SYSTEM FOR VARIABLE PITCH VERTICAL AXIS WIND TURBINE

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Abstract. Climate changes and their effect worldwide point toward high need of renewable energy resources exploitation and, consequently, adequate policies on regulation for efficient energy consumption. Wind has been used since ancient times for producing energy and this is why research on wind turbine design and performances has been carried on since. This article is aimed to present new mechanical system for variable pitch vertical axis four blades wind turbine. The pitch angle varies depending on wind flow direction due to cam and follower, linked to a four bar mechanism.

Key words: variable pitch, wind turbine, cam mechanism, angularly adjustable blades.

1. INTRODUCTION

Although wind energy has been used by mankind for over 3000 years, even today, this renewable green resource is not exploited to its full potential yet. The wind potential is harnessed through various types of turbine construction, taking into account the terrain structure and atmospheric conditions, wind direction and intensity. Romania's Energy Strategy 2022–2030, with the perspective of 2050, decides the strategic objectives, policies and forecasted needs in the energy field. It is noted that Romania's wind resources measured at a height of 50 m indicate mainly speeds of 2–8 m/s. Speeds above 8 m/s are identified on mountain tops and in the Danube Delta according to [1].

Vertical axis wind turbine (VAWT) opportunities and ways to streamline their performance are extensively investigated in [2]. Intelligent assisted design techniques, computer analysis and real environment experiments target the flow field of air currents around the rotor, blade profile, torque and installed power coefficient.

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The Crossflex wind turbine can be successfully used on high-rise buildings as it could offer viable solution for energy needs with power between 2 kW and 4 MW. Green energy production in urban areas has been developed at large scale worldwide in recent years, while design and testing of wind deflectors to improve VAWT performance is on research focus [3]. In many cases, depending on the shape and position of the baffle, the power coefficient has increased by more than 25% in the case of a Savonius turbine.

Low wind speeds do not produce enough renewable energy for there to be a sufficient rate of profitability. Especially in the case of VAWT, optimizing the attack surface of airflows is a mandatory solution to improve performance [4]. Virtual simulations of a three-blade turbine by Response Surface methodology and multi-objective genetic algorithm, provided improved results for wind speeds between 5 and 7 m/s. The design and optimization of the system took into account three main parameters: tip speed ratio (TSR); turbine solidity; pitch angle.

A thorough analysis of the aerodynamics of VAWT blades aiming to reduce instability is presented in [5]. Using the new Morphing Blades concept, the authors aim and succeed in demonstrating performance at the design model level that is simulated with various profiles and values for the TSR, gaining power, improving endurance and reliability. The aerodynamic performance of the Darrieus turbine with straight blades, but notched in three places, is investigated in terms of the output torque induced by the electric generator. The authors [6] propose a new constructive solution, called 3-PB VAWT, which besides the advantage of technical simplicity and low manufacturing price has uniform operation.

The detailed analysis of VAWT performance in [7] shows that urban and offshore equipment in particular is being studied. Research is mainly focused on airflow aerodynamics, number and spatial orientation of blades, optimization of geometric section of blade profile, equipment maintenance. Using ANSYS software, researchers [8] provide a comparative study of the main constructive parameters for two different types of VAWT. The simulation results indicate that Darrieus turbines with coil blades offer about 8.75% more torque compared to the Darrieus turbine with straight blades.

A new model of airflow dynamics, based on Duhamel's principle, is being developed and studied for VAWT in [9]. The input functional parameters are approximated by the free vortex model. The article [10] studies a novel hybrid method for calculating the overall performance of VAWT in terms of lift line theory and the free vortex model when variable stresses occur on the blades. The aerodynamic model generated and simulated on a 17m Sandia wind turbine provides superior accuracy compared to existing experimental data for the 3D vortex model (3-DVM) and the double-multiple stream tube model (DMSTM).

