STUDY ON VERTICAL AXIS WIND TURBINE PERFORMANCE BASED ON IMPROVED SAVONIUS ROTOR TYPE

Abstract: *In the context of environmental policies aimed at gradual reduction of carbon emissions around the world today must be considered the methods of obtaining energy from renewable sources at hand. Among these, wind power is a viable solution, being exploited more and more nowadays. Although the most widespread are horizontal axis wind turbines (HAWT), vertical axis turbines (VAWT) are also to be considered due to their advantages. The SAVONIUS rotor type as vertical shaft turbine, characterized by low efficiency and high negative torque compared to HAWT, offer advantages related to easier starting, working at low wind speeds, regardless of its direction of action. Based on this constructive rotor type, multiple studies and experimental researches were performed, the results of which are materialized in the constructive-functional optimization of the SAVONIUS type rotor, so that the operating performances of the initial model were far exceeded. This paper presents constructive and operating aspects of rotor typologies improved over time, as well as an overall virtual model that is analysed with Ansys CFX to highlight the operating parameters using numerical methods.*

Key words: *wind power, rotor model, three-dimensional model, air flow analysis.*

1. INTRODUCTION

It must be emphasized that not the lack of fossil fuels that will affect human society in the near future, but even their use with the effects that can be seen in the world today related to climate change, the glaciers melting and rising of sea levels. A policy towards non-polluting energy sources is needed to slow down this process.

The renewable energy sources are within human reach and it is only necessary to develop the constructive solutions of the devices needed for capture and conversion.

Wind power is an important resource that must be exploited to a greater extent than before to produce green, renewable energy.

From the point of view of used turbines type, horizontal axis turbines (HAWT) represent the most used type of rotor construction for wind energy production.

Turbines using vertical shaft rotors (VAWT) are characterized by low efficiency compared to other mentioned types, but are characterized by advantages that recommend them for lower power applications.

Based on SAVONIUS rotor multiple constructive solutions had been created that enhance the initial operating parameters in terms of provided torque and power.

These models are presented as versions with different number of rotor blades, different geometry related to the blade shape, but also solutions for using external devices for directing the air flow to the rotor active blade to avoid the occurrence of negative torque values on the opposite blade.

These constructive solutions are presented and described in the paper together with the performance parameters obtained, as well as the CFD analysis on a virtual optimized rotor model to highlight the main operating values at certain values of air circulation velocity.

2. BASIC AND IMPROVED SAVONIUS ROTOR PATTERN AND PERFORMANCE PARAMETERS

The SAVONIUS model represents a drag force vertical axis turbine rotor (Figure 1) providing many advantages related to simple constructive solution, low cost, independent operation of wind direction, easy starting with good torque values even at low wind velocities.

The direct wind action on the rotor blades determines the appearance of drag forces on the blades surface, having differences in magnitude for the blades positioned differently so that the rotational movement is obtained at the rotor axis.

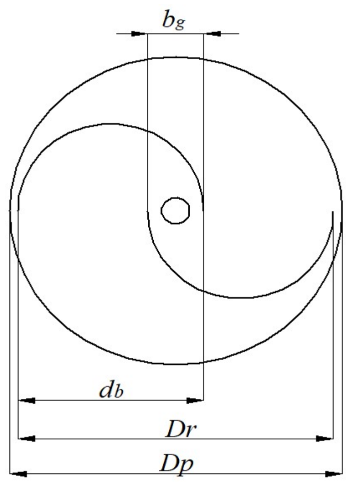


Figure 1 SAVONIUS rotor model

The performance parameters of the SAVONIUS rotor are described by means of shaft torque (CT) and power (CP) coefficients calculated according to the speed ratio (TSR) whose ratio can be expressed as follows:

$$TSR = \frac{v_{rotor}}{v_{wind}} = \frac{2R\omega}{v} \quad (1)$$

$$C_T = \frac{T_{Rotor}}{T_{wind}} = \frac{4T}{\rho_a A_b D_r v^2} \quad (2)$$

$$C_P = \frac{P_t}{P_a} = \frac{P_t}{\frac{1}{2}\rho_a A_b v^3} \quad (3)$$

$$P_t = T\omega \quad (4)$$

The initial model proposed by SAVONIUS had been continually modified in order to obtain higher power performances.

The aspects taken into account for obtaining an optimum rotor model are related to the number of blades, but also to the shape and blades arrangement.

