Ocean Wave Driven Air Pump for Savonius Turbine Blades

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Abstract— Seventy one percent of the earth's surface is covered by ocean. There is approximately 10TW of wave energy in the entire ocean, and an enormous part of which is just gone to a waste. With the world's problem today on global warming due to burning of hydrocarbon fuels to produce useful forms of energy, here presents an alternative way towards producing the energy we need for our consumption. This study aims to design, fabricate, and evaluate the experimental ocean wave driven air pump system that would practically work with ocean wave height below and equal to the stroke capacity of the air pump, and be able to produce a definite rotational speed of the shaft. A three-blade Savonius turbine enclosed in a housing assembly is fabricated to operate with a concentrated flow of compressed air from the air pump. The air flow is produced by the reciprocating action of the piston of an air pump and is driven by the forces from ocean waves. Data on ocean wave characteristics with cycle speed of two(2) seconds and heights 100mm, 200mm, 300mm and 400mm are tested experimentally. Results obtained from the system showed potential energy production of 0.013W at a wind speed of thirteen(13) meters per second.. At a full stroke of the piston, the highest attainable rotational speed is 112 rpm which is higher than 100 rpm as the minimum objective in this study. Concern like the small quantity generation of torque and power output could be resolved by further development of the system.

Index Terms— amplitude, ocean waves, reciprocating motion, renewable energy, rotational speed, savonius turbine blades, wave height

1 INTRODUCTION

THE surface of the earth is covered by land mass and body of water. The body of water that covers the earth's surface claims the seventy one percent of the earth surface and it includes the river, lakes and the ocean. The objective of this study is to design and fabricate a system that would allow the wind turbine to produce a rotational speed of about 100rpm at maximum stroke of a piston using the ocean's wave energy. Ocean wave motion, together with a horizontal-motion suspended buoy, can cause a reciprocating motion; a push and pull motion that can be used to force a plunger or an air pump device to perform a suction and discharge of a fluid, like air, turn the turbine and produce rotational speed and torque to run a generator coupled in the turbine's shaft. This study targets to design the air pump that would make the system turbine rotate in one direction despite the back and forth reciprocating motion of the pump piston.

An experimental rig will be fabricated to measure and determine the air pressure inside the pump, the shaft rotational speed and wind velocity from the air pump designed for several specified ocean wave height. Several engineering instruments will be used to measure the different thermodynamic parameters involved in the fabricated experimental rig. Pressure gages are device used for measuring pressure inside a compression chamber or even inside a vacuum space. Tachometer is an instrument used in measuring the rotational speed of a shaft or disk, as in a motor or other machine. Anemometer is a device for measuring wind speed, and is a common weather station instrument.

Upon determination of shaft torque and power produced out of each set of test data power and torque equations are used. Graphs are then generated out of the set of correlations available in order to simplify the gathered engineering data.

In this study, the type of turbine used for harnessing the power from the compressed air is the Savonius turbine. The Savonius turbine is one of the simplest and oldest turbines available in this study. Aerodynamically, it is a drag-type device, consisting of two or three scoops. Because of the curvature, the scoops experience less drag when moving against the wind than when moving with the wind. The differential drag causes the Savonius turbine and shaft to spin, creating torque and shaft power.

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General objective

The primary aim of this study is to design, fabricate, and evaluate the experimental ocean wave driven air pump system that would practically work with ocean wave height below and equal to the stroke capacity of the air pump, and be able to produce a range of rotational speed which could be used to run a generator and eventually produced an electric power.

1.1 Specific objectives

To satisfy the general objective of this study, the following specific objectives must be accomplished:

1.To design and fabricate the system that would allow the wind turbine to produce a rotational speed of about 100rpm.

2.To measure the available air pressure inside the pump, shaft rpm and wind velocity from the air pump for several specified ocean wave height.

3.To determine the average power produced out from the experimental rig.

1.2 Conceptual framework

The input properties of the experimental rig will be the magnitude from the surge of the ocean wave. The energy from the wave surge will be creating a reciprocating force on the piston's air pump. Reciprocating force compressed the air and released it from the exhaust vent with a certain wind speed or velocity thereby inducing a rotational speed on the turbine blades. The height of the ocean waves contributes to a large part of the energy that will be used to compress the air inside the air compression chamber of the air pump. The mechanical energy output of these combined energy sources will be used to drive a generator in order to measure the power being produced.

An effective design of the air pump and as well as the turbine system are needed to generate rotational speed and provide an avenue for technical data gathering. Values for the magnitude of the force acting on the turbine blades, theoretical torque of shaft, and theoretical shaft power for each set of test data could be determine through proper computation. Measurement of the different thermodynamic parameters such as the air pressure in the pressure dominant side of the pump requires an utmost accuracy in order to present a realistic technical result on this study.

