International Conference on Mechanical, Industrial and Energy Engineering 2020
19-21 December, 2020, Khulna, BANGLADESH

ICMIEE20-225

Evaluation of a Wells Turbine Model for Ocean Wave Energy Conversion using Oscillating Water Column

Rasel Ahmed[1,], *Kazi Afzalur Rahman*[1], *Monowar Wadud Hridoy*[2*]
[1]Department of Mechanical Engineering, Chittagong University of Engineering & Technology (CUET), Chottagram-4349, Bangladesh
[2]Department of Mechatronics and Industrial Engineering, Chittagong University of Engineering & Technology (CUET), Chottagram-4349, Bangladesh

ABSTRACT
Wave energy of oceans has a large potential to harness energy all over the world. Most of the wave energy extracting devices are based on the oscillating water column (OWC) technique. This study done on a small scale describes the designing of a Wells turbine to be used in an Oscillating Water Column power plant and laboratory-based test for evaluating such turbines. The test shows how RPM varies with respect to flow coefficient and gives the idea to choose turbine specification for given wave power. In this study, maximum rpm was found 396 at flow coefficient 0.425 by using a 35 cm diameter turbine whose mass inertia was 450 gm. This study shows that for large power output, the turbine size should be large in diameter and flow coefficient should be in the range of 0.4 to 0.5 for efficient turbine operation. Though power output was found small, among the various processes of conversion of wave energy, the oscillating water column (OWC) by employing Wells turbine can be a prominent and bright source of renewable energy source.

Keywords: Wells turbine, Oscillating water column, Air tube, Flow coefficient.

1. Introduction

As of late there is an overall worry to lessen CO_2 discharge and numerous ongoing energies investigates depend on biological well-disposed like breeze, sunlight-based wave and biomass, and so forth the world is searching for tackling environmentally friendly power as additional as could be expected under the circumstances. Numerous nations embraced arrangements to increment environmentally friendly power as quick as could be expected under the circumstances. Since there is a colossal capability of wave energy and there no contamination in the change of this energy, it is by all accounts an appealing environmentally friendly power source in this day and age. Around the world, the energy creation potential for sea wave energy has been assessed at around 8000-80,000 TW h/year [1]. In 2007, the European Union focused on 20% sustainable power for the year 2020. Danish Government focused on 30% environmentally friendly power for the year 2025 [2]. Numerous Technologies are embraced to change over sea wave power into electric force. It isn't clear what is the best specialized technique is. This is reflected by a wide range of specialized methodologies and various strategies and frameworks for changing over this force into electrical force like Oscillating Water Columns (OWC), pivoted form gadgets as the Pelamis, overtopping gadgets as the Wave Dragon and the Archimedes wave [3]. A swaying water segment is lowered somewhat in water with an empty development and encasing a segment of air on head of a section of water since this gadget is available to the ocean underneath the water line. The air section was thusly compacted and decompressed since the water segment is rise and fall on account of the wave development. At that point, the caught airs streamed to the air through a turbine which will have the option to turn the heading of the wind current. This turbine turn was utilized to produce power [4]. LIMPET a model that additionally knows as the coastal water segment (OWC) wave energy converter made by Wavegen with Queen's University, Belfast, which was introduced on Islay in 1999. This gadget is equipped for creating 500 kW [5]. The 30-kW multi-OWC worked in 1987 in the Kujukuri (Japan) harbor [6]. The world's originally manufactured embankment wave power plant was dispatched in 2011 on the Spanish Atlantic coast at Mutriku. It comprises of 16 single-chamber OWCs, every one with a Wells turbine, and the absolute ostensible yield power is around 300 kW (the force rate could be a lot higher in areas where waves are all the more remarkable) [7]. This study shows how RPM varies with respect to flow coefficient and gives an idea to choose turbine specification for a given wave power. The main objective of this research is to find out the optimum flow coefficient for maximum power output.

2. Experiment

The fundamental segments of the oscillating water column (OWC) are gathering chamber and power take of a system (where wells turbine is utilized to change over the pneumatic power into valuable mechanical power). The wells turbine (the turbine cutting edge has even airfoil in the plane pivot with its zero-edge pitch setting) is a low-pressure air turbine that has unidirectional revolution for bi-directional air flow. The rotation of the plane is perpendicular to air flow direction. Wells turbine was created for use in OWC wave power plants, where the ascent and fall of water name move the air in a gathering chamber that makes

* Corresponding author. Tel.: +88-01734641700
E-mail addresses: mwhridoycuet59@gmail.com

oscillating air flow. The utilization of the wells turbine dodges the need to amend the air stream by sensitive and costly check valve system.

