LATVIAN JOURNAL OF PHYSICS AND TECHNICAL SCIENCES
2017, N 6

DOI: 10.1515/lpts-2017-0039

NEW HYDROKINETIC TURBINE FOR FREE SURFACE GRAVITATIONAL WAVE TRANSFORMATION

J. Berins
Faculty of Power and Electrical Engineering, Riga Technical University1 Kalku Str., Riga, LV-1658, LATVIA

The present article deals with an alternative form of energy – the conversion of marine/ocean wave energy using an axial self-regulating blade (SB) hydrokinetic turbine (ASRBHK turbine). The article analyses the operation of the ASRBHK turbine and draws the resulting conclusions about the mechanism, in which the power transfer element is a self-regulating blade.

Keywords: *axial hydrokinetic turbine, renewable energy, wave energy, wave energy power plant, wave energy converter, wave energy receiver, self-regulating blade*

1. INTRODUCTION

The total amount of wind-generated wave energy is less than the total amount of wind power in the world, due to the fact that only part of the wind power transfers to the waves. As wind-generated wave energy accumulates, there can be significantly more energy in the aquatorium than in the same area in the air above it.

Sea and ocean waves are potential and perspective renewable energy sources – estimates of the global wave energy potential are between 8,000 TWh and 80,000 TWh per year [1]. In order to achieve this goal, it is necessary to create new, efficient equipment for the construction of wave energy power plants. At least 140 scientific institutions working on wave energy transformation issues have been involved in around 200 different projects since 2000 [2]. In spite of this fact, it is still urgent to find the most effective way of converting wave energy into rotational motion for powering electric generators. Let us look at one of the following options – *APRLHK* turbine. The article will provide insight into *APRLHK* turbine operation in a wave environment.

The aims of the article are to evaluate the principle of the axial hydrokinetic turbine with self-regulating blades, to create the receiver's operation and to draw conclusions from its analysis.

2. A SHORT DESCRIPTION OF WAVE PHYSICS

Salt water weight per m^3 is slightly over 1 ton. This indicator varies in different water areas and changes even in the same place. This is the density of the volume of water which, affected by the Earth's gravitational force in the wind created free surface wave, varies in time and space in a particular way. Looking at the surface of the water, there are characteristic changes in the wave surface, such as period, amplitude, wave length, wave phase and wave group velocity.

The motion of particles in the deep wave is shown in Fig. 1. Particle motion decreases with increasing depth; therefore, the amount of power and energy decreases. It is assumed that the energy in the deep-wave is up to depth equal to half the length of the wave [3]. With increasing depth, the amount of energy decreases exponentially. Therefore, about 95 % of the wave energy is up to depth equal to ¼ of the length of the wave.

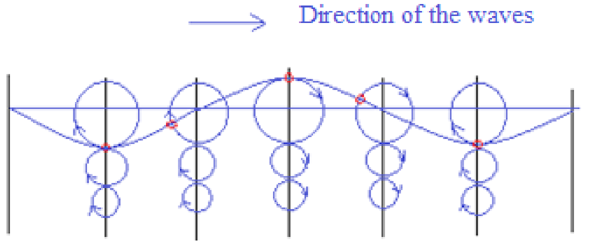

Fig. 1. Particle movement in the wave.

3. A BRIEF OWERVIEW OF WAVE ENERGY EQUIPMENT

In order to absorb and reduce wave energy, i.e., to reduce the amplitude and velocity of its particle movement, a converter is required. It is a three-dimensional body to which the wave reacts. The wave has a specific direction of expansion and action in different phases.

As a result, the spatial body moves or deforms in a manner determined by the receiver's construction and the degree and or form of its elemental freedom.

Particle movement in wave construction – the degree and / or form of its elemental freedom, deformation determines how much energy will be reflected and how much of it will be consumed by treating the wave while moving the absorber surfaces.

According to this theory, a simple point-absorber, moving up / down, spends part of the energy generating radial waves and, thus, is capable of absorbing no more than 50 % of the wave energy [4]. The shape of the receiver is the designer's choice, and the wave absorption / conversion coefficient in water is theoretically 100 % [5] (unlike air, in which it does not exceed 59 % according to Betz criterion), [6].

