FRI-9.3-1-THPE-01

EXPERIMENTAL STUDY OF TURBINE WITH OSCILLATING BLADES

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Abstract: *Current work deals with experimental investigation under laboratory conditions of a turbine with oscillating blades that can be used as the power take-off subsystem of a wave energy converter machine. The paper presents the test-rig used for the study and the conditions under which the runner of a turbine with oscillating blades is tested. Based on the settings of the test –rig are calculated the kinematic characteristics of the simulated waves as well as their power flux. The results obtained prove the ability of the tested runner to convert wave energy into mechanical work.*

Keywords: *experimental results, turbine with oscilating blades, charactrestics*

INTRODUCTION

According to the classification of the European Marine Energy centre there are 8 well-established technologies for conversion of wave energy into electricity: Attenuator, Point absorber, Oscilating wave surge converter, Oscilating water column, Overtopping/terminator device, Submerged pressure differential device, Bulge wave, and Rotating mass. The ninth group (Other) includes all devices with a unique design that differs from the above mentioned technologies or those devices which characterisitics could not be determined, [EMEC]. Part of the Wave Energy Convertors (WECs) is developed to extract wave energy onshore, another part from the waves in the nearshore (shallow) water, and the rest from the offshore (deep) water. Each WEC is composed of several subsystems, among which most important are the hydrodynamic subsystem, the power take-off subsystem (PTO), the reaction subsystem, and the control subsystem.

The object of this study, a water turbine with oscilating blades (WTOB), [Agontsev et al, 2017; Velichkova et al. 2017], belongs to the ninth group of WECs. This relatively new water turbine is actually the PTO susbsystem of a WEC. It can be used in two ways: 1) onshore in combination with the Oscilating Water Column WEC; 2) in deep water, where the wavelength (λ) is significantly less than the water dept (H) $\lambda \ll H$, in a similar way as a Point absorber.

The principal goal of this material is to present results from functional tests under laboratory conditions of a water turbine with oscilating blades.

EXPOSITION

The runner of the turbine with oscilating blades

Sketch of the runner of a turbine with oscilating blades is presented on Fig. 1. The construction of the runner blades, each of which may oscillate around its horizontal axis, allows converting the relative vertical reciprocating motion of sea water with respect to the turbine runner into unidirectional rotary motion of the vertical turbine shaft, [Agontsev et al, 2017]. The runner is with six blades, area of each blade is 0.026 m^2, runner head diameter is 90 mm, and runner maximum diameter is 550 mm. There are no limitations on the angle of rotation of each blade around its axis.

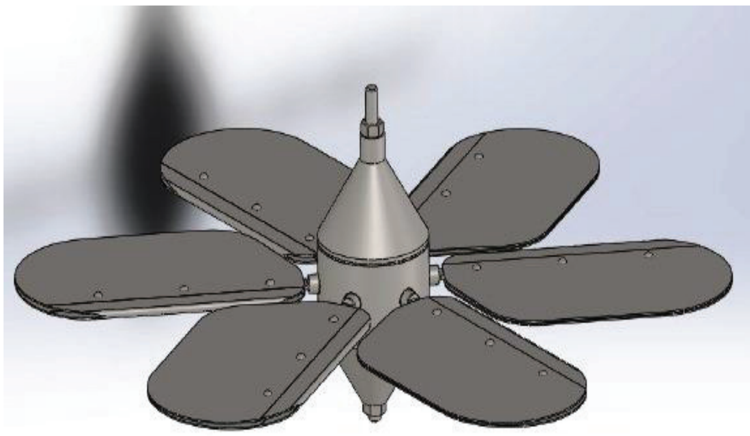

Fig. 1 Sketch of the runner of a turbine with oscillating blades

The test-rig

The aim of the experiment is to test the functionality of the water turbine runner with oscilating blades and to collect some preliminary data about it. This has preconditioned the contruction of the test-rig shown on Fig. 2. It is located in one of the labs of the Department of "Hydroaerodynamics and Hydraulic machines" in the Technical University of Sofia.

All elements of the test-rig are suppoted and fixed on their places by the framework (8). The DC motor (2) supplied with electricity by the rectifier (1) rotates through the gear box (4) the crank (5). The rotary motion of the crank is converted into reciprocating vertical motion of the mobile platform (9) with the use of a lanyard (6) and several rollers (14). Tested runner (12) is mounted on the shaft of a generator (11) which is fixed to the mobile platform. In this way, the reciprocating vertical motion of the mobile platform causes relative vertical motion of the runner with repect to the water in the tank (13). With the help of two DT-2199 LUTRON stroboscopes (3) and (10) is measured the revolutions of the DC motor shaft and turbine shaft. By the radius R, Fig. 2, is set the amplitude of the waves (A, m) and by the revolutions of the crank (n_c, rpm) is set the period of the waves (T, sec). The"amplitude of the waves", i.e the path travelled by the mobile platform (9) in one direction is measured by a displacement sensor - ODR18x311xLR STS-Electronic optical sensor with a 50x50mm reflector.

