Modelling of an Air Turbine for a Hybrid System for Sea Wave Energy Utilisation

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Abstract: In connection with global warming and the depletion of energy production resources, new clean ways of obtaining energy are increasingly being sought. A source of renewable energy harvesting is the energy of sea wind waves. The present paper reports the design and modelling of an air turbine, which will be used in a hybrid system for utilisation of the energy of wind waves.

1 INTRODUCTION

Wind energy is a type of solar energy, as it results from solar energy. Solar energy is absorbed by both the land and water surfaces (Mafimidiwo et all,2017), but due to the water's high heat capacity, the efficiency of the accumulated solar energy in the water basins is higher than that in the land. The statistics on the wave energy market show that wave energy production and utilisation reached $43.8 million in 2019, with the expectations of increasing its value up to $141.1 million by 2027 (Dixit et all,2020).

The only water basin in Bulgaria where the sea waves could be considered an energy source is the Black Sea. To assess the resources of sea waves, the main characteristics and features of the respective water basin are used (Kalogeri et all,2017) Among the meteorological stations located on the Black Sea coast, Kaliakra station gives the best information about wind resources on the high seas. The reason is that Cape Kaliakra is the most protruding point of the land in the sea. Usually, the wind speed during a storm is not constant - it increases and decreases after reaching a peak, with fluctuations in time and direction (Rusu et all, 2018).

Determining is, in the end, the power of the sea waves in the deep-water zones, normalised to one linear meter of the wave format. The value of this indicator in the USA and Japan's coastal areas is about 40 kW/m, on the west coast of England – up to 60 kW/m, and for the Black Sea coast (Bulgaria) – up to 12-15 kW/m (Rusu et all,2018),(Valchev et all,2012), (Markov et all,2017), (Lehmann et all,2017). An estimation of the theoretical energy resource of the waves in the Bulgarian territorial sea waters was made in 20 points, almost evenly distributed along the coastline, based on the results of numerical simulations of the wave climate in the western Black Sea (Markov et all,2018).

The Wells turbine for capturing wave energy was invented in the 1980s (Shehata et all, 2017). The Wells turbine is mainly used in power plants to absorb wave energy, but some drawbacks make the technology difficult to implement. The efficiency is very low, and in case of low airflow, the turbine switches off. The turbine blades have a large spread but are closely spaced, which requires them to be permanently used.

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The aim of our paper is to present results from the modelling and design of an air turbine for a hybrid system for wave energy utilisation. The hybrid system experimental stand consists of two turbines: an air turbine, which is presented in this paper and a water turbine with oscillating blades, which has already been presented in (Velichkova et all, 2018). The designed air turbine is a modification of the Wells turbine, and the designed calculations are presented.

2 DESIGN CALCULATIONS

2.1 Design Principle of the Wells Turbine

The Wales turbine is an axial reaction flow turbine used to extract wave energy by changing the airflow. It is connected to the electric generator and works with or without guide vanes (Raghunathan et all 1982). The turbine is made of symmetrical wing profile type blades, located around a central hub and rotating in one direction, regardless of airlow direction. It works based on the general aerodynamic theory of the aerodynamic wing (Gato et all, 1988), (Raghunathan et all,1995).

The blades are horizontal that allows them to rotate in the same direction no matter where the working fluid comes from – Figure 1. The air's absolute speed strikes the blades in the axial direction, and the tangential speed of the blade acts in a direction parallel to the plane of rotation. The relative speed W acting at an angle α (angle of attack) relative to the turbine blade causes a lifting force L perpendicular to W and a force of frontal resistance D in the W direction. In this case, the lifting force can be divided into axial and tangential forces, the direction of the tangential one always being in the same direction or the direction of turbine's rotation.