Machines that completely stifle waves and, thus, wave energy tend to be called wave terminators. In literature, there are also the following names: Salter's Duck [7], Evans or Bristol Cylinder [8]. It is possible that the Cycloidal wave energy converter [9] may also be counted as such (as do all terminators that have a frequency-dependent efficiency curve). An oscillating water column with a resonance chamber, in which, as the direction of the water flow changes, the direction of rotation of the hydro turbine does not change, because the turbine blades are either swivelable [10], in two directions, TWO-WAY tilting blades, or have servomotor controlled blade angles [11]. Stage of readiness of the prototype at a scale 1: 1.5 [12], at D = 6m is a declared efficiency 8 to 30 % in technology development. The machine is designed in two versions:

1. As a "static" fixed to a stand, the shore, or wind generator mast;
2. As a floating design with 4 "slings".

A test prototype (at scale X: Y) power 4.5 kW Ecofys Wave Rotor, Ocean Mill is a vertical axis velocity boost turbine, whose productivity is supplemented by the Wells hydro turbine wave to capture the kinetic energy of the vertical component [13]. CycWec is a cross-flow turbine with two blades, but unlike the Darius turbine it has a horizontal axis, an angle of inclination of steerable blades and a controllable wave detection angle [14]. Fixing / anchoring methods – a mast or floating frame. Total efficiency coefficient of electricity generation is 15 %. The developer suggests that by improving the blade profile it is possible to achieve an efficiency coefficient of up to 70 %.

4. APRLHK TURBINE TECHNICAL SOLUTION

Because of the fact that it is possible to achieve similar shapes with *SB*, as with classical hydrokinetic turbines, we design and view the *ASRBHK* turbine, which would be more suitable for changing a wave direction and changing load conditions (see Fig. 2). The *ASRBHK* turbine consists of a vertical fixed axis *"A",* a flywheel *"FW"*; turbine blades *"SB",* spindles *"SP"* and bearings *"B"* (see Fig. 2). The axis *"A"* shown in Fig. 2 is fixed rigidly in the vertical position to prevent the turbine wheel from moving up and down and sideways. It provides the maximum effect of wave forces on *SB*. The *SP* holds the longest edge of the *SB* tensioned (see Fig. 3 – marked with a red line), thus promoting the transfer of wave forces to the turbine wheel in all *SB* positions. Figure 3 shows three *SB* positions (*P1, P2* and *P3*) demonstrating the *SB* states and the effect of water particles (indicated by the speed vertical and horizontal components v_n and h_n) on it. With the abbreviation *"TB",* Fig. 3 illustrates the *SB* bearing structure or the turbine branch, but with *"SB"* – the self-adjusting blade.

The density of salt water can be 1030 kg m3 or more. In the case of turbine moving parts (*SB*), it is better if their volume is as close to the volume of the water they work in as possible, so as to reduce the negative effect of additional gravity or lift on wave power transfer efficiency. Therefore, a significant indicator is the average value of water density in the aquatorium.

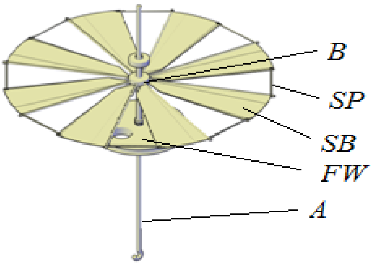

Fig. 2. Sketch of the *ASRBHK*.

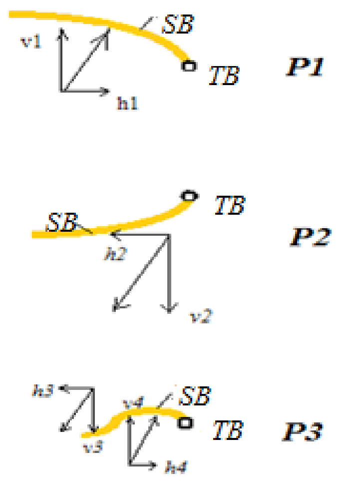

Fig. 3. Water particle effect on *SB*.