1.3 Significance of the study

Conversion of renewable energy is a hot topic these days especially with the issues about global warming and energy crisis our planet is facing. The significance of this study is focused with the following line of thoughts:

1.Presentation of a clean and pollution-free method of producing an alternative source of renewable energy.

2.The experimental design of ocean wave energy converting system would help promote further any renewable resources, particularly ocean wave energy, and to become an alternative way of generating mechanical work output for the production of electrical energy.

3.If successfully implemented to its designed application, it would help reduce the amount of greenhouse gases emitted into the earth's atmosphere.

1.4 Scope and limitations

Due to time constraints of the study, this endeavor is only limited to the design and fabrication of an effective experimental rig used for harnessing renewable energy from the ocean waves. The necessary parts needed by the system are limited to the locally available materials and the available tools and equipment in the mechanical engineering laboratory. Measurements and data gathering of the engineering properties surrounding the experimental rig will be done in beaches within the vicinity of the city of Cagayan de Oro and the province of Misamis Oriental.

2 METHODOLOGY

This study will implement an experimental method in the data gathering needed in the analysis of the results. An experimental rig will be fabricated in order to measure the required parameters needed in the analysis of the relationship between wave heights, wind velocity and shaft rotational speeds.

2.1 Flow of the study

This study will start in gathering information from related literature on the latest wind and wave energy technologies especially from textbooks and recent renewable energy journals. Next, is the selection of materials to be used and the engineering design for the experimental rig. When the design of the experimental rig is done, fabrication of the Savonius turbine blades will start together with the other parts of the experimental rig. After the fabrication of the experimental rig, preliminary testing will be done and the data gathering from the experimental rig will immediately commence. The last step of the study is the analysis of the data with the required calculation on the power output from the rig.

2.2 Materials and equipment

For convenient purposes in the fabrication of the Savonius turbine blades, the authors will use Chaps-Stran-Mat Fiber, with its reagents: resin (mixture of cobalt and styrin), hardener, thinner; to mold and form the turbine blades, to be fixed in a length of 304.8mm and in a 6.35mm diameter stainless steel shaft. The layout of the Savonius turbine blade is shown in Fig.1.

The straight arrows represent the direction of flow of the compressed air from the air pump as it strikes on the turbine blades.

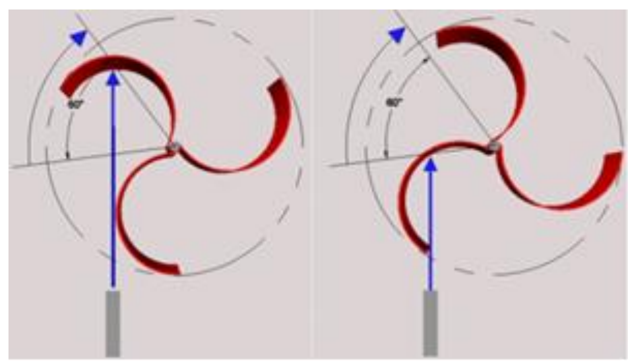

Fig.1. Layout of the Savonius blades

Since the concept of the fabricated system in the study is new, this fabricated system would only serve as a prototype, in which the authors find it best to be in the given convenient size. The turbine blade will then have a dimension of 76.2mm semicircle diameter and blade length of 76.2mm, as indicated in Fig.2.

Ball bearings for the 6.35mm diameter shaft are attached at both sides for smooth rotation when the turbine is enclosed in its housing as shown in Fig.2.

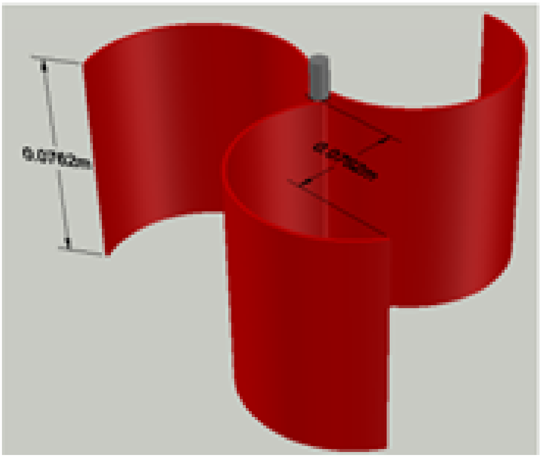

Fig.2. Turbine blade profile

The turbine housing will be made out of wood since with right tools such as jigsaw and scroll saw will be easy and convenient to construct for the turbine housing, rather than using steel plate. The housing would be composed of two segments; there is turbine frame and the turbine cover. After the turbine is set inside the frame, the cover would then fix the turbine inside the housing in such a way that the turbine can rotate smoothly inside without any obstruction. There would only be a spacing of about 4mm to 5mm from the turbine to the housing in all angles when the turbine is fitted inside the housing as shown in Fig.3. There would be two holes found on the housing and these holes are for the inlet and exhaust of air passages.