For the rotor, different numbers of the blades starting from 2 to 3, 4, 5 and even more blades were considered, in radial arrangement, being performed numerical analyzes and experimental tests using the wind tunnel.

Some of the geometric parameters are shown in figure 2 for SAVONIUS with 3 and 4 blades, having end plate mounted for enhanced performance in power production.

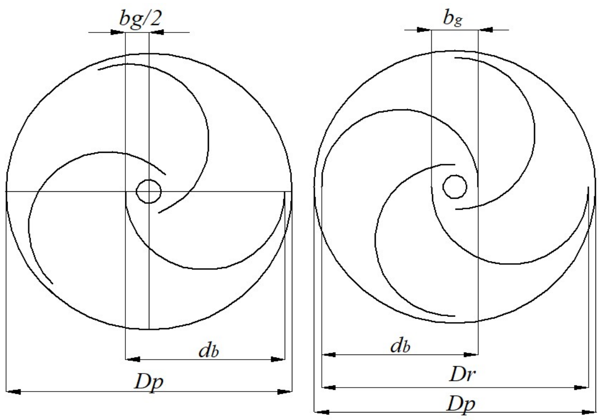


Figure 2 SAVONIUS rotor with 3 and 4 blades

Specific operating values or specific parameters are represented by the power coefficient and torque at the rotor shaft.

WENEHENUBUN et al. conducted an wind tunnel experimental study on the performance of SAVONIUS wind turbine with 2, 3 and 4 blades in order to reveal the tip speed ratio (TSR), torque (CT) and power coefficient (CP) values function of wind velocity and to demonstrate the rotor blade number influence in performance efficiency of vertical axis turbine rotors.

The obtained results show that rotor blade number play an important role on the performance parameters of SAVONIUS turbine type.

The 3 bladed rotor model provide higher values of rotational velocity and tip speed ratio than the other analyzed models with 2 and 4 blades. The highest tip speed ratio value is of 0.555 for 7m/s wind velocity.

The 4 bladed rotor model provide highest torque values compared with other 2 or 3 bladed rotor models.

The 4 bladed rotor model register good performance at low TSR values, but 3 bladed model presents the best performance at higher TSR values [1].

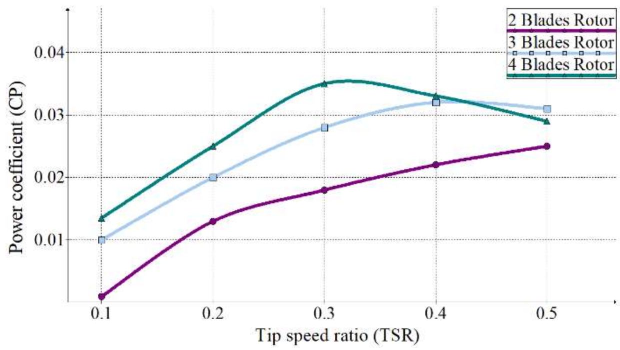


Figure 3 Power coefficient (CP) values for SAVONIUS rotor model [1]

The initial rotor model was equipped with end plates for obtaining an improvement in performance parameters.

Experimental research conducted by MAHMOUD et al. highlighted the higher values of the power recorded at the turbine shaft when using the end plates. The explanation is given by capturing a larger air volume that acts on the rotor active blade [2], [3].

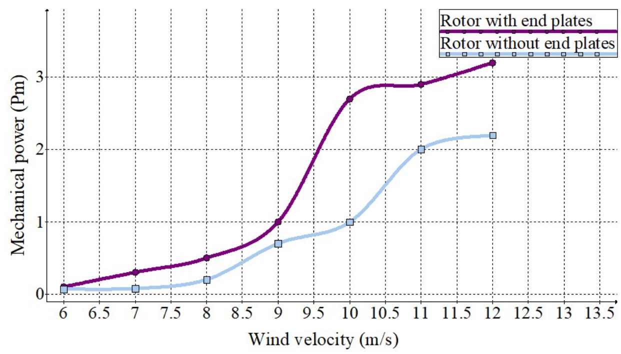


Figure 4 Mechanical power of SAVONIUS rotor with and without end plates [2], [3]

The ratio between the rotor height and width is considered aspect ratio. The value of this coefficient influences the performance parameters of the SAVONIUS rotor.

From the research conducted by ZHAO et al. it turns out that the high values of the aspect ratio cause the appearance of turbulences in the air flow having the effect of decreasing the operating performance of the rotor [4].