5. ASRBHK TURBINE OPERATION TESTS AND THEIR RESULTS

In order to test the *ASRBHK* turbine, a model for work in a laboratory was made, where the parameters of incoming and outgoing waves (Frequency γ, Hz and amplitude *A*, m) were measured and data were obtained by receiving signals from laser sensors. The signals then arrived at the data analyser and, using special software, they were archived and processed by creating a wave analysis scheme (see Fig. 4). One dominant wave direction was taken – in the direction of a wave generator to a wave-energy receiver. Due to reflection, the tidal wave and waves, the direction of which coincided with the initial wave, arose for this direction of waves [15]. Measurements were made following a specific measuring structure and optical circuitry [15]. A chronometer was used to measure turbine speeds at different braking loads of the driving pulley as well as without load. Load was put on the flywheel *"SK"* (see Fig. 2) by winding a cord around it and changing its strain strength (*F*) which was read using a dynamometer. As the strength changed minutely, we used video surveillance during the tests. This made it possible to capture variations in the force according to time and to calculate its average value. The indicators w (angular velocity, rps.) were calculated from the speed of the fixed receiver n and the test time t, s, obtained with the chronometer. The loading arm, m, which is equal to the flywheel radius *r*, was measured with a tape measure. Some of the most significant parameters used in the relationships (*w, F* and *r* – measured, *v, P, P (AK)* and η – calculated) are shown in Table 1. *P* – the power dissipation *W* was calculated using the equation:

$$P = v \cdot F, \tag{1}$$

where *P* – power, W;
v – speed, m/s;
F – force, N.

Let us calculate velocity v from the measured angular velocity w:

$$v = w \cdot \pi 2r/t, \tag{2}$$

where t – time, s;

w – angular velocity, rps;

π – constant of the circle line;

r – loading arm, m.

and $P\ (AK)$ the wave power calculated from the obtained wave parameter measurements of (3), [3]:

$$P(AK) = \frac{\varphi g H^2\, c_g\, b}{8}, \tag{3}$$

where $P\ (AK)$ – calculated wave power before receiver, W;

f – water weight, kg/m³;

g – free fall acceleration, m/s²;

H – mean wave height, m;

c_g – wave group speed, m/s;

b – the wave-width to be detected, m.

As the experiment was performed in freshwater, in a laboratory, we assumed that the weight of the water was 1000 kg / m3, the free fall acceleration $g \sim 9.81$ m / s², $H = 2A$, where the measurement method for amplitude A was described in [15], but test data were archived using a specially designed computer program and the received wave width was 0.90 m, which was equal to the receiver diameter.

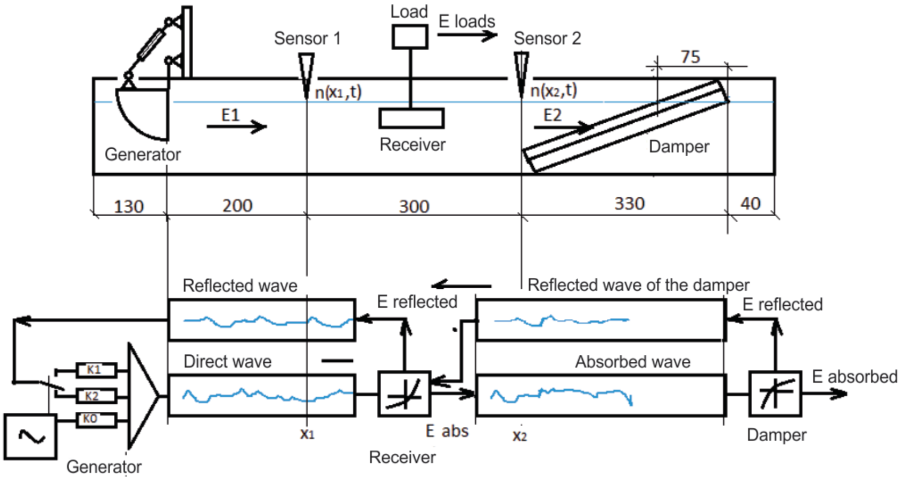

Fig. 4. Wave process analysis scheme [15].