Research results on variable pitching by cam and follower mechanism are presented in [11]. Vertical axis wind turbine with cam and follower pitching mechanism is tested for different wind speeds so that to increase its efficiency, evaluated by the power coefficient. The authors of [12] evidence the need for a unitary, scientifically standardized approach to wind turbine research, namely: conception, design procedures, methods of computerized analysis of air/fluid flow dynamics (CFD), testing in virtual and real environments.

This paper is further structured in chapters as follows: chapter 2 evidences the concept and design of the mechanic system for variable pitching; chapter 3 shows the modeling and simulation results; chapter 4 presents the conclusion and further development of the research.

2. CONCEPT AND DESIGN OF THE SYSTEM

In addition to the location area, the type and mechanical structure of the of the wind turbine have an extremely important role on performance. The proposed concept of VAWT is based on Giromill type one, with four blades (different from the typical three blades one) and a cam follower mechanic system that adjusts the pitch angle depending on the airflow direction and intensity. The purpose is to aid starting turbine rotation at low wind speed and further, improve the rate of wind energy conversion into electric power.

The kinematic scheme of the innovative system is shown in Fig. 1. The mechanic system is made of a four bar linkage mechanism, ABCD, where the A joint is fixed to the turbine blade, P. The kinematic elements are represented by the bars named 1 (crank); 2 (coupler); 3 (rocker) and the joints named A; B; C; D.

Furthermore, the 3 element (defined by CE and DE bars) has a cylindrical follower mounted in the joint E that keeps contact with the active surface of the cam (4). The kinematic analysis of the four bar mechanism is based on relations (1) and (2), as follows:

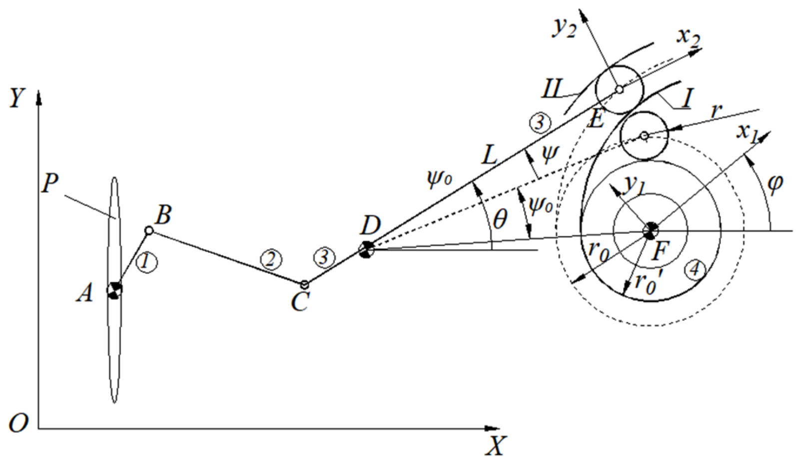

Fig. 1 – Kinematic scheme of the mechanic system.

$$f_{10} = \arccos\left(\frac{XD}{AD}\right) + \arccos\left(\frac{AD^2 + (AB+BC)^2 - CD^2}{2AD(AB+BC)}\right) \tag{1}$$

$$AD = \sqrt{XD^2 + YD^2} \tag{2}$$

Basically, the initial position for the mechanism is determined by the value of crank angle and it is defined as the minimum value of DC vector and the positive side of Ox axis (elements 1 and 2 are collinear). The coordinates of joint C, for the initial position are linked to the rigid structure of the wind turbine.

The anemometer (for monitoring airflow intensity and direction (is fixed on top of the turbine, connected to cam and, consequently, rotating it in the direction of wind blow. Rotation motion of AB element is limited to the value, φ_{10}=100 deg.

One step forward the in the system design is that of synthesis of cam follower mechanism. As shown in Fig. 1, the follower has rotation motion and its contact surface is cylindrical, rotating over the active cylindrical surface of the cam. It can be considered the equations of overlapping circle family moving their center along the theoretical profile of the cam, see equations (3) and (4)

$$(x - x_{1i})^2 + (y - y_{1i})^2 - r^2 = 0 \tag{3}$$

$$(x - x_{1i})\frac{\mathrm{d}x_{1i}}{\mathrm{d}\varphi} + (y - y_{1i})\frac{\mathrm{d}y_{1i}}{\mathrm{d}\varphi} = 0 \tag{4}$$

where *i* stands for the iteration step.