2.1 Principle and Operation

The water wave energy was first changed over to pneumatic pressure energy noticeable all around, which at that point sways occasionally through a self-correcting, axial air flow Wells turbine. The turbine was made of various symmetric airfoils mounted with the center radially at 900 stagger angles, with the harmony plane ordinary to the hub of revolution. As indicated by the standard airfoil idea, if the airfoil is set at a point of occurrence in a liquid stream, it will create a lift power FL typical to the free stream and a drag power FD toward the free stream [8]. These extraneous powers are a similar way and provide turn in a similar guidance for swaying wind current.

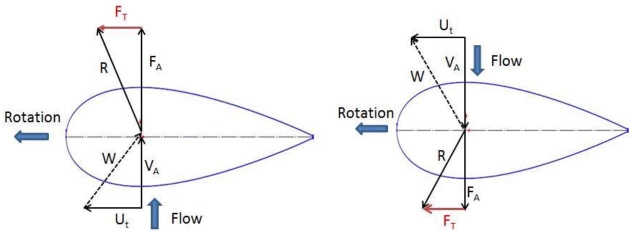


Fig. 1 Axial and tangential forces acting on a Wells turbine [8].

2.2 Methodology

The oscillating water column (OWC) permitted water to enter through a subsurface opening into a chamber with air caught over it. At the point when the wave moved toward the gadget, it constrained the air in the chamber to waver here and there like a cylinder. Here a plastic drum of round and hollow shape was utilized as gathering chamber or air chamber which was wavered like a cylinder to compel the air in and out as it has a weight effect that causes swaying the air. The swaying was done physically in a lake. The gathering chamber was associated with a turbine at the head of the structure, which pivots as for the air development and, along these lines, by implication changed the wave energy over to rotational motor energy. The turbine was additionally associated with a generator, which did the last change into power. From the generator, the yield power was determined for a specific burden.

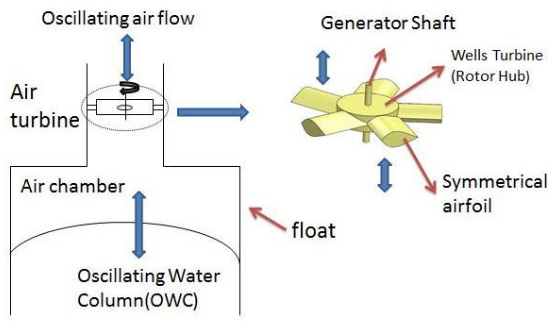
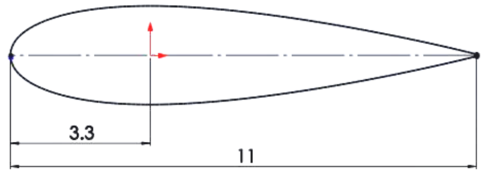


Fig. 2 Schematic diagram of experimental setup

2.3 Fabrication

In this study, NACA 0021 blade profile was used because several investigations show that NACA 0021 airfoil profiles (21% thickness) gives the best performance for conventional monoplane Wells turbines [9]-[10]. Here cord length 11 cm was used which give maximum thickness 2.3 cm at 30% distance (3.3 cm) shown in Fig. 3.



All dimensions are in cm

Fig. 3 Blade profile

The turbine is shown in Fig. 4(a) was 35 cm in diameter which means the tip radius was 17.5 cm. The hub radius was 8 cm which gave hub to tip ratio 0.46. The total number of blades was 4 and the total mass of inertia was 450 gm. The turbine was mounted in the middle of a shaft having length 20 cm. Then the shaft with the turbine was mounted through bearing at the center of a cylindrical air tube having a diameter of 36 cm which gives tip clearance 1 cm. A generator was coupled with the turbine to produce electric power shown in Fig. 4(b).

(a)

(b)

(c)

Fig. 4 (a) (b) Blade profile**; (c)** Wells turbine off air tube

This assembly was mounted with a collecting chamber shown in fig. 5. The collecting chamber is made of thick plastic drum of cylindrical shape having a diameter of 55 cm & 2 m long.