Table 1

Measured and Calculated Parameters of the Tests

w, rps	F, N	r, m	v, m/s	P, W	P (AK), W	w, rps	η, %
-	1.628	0.15	-	-	1.472	-	-
0.03	1.218	0.15	0.03	0.04	1.462	0.03	2.62
0.05	1.099	0.15	0.05	0.05	1.483	0.05	3.49
0.08	0.809	0.15	0.08	0.06	1.424	0.08	4.46
0.12	0.541	0.15	0.11	0.16	1.491	0.12	3.99
0.17	-	0.15	0.16	-	1.474	0.17	-

In deep-water conditions, the group wave velocity is expressed as follows [3]:

$$c_g = c/2, \tag{4}$$

where
c – wave speed, m/s.
Wave speed is expressed as follows [3]:

$$c = \frac{gT}{2\pi}, \tag{5}$$

where g – free fall acceleration, m/s^2;
T – wave period, s;
π – constant of the circle line.

Wave frequency was measured during the test. Therefore, in the calculations of wave speed c, we used (6):

$$\gamma = \frac{1}{T}, \tag{6}$$

where γ – wave frequency oscillation per second;
T – wave period, s.

To determine the *ASRBHK* turbine efficiency, we used (7):

$$\eta = \frac{P}{P(BK)} \cdot 100\ \%, \tag{7}$$

where η – efficiency factor, %;
P – turbine load capacity, W;
P (AK) – wave energy, W.

The efficiency coefficient curve of mechanically tensioned *ASRBHK* turbine, under laboratory conditions, is shown in Fig. 5.

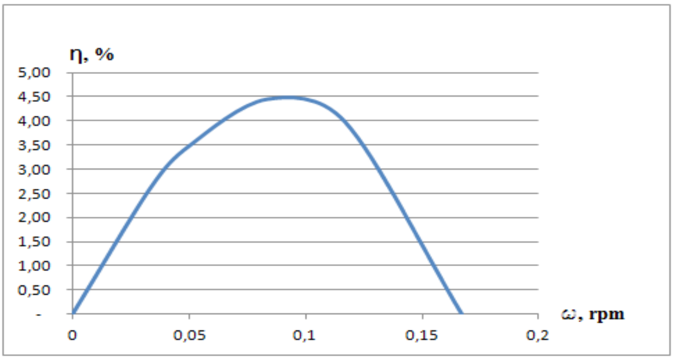

*Fig. 5.*The efficiency coefficient curve of mechanically tensioned *ASRBHK* turbine.

6. ASRBHK TURBINE PERFORMANCE ANALYSIS

From the *SB* positions *P1, P2* and *P3* in Fig. 3, which exist in three different wave phases, we can see that:

a. In position *P1*, the vertical component of the forces generated curves the *SB* upwards, but the horizontal component – in the direction of rotation of the turbine;
b. In position *P2*, the vertical component of the forces generated pushes the *SB* downwards, while the horizontal component moves it counter to the direction of rotation of the turbine and produces an increased hydraulic resistance in the curved *SB* surface;
c. In position *P3, SB* is simultaneously in two wave phases and the effects of wave particles characteristic of one and the other wave phases are acting accordingly.