Considering the geometrical representation in Fig. 1, there can be considered the following relationships:

$$x_{1i} = (XE - XF)\cos\varphi + (YE - YF)\sin\varphi + L\cos(\theta - \varphi) \tag{5}$$

$$y_{1i} = -(XE - XF)\sin\varphi + (YE - YF)\cos\varphi + L\sin(\theta - \varphi) \tag{6}$$

$$\frac{\mathrm{d}x_{1i}}{\mathrm{d}\varphi} = -(XE - XF)\cos\varphi + (YE - YF)\sin\varphi + L\sin(\theta - \varphi)\frac{\mathrm{d}\theta}{\mathrm{d}\varphi} \tag{7}$$

$$\frac{\mathrm{d}y_{1i}}{\mathrm{d}\varphi} = -(XE - XF)\cos\varphi + (YE - YF)\sin\varphi + L\cos(\theta - \varphi)\frac{\mathrm{d}\theta}{\mathrm{d}\varphi} \tag{8}$$

so that finally results the defining equations for active surface cam profile, I – see relation (9) and follower trajectory profile, II – see relation (10).

$$x_{1I} = x_{1i} + \frac{r\frac{\mathrm{d}y_{1i}}{\mathrm{d}\varphi}}{\sqrt{\frac{\mathrm{d}x_{1i}^2}{\mathrm{d}\varphi} + \frac{\mathrm{d}y_{1i}^2}{\mathrm{d}\varphi}}}, \quad y_{1I} = y_{1i} - \frac{r\frac{\mathrm{d}x_{1i}}{\mathrm{d}\varphi}}{\sqrt{\frac{\mathrm{d}x_{1i}^2}{\mathrm{d}\varphi} + \frac{\mathrm{d}y_{1i}^2}{\mathrm{d}\varphi}}} \tag{9}$$

$$x_{1I} = x_{1i} - \frac{r\frac{\mathrm{d}y_{1i}}{\mathrm{d}\varphi}}{\sqrt{\frac{\mathrm{d}x_{1i}^2}{\mathrm{d}\varphi} + \frac{\mathrm{d}y_{1i}^2}{\mathrm{d}\varphi}}}, \quad y_{1I} = y_{1i} + \frac{r\frac{\mathrm{d}x_{1i}}{\mathrm{d}\varphi}}{\sqrt{\frac{\mathrm{d}x_{1i}^2}{\mathrm{d}\varphi} + \frac{\mathrm{d}y_{1i}^2}{\mathrm{d}\varphi}}} \tag{10}$$

3. MODELING AND SIMULATION OF THE SYSTEM

Modeling of the vertical axis wind turbine with variable pitch has been done, based on the idea of improving wind energy conversion rate and enabling turbine to start at, relatively, low wind speeds 2 – 4 m/s. Due to the cam and follower system attached to the four bar linkage mechanism, turbine blades adjust their angular position, pitch, depending on the airflow direction and intensity.Images of the 3D model are shown in Fig. 2.

Calculi program for the kinematic parameters: position, speed, acceleration has been designed for the four bar linkage mechanism – see also relations (1), (2) and [13]. The values of φ_{10} incrementally varies by 10°.

The simulation results for the kinematics of elements 1; 2 and 3 are presented as numerical values in Table 1 and as graphs in Fig. 3.