2.4 Experimental Procedure

Firstly, the air tube assembly without collecting chamber was tested in a laboratory with wind blower & data were taken from here. Though these were not giving actual characteristics data of prototype, this was done for simplicity & to overcome some limitations. One of the limitations was that the turbine is not self-starting. As the setup was not designed to give starting torque from external sources until the turbine reaches a certain speed, the generator was mounted manually with the turbine shaft to overcome this limitation which was not possible during oscillation in a later step which was discussed in the following step. Here a blower was used to make different air velocity and an anemometer was used to measure the air velocity. A tachometer was used to measure the speed (rpm) of the turbine (without load). A multimeter was used to measure the voltage and current flow. Secondly, the air tube was mounted on a circular plastic drum which was used as a collecting chamber. Here the whole setup oscillated vertically in a pond in Chittagong University of Engineering & Technology, Chittagong, Bangladesh. As the drum oscillates, the pressure became up & down. So, air oscillated concerning fo to the turbine and the turbine rotates. Here only RPM and oscillation rate were taken as data for calculation where the turbine was rotated without load as it was not self-starting and power was not measured. The air velocity hence flows coefficient was found by calculation. This method was applied because the collecting chamber was not designed for extracting wave energy from the ocean. So, the whole setup oscillated in the pond, and measurement of flow coefficient was not possible by an anemometer.

Fig. 5 Practical view of the study

3. Result and Discussion

In this study, rpm and power was found with respect to flow coefficient in the first step which was done in the laboratory and in the second step which was done in the pond; rpm was found with respect to flow coefficient.

Flow co-efficient, $\Phi=\frac{V}{\omega . r_t}$ (1)

Power, P=IV (2)

3.1 Results found from wind blower

In the laboratory test with a wind blower, it was found that rpm was increasing with the increase of flow co-efficient. Maximum RPM was 257 at flow co-efficient 0.403 & maximum power 0.031 watt at 2.28 V. At low flow co-efficient 0.235; RPM was found 174 and power output was 0.012 watt. At the flow coefficient, 0.279 rpm was found 215 and power was 0.016 watt. At flow co-efficient 0.347 rpm was found 244 and power was 0.027 watt. Fig. 6 shows RPM is increasing but the slope of the line is decreasing with the increase of flow coefficient. This is because of high drag co-efficient at high flow co-efficient.

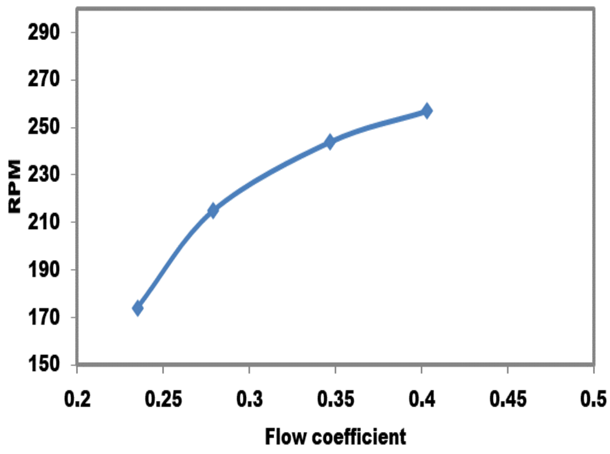


Fig. 6 Variation of RPM with flow of co-efficient

Fig. 7 shows power is increasing with the increase of flow coefficient. In this study, power output is found low. This graph is symmetric with rpm vs flow coefficient graph.

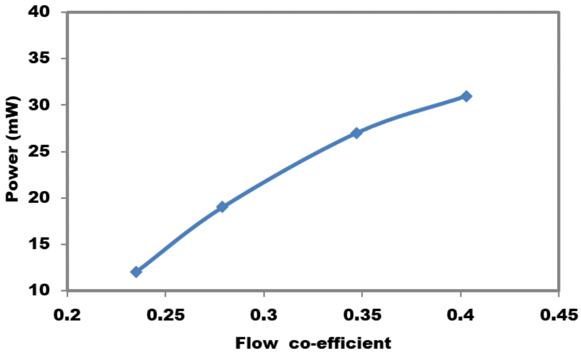


Fig. 7 Variation of power with flow co-efficient

3.2 Results found from wave oscillation

Here some assumptions are considered to simplify this calculation. They are: the height of oscillation is constant; the density of air is constant at this range of variation of pressure and all the air is fully reciprocated (passed through turbine) during oscillation.