Let us look at the forces at work on the temporarily free form blade (see Figs. 7 and 8). The blade bearing structure is marked with *"B"*. The vertical component of the velocity of the water particles is the force acting on the *SB* and is shown in the top left corner of Fig. 7, but how it will act on *SB* – with different shades (the darker the stronger the effect) of blue and red (depending on the direction of action – up with red or down with blue) below, where three *SB* positions (*P1, P2* and *P3*) are displayed. Figure 6 shows one static moment in which the wave crosses *ASRBHK* turbines *SB*. In addition, it is assumed that the wavelength is equal to the length of the blade to better highlight the phenomenon that occurs in *SB* in the wave environment. However, be aware that real wavelengths will vary, they may be shorter or longer than *SB*. Figure 6 also shows the direction of the *ASRBHK* turbine rotation with angular velocity w and horizontal direction of travel. The horizontal component of the wave energy also acts on the *ASRBHK SB*. This effect is shown in Fig. 8. The direction of the horizontal flow in blue is in the direction of the wave (the darker the colour, the more intense the flow), but red – in the opposite direction.

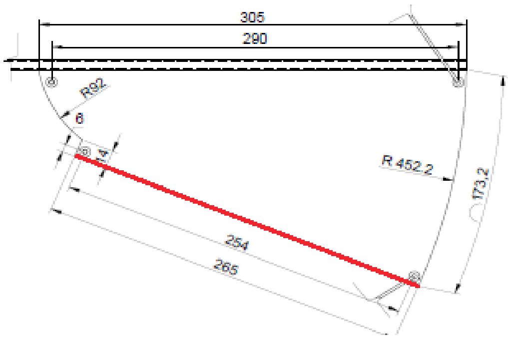

Fig. 6. Self-regulated blade of turbine *(SB)*.

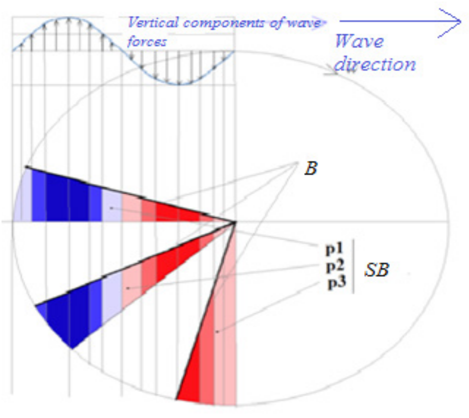

Fig. 7. Scheme for the propagation of vertical forces on the *ASRBHK* turbine *SB*.

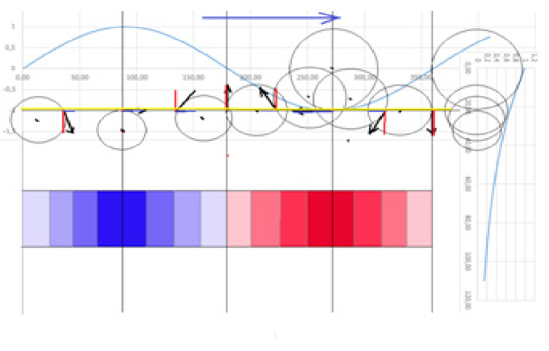

Fig. 8. The effects of the horizontal components of the wave force on the *ASRBHK* turbine *SB*.

7. CONCLUSIONS

1. The *ASRBHK* turbine (see Fig. 2) is capable of turning the variable directional flow in the direction of rotation, due to the *SB* sails functionality.
2. When operating in *SB* rotation around the vertical axis, it simultaneously falls into it, but not only with opposing forces. This reduces the effectiveness of *SB* operations.

3. In order to increase the efficiency of *SB*, technical solutions are needed to ensure that *SB* is continuously positioned perpendicularly to the direction of wave movement.
4. Moving parallel to the wave direction of motion, *SB* receives the wave forces more efficiently, since they are in different wave phases for a shorter period of time.

7. FUTURE RESEARCH

A mechanism must be developed that ensures the *SB* position is perpendicular to the direction of the waves and complimented by the energy potential of the target aquatorium of the power plants. The algorithm for calculating the size of the equipment must be developed by proceeding from the wave parameters characterising the aquatorium. It is necessary to modify or develop material for industrial equipment *SB*.