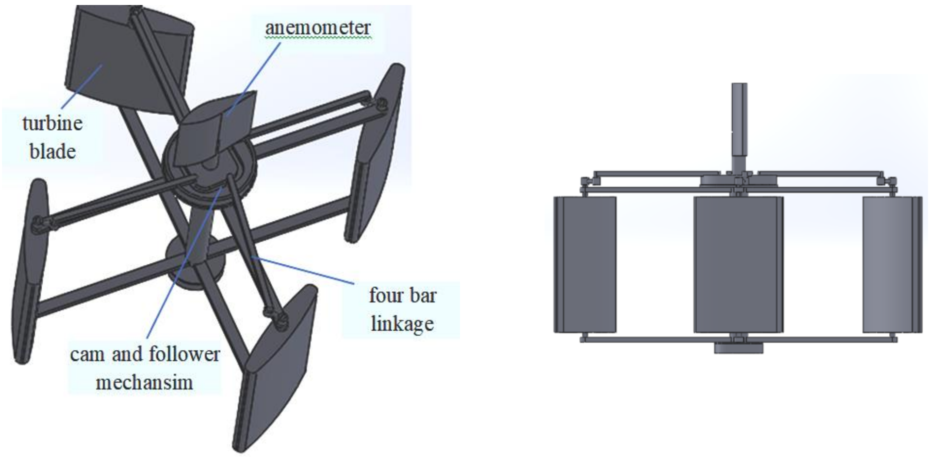

Fig. 2 –3D model of the VAWT with cam and follower mechanism.

Table 1

Numerical values for kinematic analysis of four bar mechanism

Position number	fi1	fi2	fi3	om2	om3	eps2	eps3
0	0.5230	2.7447	1.2889	0.4105	1.2012	-3.7176	8.8836
1	0.6975	2.7513	1.3112	0.3416	1.3398	-4.1558	6.9619
2	0.8721	2.7566	1.3355	0.2659	1.4429	-4.5063	4.8136
3	1.0466	2.7606	1.3613	0.1848	1.5068	-4.7791	2.4771
4	1.2211	2.7631	1.3879	0.0995	1.5285	-4.9815	-0.0043
5	1.3957	2.7640	1.4144	0.0113	1.5061	-5.1165	-2.5815
6	1.5702	2.7634	1.4402	-0.0787	1.4382	-5.1810	-5.1972
7	1.5702	2.7634	1.4402	-0.0787	1.4382	-5.1810	-5.1972
8	1.9193	2.7575	1.4862	-0.2584	1.1672	-5.0493	-10.2559
9	2.0938	2.7523	1.5048	-0.3446	0.9680	-4.8109	-12.5177
10	2.2683	2.7455	1.5197	-0.4254	0.7321	-4.4212	-14.4562

Observation. fi1 represents the incremental value for φ_{10} [rad]; om – is the angular speed [rad/s]; eps – is the angular acceleration [rad/s^2].

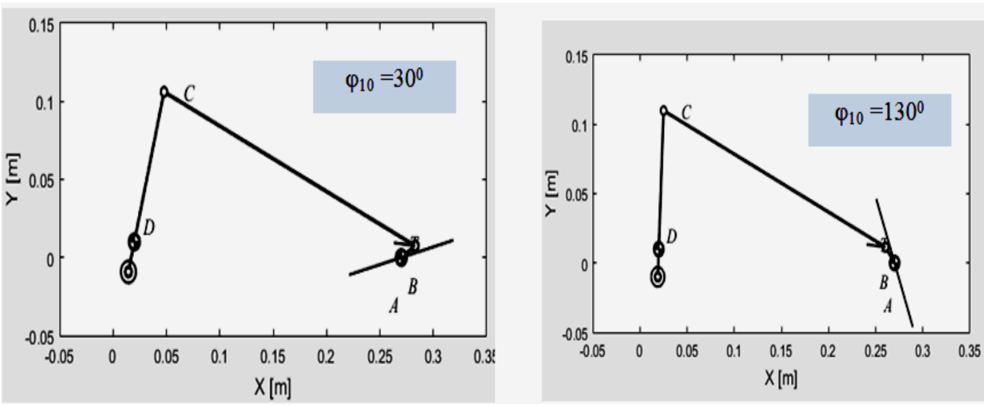

Fig. 3 – Simulation of blade pitch in four bar mechanism.