Experimental research conducted by KAMOJI et al. establish the performance coefficients values for different rotor types with aspect ratio 0.88, 0.93 and 1.17 having 90 degrees twist at 12e + 6 Re, emphasizing the differences that appear in power coefficient values depending on TSR, (Figure 5) [3], [5].

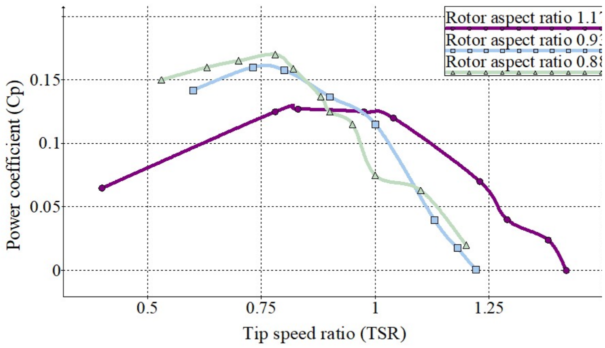
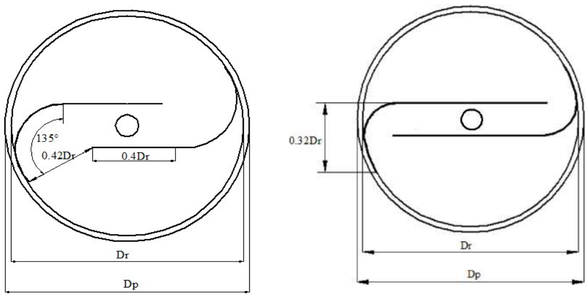


Figure 5 SAVONIUS rotor power coefficient for TSR at different aspect ratio values [3], [5]

Also, the rotor blades shape has an influence in obtaining the performance values of the SAVONIUS type rotor.

Thus, innovative models were developed that use blades with modified geometry of elliptical shape, but also of BACH and BENESH type, presented schematically in figure 6.



a) BACH type b) BENESH type

Figure 6 Improved rotor models [7], [8]

Experimental research has highlighted improved power coefficient values for modified rotor models compared to SAVONIUS classic (Figure 7).

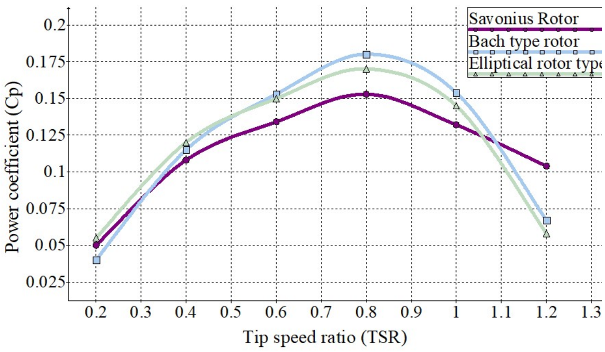


Figure 7 Comparative power coefficient values [6]

3. THREE-DIMENSIONAL MODEL OF IMPROVED SAVONIUS ROTOR ASSEMBLY MODEL

From the results of the research carried out so far, it can be considered that a rotor model with a modified blades geometry with mounted end plates is an optimal model to be used within a vertical axis wind turbine.

A rotor assembly model is built using the Solid Edge program.

The rotor diameter is of 0.7 m, the height is 0.3 m (aspect ratio of 0.428).

The rotor consists of two blades built on the BACH model (Figure 8). The thickness of the blades is 3 mm and the distance between the blades is 140 mm.