ACKNOWLEDGEMENTS

This article and article "Mesurements of wave power in wave energy converters effectiveness evaluation" *(Latv. J. Phys Tech. Sci., 2017, Vol. 54 Iss 4, pp. 23-35) have been written in accordance with contract No. 1.2.1.1/16/A/005 between Competence Center of Smart Materials and Technologies Ltd. and the Central Finance and Contracting Agency, concluded on 26 September 2016, the study is conducted by SensoTech Ltd. with support from the European Regional Development Fund (ERDF) within the framework of the project "Competence Center of Smart Materials and Technologies".*

REFERENCES

1. Holmberg, H., Anderson, M., Bolund, B., & Stananger, K. (2011). *Wave Power, Surveillance Study of the Development.* Elforsk rapport 11: 02.
2. Berins, J., Grickus, A., & Kalnacs, A. *Wave Energy Conversion-Overview and Perspectives*. Available at http://site-11936.mozfiles.com/files/11936/Wave_enrgy_conversion_publication_2a.pdf
3. McCormick, M.E. (2007). *Ocean Wave Energy Conversion*. New York: Dover Publications Inc.
4. Falnes, J. *Principles for Capture of Energy From Ocean Waves. Phase Control and Optimum Oscillation*. Department of Physics, NTNU. Available at http://folk.ntnu.no/falnes/web_arkiv/InstFysikk/phcontrl.pdf
5. Evans, D. V. (1976). A theory for wave-power absorptionby oscillating bodies. *Journal of Fluid Mechanics*, *77*, 1–25.
6. Betz, A. (1920). Das maximum der theoretisch m¨oglichen ausn¨utzung des windes durch windmotoren. *Zeitschrift fürdas gesamte Turbinenwesen*, *26*, 307–309.
7. Salter, S. H. (1989). World progress in wave energy-1988. *International Journal of Ambient Energy,10*(1), 3–24.

8. Evans, D. V., Jeffrey, D. C., Salter, S. H., & Taylor, J.R. M. (1979). Submerged cylinder wave energy device: Theory and experiment. *Applied Ocean Research, 1*(1), 3–12. Available at http://oregonwave.org/oceanic/wp-content/uploads/2014/10/Oregon-Incubator-Stefan-Seigel.pdf
9. Grases, G.M., & Grases, M.J.M. (2013). *Hydraulic turbine having pivoting blades for the bidirectional use of fluids.* Patent No. WO2013021089A2. Available at http://google.com/patents/WO2013021089A2?cl=en
10. Grases, G.M., & Grases, M.J.M. (2013). *Hydraulic turbine having pivoting blades for the bidirectional use of fluids*. Patent No. 2013021089 A3. Available at http://google.com/patents/WO2013021089A3?cl=en
11. Fundación Repsol. (2014). *Sendekia presents its prototype at the RTC*. Available at http://www.fondoemprendedores.fundacionrepsol.com/en/up-to-date/news/sendekia-presents-its-prototype-rtc
12. Scheijgrond, P.C. (2009). *Device for the utilisation of wave energy and a method*. Patent US 20110198849 A1. Available at https://www.google.ch/patents/US20110198849
13. Siegel, S.G. (2014). Cycloidal wave energy converter. Development progress and outlook. *Ocean Renewable Energy Conference IX*. Available at http://oregonwave.org/oceanic/wp-content/uploads/2014/10/Oregon-Incubator-Stefan-Seigel.pdf
14. Berins, J., Berins, J., & Kalnacs, A. (2017). Measurements of wave power in wave energy converter effectiveness evalution. *Latvian Journal of Physics and Technical Sciences*, 54(4), 23–35.

HIDROKINĒTISKA TURBĪNA BRĪVAS VIRSMAS GRAVITĀCIJAS VIĻŅU PĀRVEIDOŠANAI

J. Beriņš

Kopsavilkums

Raksts ir par vienu no alternatīvās enerģijas veida – jūras/okeāna viļņu enerģijas pārveidošanu ar aksiālu pašregulējošu lāpstiņu (PL) hidrokinētisko turbīnu (APRLHK turbīna). Raksta devums ir APRLHK turbīnas darbības analīze un no tās izrietošie secinājumi par to, kādam jābūt mehānismam, kurā spēka pārneses elements ir pašregulējoša lāpstiņa.

19.10.2017.