Further research was done on kinematic analysis for whole system, meaning the cam and follower mechanism linked to the four bar mechanism in the vertical axis wind turbine. The cam rotation depends on wind airflow while the crank gets a complete rotation motion.

The simulation results for the kinematics of elements 1; 2 and 3 are presented as numerical values in table 2 and as graphs in Fig. 4 (as example for distinct rotation angle values of 0° and 270°).

An image of the system for variable pitch vertical axis wind turbine, as prototype is presented in Fig. 5.

Table 2

Numerical values for kinematic analysis of cam and follower mechanism linked to the four bar mechanism

Position number	fi1	fi2	fi3	om2	om3	eps2	eps3
0	0.0000	2.7448	1.2890	9.6718	9.0386	-2.3803	5.6816
1	0.5236	3.2520	1.7768	9.5834	9.3316	-1.6277	7.6240
2	1.0472	3.7756	2.3004	9.5065	9.2083	-2.2839	10.6977
3	1.5708	4.2992	2.8239	9.5065	9.2083	-2.2294	10.7852
4	2.0944	4.8457	3.4056	9.6765	8.7299	-3.6974	6.3863
5	2.6180	5.3776	4.0937	10.2033	8.8150	-4.6204	-7.9994
6	3.1416	5.8938	4.6465	10.3269	9.0834	-4.3555	-11.1466
7	3.6652	6.4174	5.1701	10.3269	9.0834	-4.3555	-11.1466
8	4.1888	6.9410	5.6937	10.3269	9.0834	-4.3555	-11.1466
9	4.7124	7.4737	6.1768	10.1605	8.7450	-4.6554	-6.8581
10	5.2360	7.9990	6.6240	9.9061	8.5515	-4.4639	0.1447
11	5.7596	8.5162	7.0952	9.7483	8.6324	-4.0200	4.4663
12	6.2832	9.0279	7.5722	9.6112	8.8612	-3.2971	8.0979

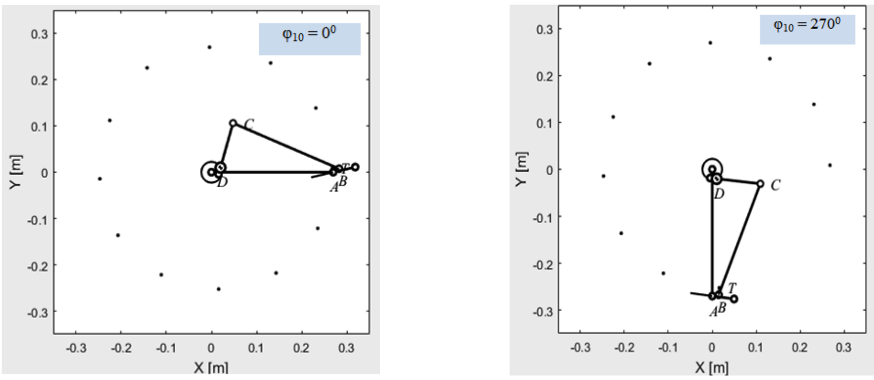

Fig. 4 –Simulation of blade pitch in cam and follower to bar mechanism.

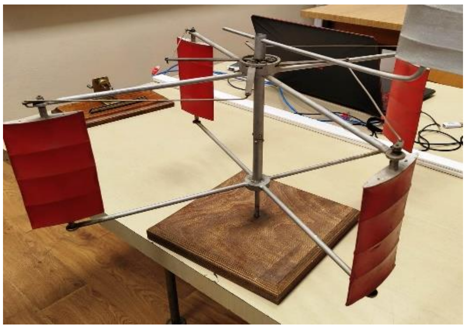

Fig. 5 –Prototype of VAWT with variable pitch system [14].

4. CONCLUSIONS

The innovative system proposed for VAWT has the advantage of being simple, inexpensive construction, with small dimensions that could be extrapolated to increase the installed power. Dynamic balancing can be easily achieved. The main disadvantage is that of the wear on the contact surface between the follower and the cam.

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