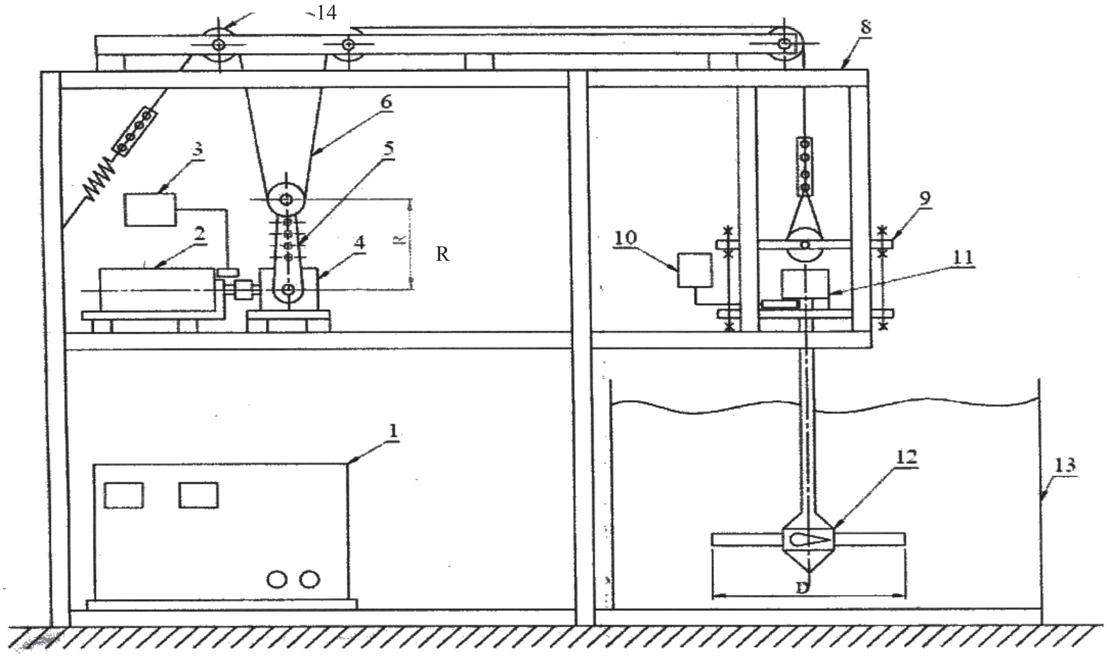

Fig.2 Sketch of the test rig

With the help of this test-rig is simulated the process of interaction of the runner of the water turbine with oscillating blades with the seawater under the conditions for use of the:

1) Oscillating water column technology – the generator is fixed to an unmovable structure onshore;

2) Point absorber technology – the generator is fixed to a buoyant platform and the runner is immersed deep into the still water beneath the zone affected by the sea surface waves.

The experimental study

The functionality of the studied runner is tested under 11 conditions with respect to the settings of the test-rig. In Table 1 are presented the stuied cases together with the characteristics of the simulated waves and the results of the test, namely the revolutions of the runner (n_r) and hence the revolutions of the turbine shaft. On Fig. 2 the variation of turbine shaft revolutions as a function of the wave amplitude and wave angular velocity is presented.

Wave amplitude A is equal to 4R, wave period T is equal to $60/n_c$, and wave angular frequency is $\omega=2\pi/T$.

The length of the simulated waves (λ, m) is obtained by the dispersion relation, which relates the wave angular frequency and the wavenumber (k)¨

$$\omega = \sqrt{gk\ \tanh(kH)}. \tag{1}$$

In (1) g is the acceleration of gravity (with standard value of $g=9.80665\ m/s^2$) and H is the height of the undisturbed surface above the bottom of the water body. Wave number is related to the vawe length by $k = 2\pi/\lambda$. After substituting k in (1) for the case of deep water (H>>λ and hence $\tanh(kH) = 1$) one can get a relation between the angular frequency of the waves in deep water and its wavelength:

$$\lambda = g\frac{2\pi}{\omega^2} \tag{2}$$

Table 1 Experimental conditions and results

Cases	Test-rig settings		Simulated wave characteristics					Runner
	R	n_c	T	ω	A	λ	k	n_r
	mm	rpm	sec	rad/sec	mm	m	m^{-1}	rpm
T1- 1	50	25.00	2.4	2.618	200	8.9901	0.6989	68.57
T1- 2	70	25.00	2.4	2.618	280	8.9901	0.6989	60.00
T1- 3	90	25.00	2.4	2.618	360	8.9901	0.6989	50.00
T1- 4	110	25.00	2.4	2.618	440	8.9901	0.6989	25.00
T1- 5	50	37.50	1.6	3.927	200	3.9956	1.5725	54.55
T1- 6	70	37.50	1.6	3.927	280	3.9956	1.5725	48.00
T1- 7	90	37.50	1.6	3.927	360	3.9956	1.5725	38.30
T1- 8	110	37.50	1.6	3.927	440	3.9956	1.5725	22.22
T1- 9	50	46.15	1.3	4.833	200	2.6377	2.3821	56.25
T1-10	70	46.15	1.3	4.833	280	2.6377	2.3821	48.65
T1-11	90	46.15	1.3	4.833	360	2.6377	2.3821	31.58

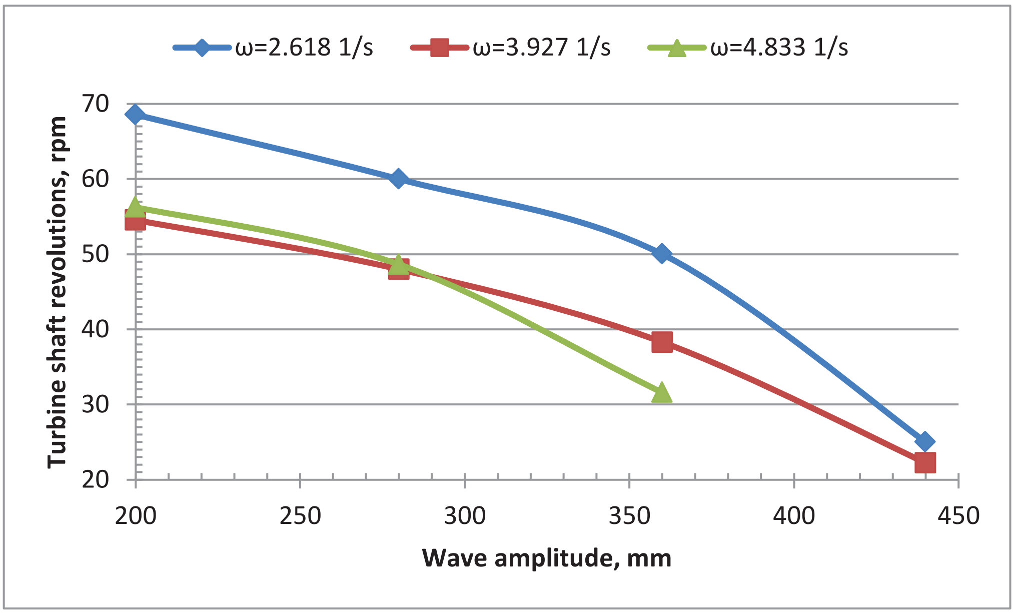

Fig. 2 – Turbine shaft revolutions as a function of wave amplitude (A) and wave angular frequency (ω)

Free sea surface vertical displacement a(x,t), x is the wave direction of propagation, with respect to the height (H) of the undisturbed sea surface above the bottom of the sea bed caused by a wave is given by, [Cushman-Rosin B.]:

$$a(x,t) = A\cos(kx - \omega t) \tag{3}$$

The rate of surface displacement, i.e. vertical velocity at the free surface, is given by

$$w(x,t) = \frac{\partial a(x,t)}{dt} = \omega A\sin(kx - \omega t) \tag{4}$$

The acceleration at the free surface along z axis is given by

$$a_z(x,t) = \frac{\partial w(x,t)}{\partial t} = -\omega^2 A\cos(kx - \omega t) \quad (5)$$

The wave energy flux through a vertical plane of width L perpendicular to the wave propagation direction (wave power), is equal to

$$P = \frac{\rho g^2}{32\pi} T A^2 L, \text{ W} \quad (6)$$

where ρ is sea water density (1025 kg/m^3).

Maximum values of vertical velocity at the free surface and vertical acceleration at the free surface for the investigated cases are given in Table 2. There is given as well the wave power defined by (6) for the simulated cases of sea waves at unit width of the wave front (L=1 m). On Fig. 3 is presented the variation of turbine shaft revolutions as a function of relative velocity of the water with respect to the runner at fixed wave period.