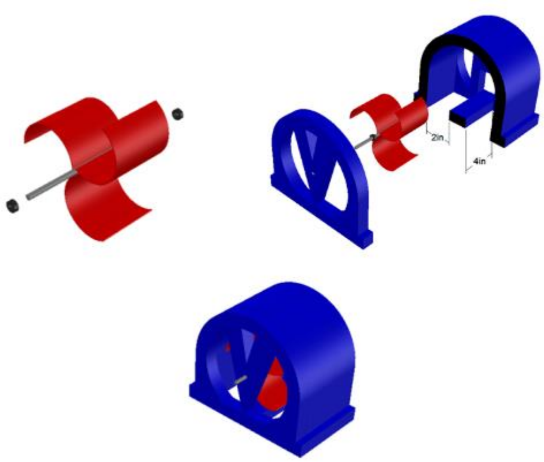

Fig. 3. Turbine blade housing assembly

The authors will also fabricate the air pump system since it is very difficult to find the type of pump needed in the rig. The pump will be composed of several parts, namely: the pump cylinder, the piston, the piston ring, the aluminum air pipe, and the flapper valves as shown in Fig.4.

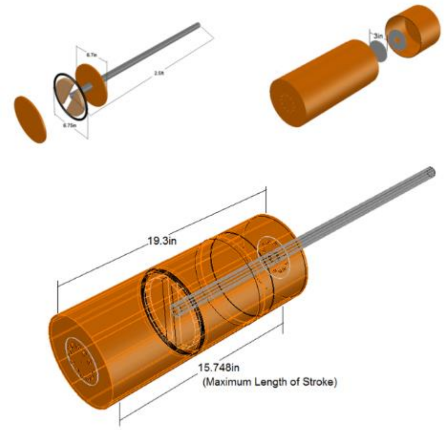

Fig. 4. Air pump components and assembly

The pump cylinder and piston will be made out of Chaps-Stran-Mat fiber. Pressure gage will be installed at the bottom of the pump (pressure side of the pump) to obtain the value of the wind speed for the turbine during the test.

For the frame structure of the whole system, the material to be used are thin sheets of u-beam since by design calculation, the whole system would not be heavier above forty(40) kilograms, the structure would just hold the system components in place and provide guide to the dynamic components such as the air pump cylinder and the frame of the Savonius turbine blades..

2.3 Fabrication of the experimental rig

All fabrication and assembly of the experimental rig were done in the mechanical engineering laboratory. The available mechanical tools and equipment were used in cutting the required materials and welding of the different parts of the experimental rig as shown in Fig.5.

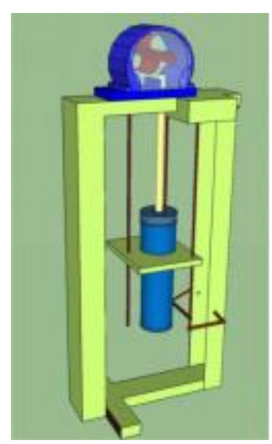

Fig. 5. The experimental rig

The air pump has a stroke capacity of 400mm which is divided into 4 segments of 100mm, 200mm, 300mm and 400mm marked on the air pump cylinder, and the marks are assumed to be the heights of waves during the test. For each set of the wave height, the complete compression cycle will be done under two(2) seconds. From trough to crest and crest to trough is the complete cycle of a single wave.

2.4 Data gathering

After the set-up of the whole system is done, the system will then be ready for testing and data gathering. The testing and data gathering must be done in the beaches within the vicinity of the city of Cagayan de Oro and within the province of Misamis Oriental. Safety precautions will be highly observed for the authors and the hired laboratory assistantss.

For the convenience of the test, the maximum length of stroke will be divided into four(4) segments which then would be assumed to be equal to the heights of the ocean wave. For each of the given wave height, the cycle will take two(2) seconds to complete the 360^o rotation of the shaft, meaning, from trough to crest and crest to trough the complete cycle. For each given wave height during the test, the factors to be measured are: (1) the wind velocity on the exit of the aluminum pipe, (2) the rotational speed of the turbine shaft, and (3) the air pressure at the pressure dominant side of the pump. The shaft rotational speed will be measured with the use of the laboratory hand tachometer, wind velocity will be measured with the laboratory hot wire anemometer, and the pump pressure will be measured with the use of the pressure gauge installed at the bottom of the air pump cylinder. The test will be done in ten(10) trials.