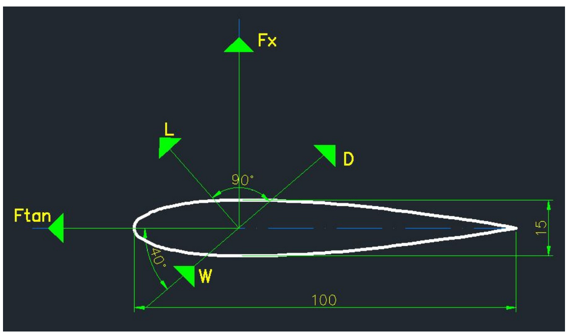
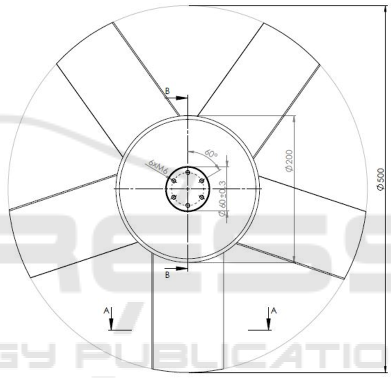


Figure 1. Wing profile of a Wells turbine blade.

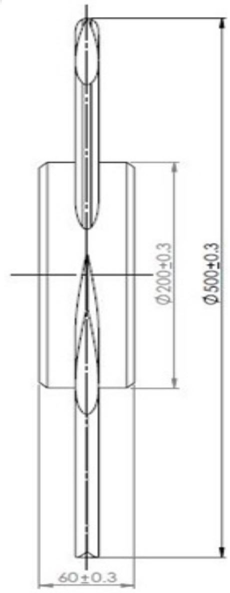
Where F_{tan} is draft force, F_x is lift force and W,D and L represent the reduced of drag force.

2.2 Design and Calculations

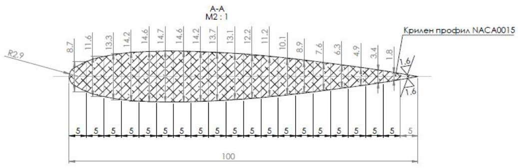
The turbine we designed and built for our experimental stand is a modification of a Wells turbine and should work without a guide device. It should be made of a whole aluminium block and to have 5 blades with a wing area of F = 0.0147 m^2, or for all blades, the turbine area is F_{total} = 0.0735 m^2. The diameter of the hub is Φ = 200 mm, and the entire diameter of the turbine with blade span is Φ = 500 mm. Figure 2 presents a drawing of the turbine wheel and its projections. The section of the turbine blade is presented in figure 2c and gives clarity about the construction of the wing profile of the blade itself and a cross-section of the turbine blade.



a) top view of the turbine wheel



b) right view of the turbine view



c) cross-section through the turbine wheel blade

Figure 2. Drawing of the turbine wheel.

The following data and assumptions are used to calculate the turbine:

- NACA 0015 wing profile is selected. It has proven its potential in scientific developments among different wing profiles for air turbines, which have been tested several times. The wing profile allows the turbine to rotate in the same direction no matter where the airflow comes from.
- The air density is assumed to be $\rho = 1.29$ kg/m^3.
- The pressure difference is H = 3 m.
- The turbine efficiency is assumed to be $\eta = 0.9$.
- The air velocity is v = 1.8 m/s;
- The diameter of the pipe, in which the air turbine will be installed is $D_{tube} = 0.53$ m.
- The area of the tube of the experimental stand is S = 0.217 m^2.
- The flow rate is determinate by:

$$Q=V.S=0,39m^3/s \tag{1}$$

- The power of the turbine is calculated as:

$$P=\frac{\rho g Q H \eta}{1000}=283W \tag{2}$$

- The velocity of rotation is:

$$n=21,432Q^{-0.364}\left(gH\right)^{0.586}= \tag{3}$$
$$=67.762\,\mathrm{min}^{-1}$$

- The angular speed of the turbine is determined using the equation:

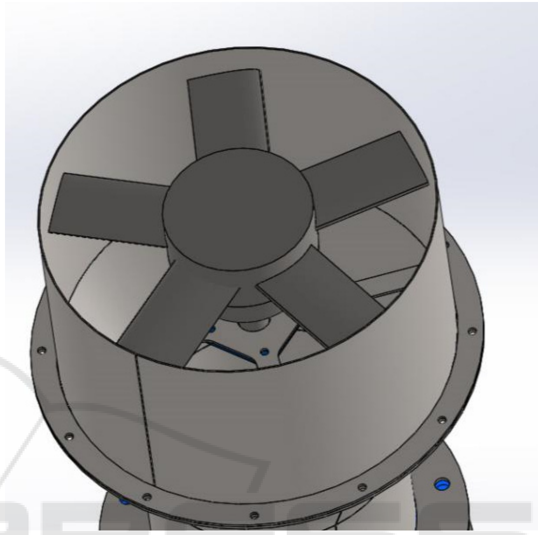
$$\omega=\frac{\pi n}{30}=7.096s^{-1} \tag{4}$$