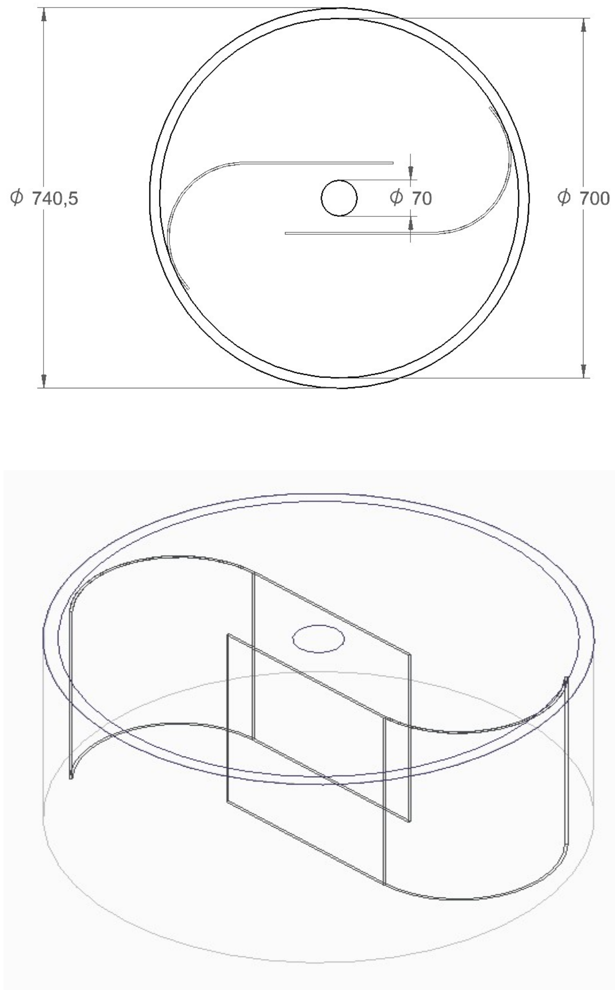


Figure 8 The schematically rotor representation (dimensions in mm)

The rotor construction offers the possibility to take over a part of air volume, from the main stream, inside the blade arranged in frontal position, as well as the air rejection on the opposite blade, being ensured the premises of rotational movement of the rotor due to the air circulation.

This model represents an improved rotor model starting from the original SAVONIUS rotor variant.

4. AIR FLOW ANALYSIS ON THE ROTOR VIRTUAL MODEL

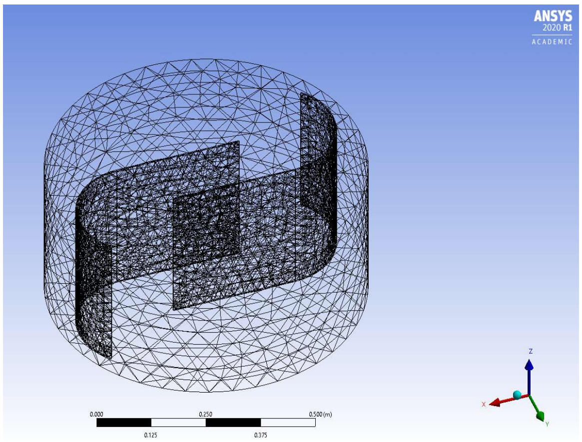
In order to highlight the performance characteristics of the rotor model, an analysis of the air flow on a virtual model performed with Ansys CFX is performed.

The overall 3D model of the previously built and presented rotor is launched in fluid flow analysis.

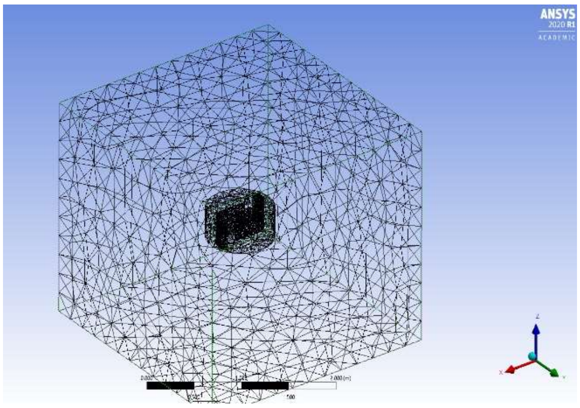
The working fluid is air at 25 degrees Celsius.

Based on the air inlet values describing the air velocity of 8 m/s, the values of air pressure and velocity at the level of the fluid region containing the rotor will be determined.

The discretization network of tetrahedral shape, with a number of 37393 nodes and 23678 elements is made for the main analysis domains (Figure 9).



a) Rotor



b) Fluid region

Figure 9 Mesh network

Boundary conditions related to the reference pressure, air inlet, as well as the air outlet of opening type are declared on the region of the main stationary fluid.

The rotor is declared as immersed solid within the fluid region having the possibility to perform rotational motion around its own axis (z axis) following the direct air action on the blades.

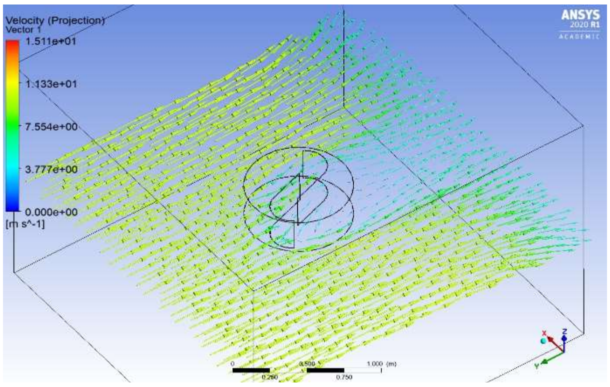
Turbulence option is set for k-epsilon model, initialization with medium intensity (5%).