To assess the convenience of data gathering for each trial and for the sake of convenient visualization as well, graphs and data tables are to be generated. The graph will contain: (1.)the shaft rotational speed vs. the wind velocity, (2.) the wind velocity vs. the shaft power, and (3.) the wave height vs. the wind velocity.

The tabulated data will also contain: (1.)the wave height, (2.).the shaft rotational speed, (3.) the wind velocity, (4.) the air volume flow rate, (5.).the air pump pressure, (6.) the force acting on the turbine, (7.) the torque of the shaft, and (8.) the shaft output power.

With wave height as the independent variable, the dependent variables are the wind velocity, the force acting on the turbine blades, the shaft rotational speed, the shaft torque and the shaft output power. The hand tachometer used during the test is well calibrated with the standard tachometer available in the laboratory.

3 Experimental

During the test, the authors used a timer and conducted the test on the open sea. The test was performed with each specified and approximate wave height, measuring the air pressure, the wind velocity and the shaft rotational speed. The test was done with ten(10) trials each. The results showed that at constant time of completing a cycle of wave, the shaft rotational speed, the wind velocity, and the air pressure varies with the height of the ocean wave. The higher the heights of the ocean wave, the higher the air pressure in the pump, the greater the wind velocity and the higher the values of the rotational speed on the shafts. With known parameters such as the shaft rotational speed, the moment arm from the center of shaft to resultant force of wind direction, the diameter of pump cylinder, the inside diameter of pump aluminum pipe and the air pressure on pump varying with the wave height, then the shaft torque and output mechanical power are obtained from calculation using mathematical relations and equations. The other factor causing the significant difference between the line-profiles of the graphs generated within each of the trial is the appropriate use of measuring device mounted in the experimental rig. The experimental rig utilized bourdon type of pressure gage because the available data logger has yet to be designed as a water proof device. Initially, because of unpredictable pressure for the available wave heights, the use of high capacity pressure gage was used which enables a lesser accuracy in the reading of the pressure during the test. After which, a lower capacity pressure gages were used in order to improve the efficiency of the air pressure measurement inside the air pump. The inaccuracy of the pressure reading of the air pump caused by high capacity pressure gage will contribute to an inferior result on the calculation of the torque and to the power output of the experimental rig. As depicted in Table 1, the results showed that the torque and power varies with the wave height, rotational speed of the shaft, and the amount of force generated by the wind ramming the turbine blades. As the values of the ocean wave height increases, air pump pressure increases, rotational speed of the shaft and magnitude of force will also increase. As a result, the shaft torque and power would also increase. The maximum available wave height accomplished by the experimental rig is 400mm high. The maximum air pump pressure delivered by the air pump chamber at 400mm wave height is 2,253.2 Pa with a wind velocity of 17.48 meter per second and has an equivalent shaft power of 0.013W as shown in Table 1.

Table 1. Wave heights against shaft power

Wave Height, m	Shaft Rotational Speed, rpm	Wind Velocity, m/s	Air Volume Flow Rate, m^3/s	Pump Pressure, Pa	Force Acting on Turbine, N	Shaft Torque, Nm	Shaft Power, W
0.1	36.6	4.35	0.0025	320.2	0.0043	0.0002	0.00068761
0.2	52.3	11.88	0.0068	573.1	0.0076	0.0003	0.00174865
0.3	74.6	13.47	0.0078	1107.3	0.0147	0.0006	0.0048
0.4	98.7	17.48	0.0101	2253.2	0.0300	0.0012	0.01280842

The amount of torque and power obtained from the data gathering are calculated using the mathematical relations and equations. The torque of the system as could be observed in the results, are relatively small. But looking at the system, one will realize that the results are logical, since the turbine diameter has a minimal size, resulting with a smaller length of moment arm from center of shaft to the resultant wind force acting on the turbine blades.

4 Results And Discussion

For every set of data from every trial being made during the experiment, a correlation of shaft power and wind velocity, shaft rotational speed and wind velocity, and wave height and wind velocity were made. With the use of Microsoft Excel, graphs of the said correlations are generated as part of the specific objectives of the study. Mean data graphs of trials 1-10 correlations are illustrated in Fig. 6 and Fig. 7.

