opposing to it behind the vane, and that is why the vane is reducing the drag loss.

Table 3 Summary of test results of guide vanes in two current directions

Forward current without guide vanes	Backward current without guide vanes
no rotation	TSR=0.66
(A)Forward-Center type	(C)Backward-Center type
TSR=0.55	no rotation
(B)Forward-Side type	(D)Backward-Side type
no rotation	TSR=0.77

CONCLUSIONS

In the present work, the effectiveness of the guide-vane technique was investigated both for the single Darrieus water turbine and for the twin-turbine configuration. At the single turbine configuration the effective position of the guide vane was sought first in the wind tunnel, and then the turbine with the best guide vane was provided for the power generation tests in the water tunnel. Next, the guide vanes for the twin-turbine configuration were also investigated using the wind tunnel. Finally, the relative position of the guide vanes to the current was investigated in the water tunnel. The obtained results can be summarized below.

1. The power coefficient of the single turbine with the guide vane achieved 0.25 at the tip speed ratio beyond 2, whereas that of the turbine without the guide vane was 0.225.
2. The generated power of the single turbine with the guide vane in the water tunnel increased by 5% under all the tested water velocities.
3. The addition of the guide vanes at the central position to the twin-turbine configuration increased the rotational numbers by 5 times at maximum in the wind tunnel test.
4. Evne in the twin-turbine configuration the effective position of the guide vane relative to the turbine was similar to that in a single turbine configuration. This can be explained as the drag-reductive effect of the vane.

REFERENCES

(1) Japan Coast Guard hydrographic office, Kanmon Kaikyo Tyoryuzu (Tidal current chart of Kanmon Strait), (1974), Japan Coast Guard (in Japanese)

(2) Seki,K. and Ushiyama,I., Verical Axis Wind Turbine, (2008), POWERSHA Inc.(in Japanese)

(3) Ryo Wakita, Preliminary experiment and flow field visualization of Straight-bladed Vertical Axis Water Turbine for tidal current power generation, 2009, Bachelor Thesis, Kyushu Institute of Technology (in Japanese).

(4) Ryo Wakita, Positioning control of movable guide vane for S-VAWT, 2007, Graduation study, Matsue college of Technology (in Japanese).
(5) Manabu Takao, A Study on Straight-bladed Vertical Axis Wind Turbine with a Directed Guide Vane, 2008, Society of Mechanical Engineers, 2008(46), 185-186, 2008-02-26.