- The specific velocity of rotation is calculated as:

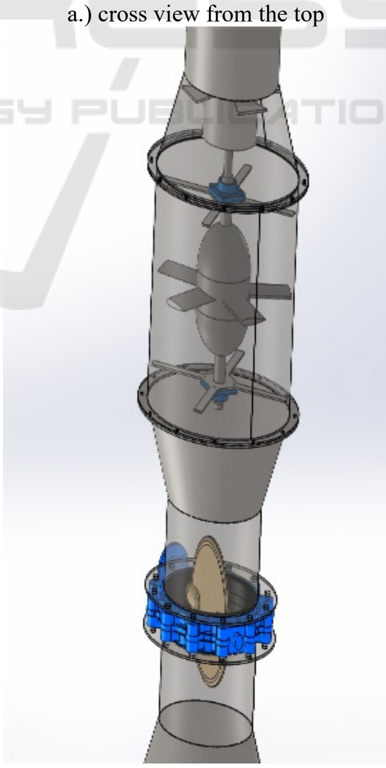
$$n_s=\frac{n\sqrt{P}}{H^{1,25}}=9,128 \tag{5}$$

3 MODELLING AND DESIGN OF THE AIR TURBINE

Before the design of the real air turbine, it was modelled using Solid Works 2019. The basic drawings of the model, showed in figure 2, were considered. Figure 3 presents the 3D model of the experimental stand with the Wells type air turbine.



a.) cross view from the top



b) view of air turbine and butterfly valve

c) view form front

Figure 3. 3D model of the experimental stand.

The turbine (figure 3a) is housed in a specially designed tower (figure 3b). The tower is made of sheet steel with a circular cross-section through which the airflow passes and transfers its energy to the turbine blades. The cylinder, in which the air turbine is housed, has an inner diameter of 0.526 m.

Several segments and details are used in the modelled stand to build the turbine tower (figure 3c). In the upper and lower part, segments with an inner diameter of 0.526 m are mounted, after which the transition segments are attached using flange connections, which change the inner diameter from 0.526 m to 0.346 m. This transition has a double function in the stand:

- to allow the assembly of a butterfly valve in the lower part again by means of a flange connection;
- to allow the increment of the fluid velocity directed to the turbine blades.

The butterfly valve is installed to stop the air flow to the turbine; certainly, a blockage is provided in the generator against unintentional rotation of the turbine. In the model stand, shown in Fig. 3, the turbine is mounted in two places, and the bearing bodies are reinforced to the respective segments.

The principle of operation of the experimental stand (figure 3c) is the following: airflow is supplied from the underside of the turbine, which in turn rotates the turbine and transfers its energy to the windings of the generator. Then an airflow is supplied from the upper side, and again the turbine produces electricity through a generator coupled to it.

In this way, the action of the waves, for which the installation is intended, is simulated. The airflow action is expressed in the wave's amplitude: the airflow climbs the tower when it is in the wave's maximum amplitude and gives energy to the turbine. In the other case, when the airflow is in the lowest part of the wave, it is sucked from the upper part of the tower and energy is again given to the turbine blades.

As a result, the system produces energy all the time. When the butterfly valve is closed, it separates the lower airflow from the system hermetically and thus, neither air can be forced in nor sucked in. This valve stops the operation of the system.

Figure 4 shows the designed air turbine based on the performed calculations and computer modelling.

a) top view b) blade profile

Figure. 4. The manufactured air turbine.

4 CONCLUSIONS

The design of an air turbine that is a part of an experimental stand for investigation of the harvesting of the energy of wind waves is shown. The main calculations are shown. The design of a modification of the Wells turbine is presented.

Further investigations in the project include different tests related to the performance of the hybrid system and its parameters, as well as the effect of environmental factors.

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