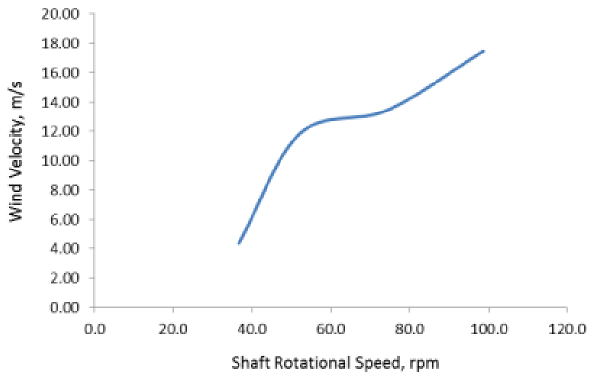

Fig. 6. Shaft rotational speed with respect to wind velocity.

The graphs generated from the correlation of parameters with each of the trials made during the test displayed a significant stability between the results of the rotational speed of the shaft with respect to the wind speed from the air pump. With the degree of careful execution done by the authors during the test and data gathering, the result showed the significant values for the shaft rotational speed. It is evident in the gathered data that there is a proportional increase in rotational speed of the shaft at an available wind velocity from the air pump. It is quite evident that there is a steep proportionality constant of the shaft rotational speed with the air pump wind speed below thirteen (13) meters per second. Above thirteen(13) meters per second of air pump wind speed, the proportionality constant between the shaft rotational speed and the wind velocity becomes less steep compared to the proportionality constant below thirteen(13) meters per second of air pump wind speed as depicted in Fig.6. Other than the concerns with the factors causing different graph line profiles with each of the trials being made, the graphs generated out of the correlations shows the direct proportion of the wind velocity, shaft rotational speed and the shaft output power to the ocean wave height. The greater the ocean wave height, the higher the air pressure in the pump that creates a better wind velocity for the turbine blades resulting to a higher rotational speed on the shaft. With the higher torque on the shaft will result to a higher mechanical output on the experimental rig as shown in Fig.7.

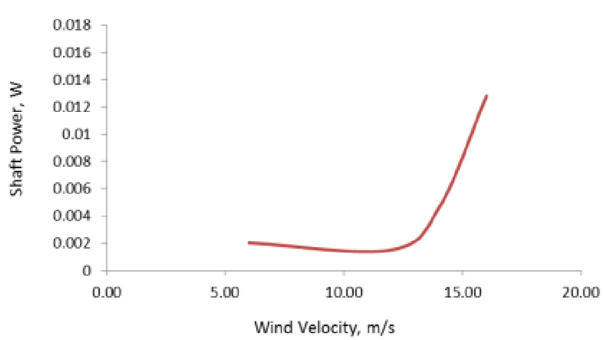

Fig.7. Shaft power output with respect to the wind velocity

The mechanical output of the experimental rig do not have a proportional increase in terms of the wattage output for a certain range of wind velocity of the air pump up to thirteen(13) meter per second. From six(6)meter per second up to thirteen(13) meter per second, the mechanical output is pinned at 0.002 Watts. But when the heights of the ocean wave increases, the air pump air pressure also increases bringing up a higher wind velocity on the turbine blades. With the ocean wave height increases, the air pressure of the pump increases and the mechanical output also increases to as high as 0.013W for the fabricated experimental rig. The proportionality constant of the power output from thirteen(13) meter per second up to seventeen(17) meter per second is very steep and traversed a straight line. If there is an available open sea location that could provide an ocean wave height bigger that 400mm, a wind velocity greater than 17 meters per second can be harnessed for a greater power output. With the trend of the graph, a better and a higher mechanical output can be expected for bigger ocean wave heights. With a greater wave heights and at a greater wind velocity, there would be some doubts that the fabricated experimental rig could withstand the higher stress imposed on the bigger ocean waves.

5 Conclusion

With the data gathered from ten(10) trial tests made during the experiment, the system showed potential energy source conversion for renewable energy. Some concern like the small quantity generation of torque by the system could be resolved by further development for a bigger system, particularly the turbine and air pump components. With proper ratio of the pump volume flow rate and turbine size, the system would provide satisfactory results with a more effective design for an energy conversion system components and would further improve its output and an overall mechanical efficiency. It is quite evident that there is a steep proportionality constant of the shaft rotational speed with the wind speed below thirteen(13) meters per second. Above thirteen(13) meters per second of wind velocity, the proportionality constant between the shaft rotational speed and the wind velocity becomes less steep compared to the proportionality constant below thirteen(13) meters per second of wind velocity absorbed by the Savonius turbine blades in the fabricated experimental rig.

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