Table 2 Technical characteristics of the simulated waves

	Test-rig settings		Simulated wave characteristics						Runner
Case	R	n_c	A	T	λ	w_{max}	$a_{z,max}$	P	n_r
	mm	rpm	mm	sec	m	m/s	m/s^2	W/m	rpm
T1- 1	50	25.00	200	2.4	8.9901	0.524	1.371	94.13	68.57
T1- 2	70	25.00	280	2.4	8.9901	0.733	1.919	184.50	60.00
T1- 3	90	25.00	360	2.4	8.9901	0.942	2.467	304.99	50.00
T1- 4	110	25.00	440	2.4	8.9901	1.152	3.016	455.60	25.00
T1- 5	50	37.50	200	1.6	3.9956	0.785	3.084	62.75	54.55
T1- 6	70	37.50	280	1.6	3.9956	1.100	4.318	123.00	48.00
T1- 7	90	37.50	360	1.6	3.9956	1.414	5.552	203.32	38.30
T1- 8	110	37.50	440	1.6	3.9956	1.728	6.785	303.73	22.22
T1- 9	50	46.15	200	1.3	2.6377	0.967	4.671	50.99	56.25
T1-10	70	46.15	280	1.3	2.6377	1.353	6.540	99.94	48.65
T1-11	90	46.15	360	1.3	2.6377	1.740	8.408	165.22	31.58

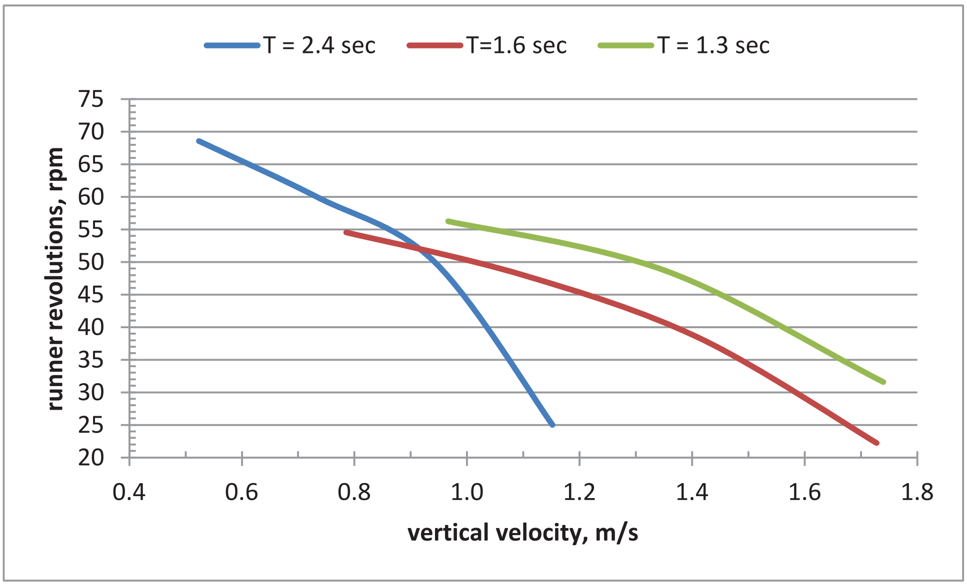

Fig. 3 – Turbine shaft revolutions as a function of vertical velocity (w) and wave period (T)

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CONCLUSION

From Fig. 2 it follows that

- a water turbine with oscillating blades may be used as power take-off subsystem of a wind energy converter machine;
- with the increase of wave amplitude (A) at a fixed wave period (T) runner revolutions (nr) decreases;
- with the decrease of wave period (T) at a fixed wave amplitude (A)
  - runner revolutions decreases monotonously for the lager amplitudes (A=360 mm);
  - runner revolutions firstly decreases and then increases for the smaller amplitudes (200 and 280 mm);

With the increase of relative velocity of the water with respect to turbine runner the power of the waves increases, Table 2, but the revolutions of the runner decrease, Fig.3. Obviously, runner construction needs improvement in order to reach better performance of the turbine, i.e to ensure increase of runner revolutions with the increase of the relative velocity of the water with respect to the runner blades regardless of the wave period.

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AKNOWLEDGEMENTS

This study is part of a bilateral project „Fundamental analysis of sea and ocean waves energy utilization by a turbine with fluctuating blades“, №ДТНС/Китай 01/08/16.12.2016, funded by Bulgarian Science Fund of the Ministry of Education and Science.