5. RESULTS

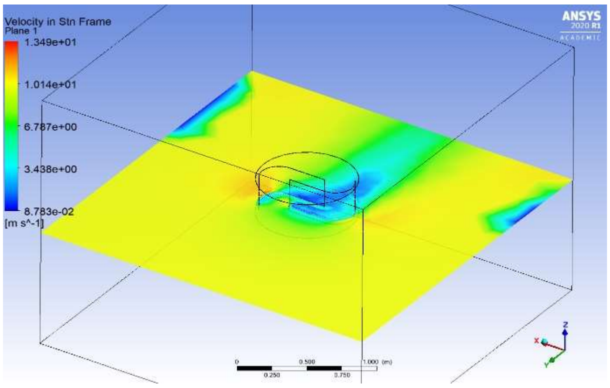
Following the performed analysis, specific results are obtained, presented below in terms of air circulation velocities, as well as pressure at the level of the analyzed fluid region.

Based on the results obtained, it is highlighted the air flow direct action on the rotor blades which tends to force the blade movement followed by the occurrence of rotational motion (Figure 10) due to the continuous action.

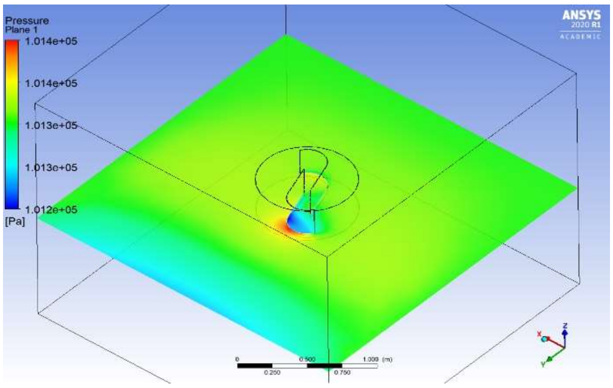
It can be seen that at the rotor blades level the air has a lower velocity, which means that it has made the energy transfer to the rotor blade, and the pressure values show this direct action on the rotor blade.



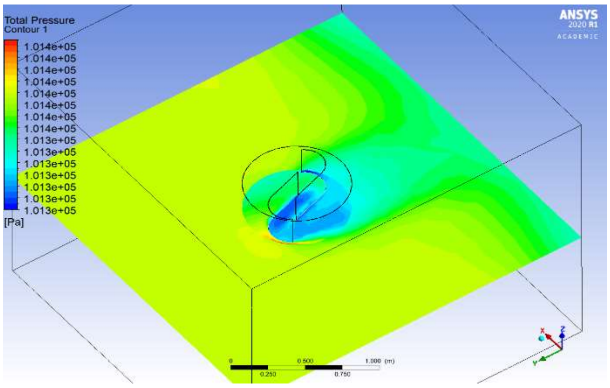
c) Air velocity



d) Air velocity in Stn Frame



e) Pressure values



f) Total pressure

Figure 10 Analysis results

The maximum values of static pressure are 101493, global average ranged of 101343 Pa at the blade surface.

The total pressure maximum values of 101552 Pa are registered at the blade tip, but the global average ranged values registered on the blade surface are situated at 101369 Pa.

The air circulation velocity values at the level of the rotor blades is approximately 7.5 m/s.

The values obtained explicitly show the possibilities of operation of the rotor under the given conditions in terms of the initial data of the analysis performed.

6. CONCLUSIONS

The use of wind power has been used since ancient times to obtain mechanical energy.

Vertical shaft turbines show lower performance characteristics than horizontal shafts, but they have advantages in terms of low manufacturing costs, as well as easier start-up possibilities regardless of the direction of action and wind speed.

This paper presents main constructive and operational aspects of the rotor typologies based on the SAVONIUS model, which have benefited from improvements over time, resulting in BACH and BENESH type models with much improved performance in terms of torque and power.

An overall virtual model based on the Bach rotor was built and analyzed with Ansys CFX in order to highlight the operating parameters using numerical methods and the results are presented in terms of air circulation speed and pressure.

The values obtained highlight the possibilities of operation of the rotor model based on the input data related to the air circulation speed.

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