During oscillation, flowing equations are used for finding the results:

Volume of the drum, $V=\frac{height \times diameter^2 \times \pi}{4}$ (3)

Volume flow rate through the air tube, $Q=V/t$ (4)

Velocity of air through the air tube= $Q/A_{\text{air tube}}$ (5)

The height of the oscillation is 1.5 m long and the diameter is 0.55 m. The flow coefficient is varied by varying oscillation rate. The velocity is found from eq. (5) and flow coefficient is found from eq. (1). The volume of the drum is 0.356 m^3 and area of air tube is 0.102 m^3. Here maximum flow coefficient 0.536 was possible to attain were rpm is found 319 and at flow coefficient 0.228 the rpm is 165; at flow coefficient 0.385 the rpm is 312; at flow coefficient 0.477 the rpm is 324; at flow coefficient 0.513 the rpm is 322 are found during this experiment.

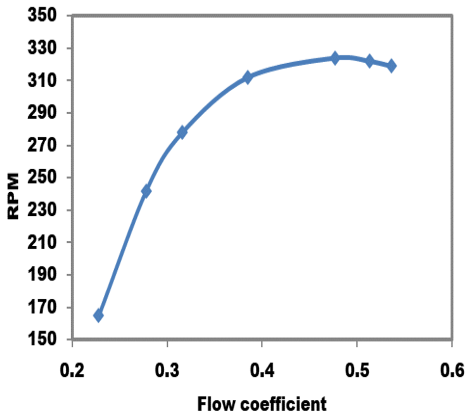


Fig. 8 Variation of RPM with flow of co-efficient

Fig. 8 shows that rpm is increasing with the increase of flow coefficient and slope of the line is decreasing and the maximum rpm was 324 at flow coefficient 0.477. After this the line is about to horizontal and slope goes negative.

4. Conclusion

This study was done for the purpose of generating power and to analyze the variation of RPM with respect to flow coefficient. Here power output was found low because of friction losses in bearings & electrical power loss. Moreover, the wells turbine had low efficiency compared with another impulse turbine & reaction turbine. However, 324 rpm was found at flow coefficient 0.477 during oscillation in the pond and 257 rpm was found during wind blower test at flow coefficient 0.403. The results were about same for both tests. The power output was found 31 mW at flow coefficient 0.403. This study shows that For large power output and rpm, the turbine size should be increased in diameter and flow coefficient should be in the range of 0.4 to 0.5 for efficient turbine operation; because it was seen that rpm and power line's slope was negative after flow co-efficient 0.5 and it was horizontal around flow coefficient 0.5. Another purpose of this project was to have an idea of extracting power from the Bay of Bengal in the costal of Bangladesh. As average wave height was 2 m long in this sea it is possible to generate power by using a significantly large collecting chamber.

References

[1] Vining JG, Muetze A. Governmental regulation of ocean wave energy converter installations. In: Industry applications conference, New Orleans, LA; 2007. p. 749-55

[2] Lund H, Mathiesen BV. Energy system analysis

of 100% renewable energy systems, the case of Denmark in years 2030 and 2050. Energy 2009;34(5):524-31.

[3] H, Polinder; M. Scutto, "Wave energy converters and their impact on power systems". Future power system, 2005. Page(s): 9 pp. 9 Digital Object Identifier 10.1109/FPS.2005.204210.

[4] European Marine Energy Centre (EMEC) Ltd., Internet: http://www.emec.org.uk/marine energy/wave-devices/, (20 Nov, 2018).

[5] I. López, J. Andreu, S. Ceballos, I. M. de Alegría and I. Kortabarria Renewable & Sustainable Energy Rev., 27, 413-434 (2013)

[6] J. Brooke, "Wave power activities in the Asia-Pacific region," in Wave Energy Conversion. Oxford, U.K.: Elsevier, 2003, pp. 79–82

[7] Y. Torre-Enciso, I. Ortubia, L. L. I.de Aguileta, and J. Marqués, "Mutrikuwave power plant: From the thinking out to the reality," inProc. EWTEC, Uppsala, Sweden, Sep. 2009, pp. 319–329

[8] M.H. Mohamed, G. Janiga, E. Pap, D. Thévenin, "Multi-objective optimization of the airfoil shape of Wells turbine used for wave energy conversion" 2010.

[9] Raghunathan S, Setoguchi T, Kaneko K. Aerodynamics of monoplane Wells turbine a review. Int J Offshore Polar Eng 1994;4(1):68e75

[10] Chi-Cong Nguyen, Thi-Hong-Hieu Le, Phat-Tai Tran, "A Numerical Study of Thickness Effect of the Symmetric NACA 4-Digit Airfoils on Self Starting Capability of a 1kW H-Type Vertical Axis Wind Turbine" 2015.