ON THE POSSIBILITY OF IMPROVING THE WIND GENERATORS

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Abstract. The article proposed an algorithm for generating sets of blades used for wind generator's propeller. The main goal is to design and realise a 1 kW wind generator that can work with high efficiency at the specific wind condition from Romania. Since a big amount of time the wind speed is lower, usually under 3 m/s it was designed a propeller that has a starting speed of 2.7 m/s. A low Reynolds number airfoil is selected regarding to the low working speed of the propeller's generator. This airfoil is considered the reference. Based on the airfoil, the necessary calculations are made in order to obtain all the points that will form the blade. It was analysed the influence of tip speed ratio, lift coefficient and attack angle upon the blade profile and generate two sets of blades. A Pascal software was written with which can directly build the NC files. In order to correct the influence of the radius of the cutter upon the final shape of the blade, was also implemented a procedure that will adjust the initial coordinates. For machining the blades a CNC milling machine was designed and realised.

Keywords: wind generator, propeller, blade design, CNC milling machine

1. Introduction

The research proposed takes in consideration the possibility of improving the wind generator efficiency. The redaction of wind speed is the one possibility. The large number of wind generators function from minimum 4 m/s of wind speed. For this purpose is very important the geometry of blade propeller, elasticity and fluid flow.

The value proposed for wind speed will allowed to build wind generators on a large surface of Romania (figure 1)

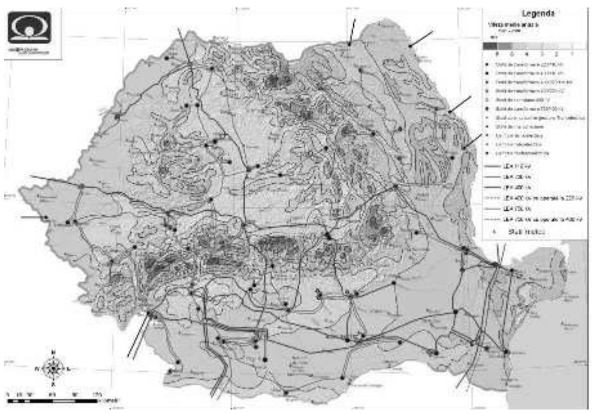

Figure 1. Wind map of Romania

2. The modelling and design of blade's propeller

A method of understanding propeller behaviour is blade element theory (BET) which is used to estimate the characteristics of propeller analytically. The inputs for analysis are chord and twist variation along the propeller radius and aerodynamic characteristics of airfoils at different blade radius.

The design of horizontal axis windmills can be performed using inverse design methods, based on the minimum induced loss windmill, as defined by Glauert and Prandtl during the 1920's. For the analysis under off-design conditions, simple blade element methods and more complex vortex lattice methods lead to accurate results. The final blade geometry can be tailored exactly to the desired main operating range by using a suitable inverse design method for the airfoil sections.

For a small horizontal axis wind turbine, the main project data were proposed considering the particularities of local wind places and the Aeolian potential of Romania. The basic parameters of the windmill were a variable speed AC generator which is linked to an accumulator system. The blade angle is constant and not adjustable.

The number of blades was limited to three. To achieve high yearly power regarding manufacturing costs on times, with short low power and non operating times, a specific power loading of 250 W/m² had been selected. A lower loading would increase the full power times, but it was not possible due to a diameter restriction.

The momentum theory correctly predicts maximum efficiency to occur at maximum diameter, but on the other hand the tip Mach number is directly proportional to the diameter for a fixed velocity of rotation. The tip Mach number was limited to 0.3, as a compromise between aerodynamics and noise constraints. This leads to local Reynolds numbers of more than 500`000, which is sufficient to achieve high L/D ratios, which are essential for good performance.

When relying on static airfoil characteristics, the airfoil sections are represented by tables of lift, drag, and pitching moment coefficients as a function of angle of attack and Reynolds number. With these tables, linear interpolation is used to determine the aerodynamic coefficients at a particular angle of attack.

In order to generate coefficients over the range, wind tunnel data can be extrapolated by assuming the airfoil behaves like a flat plate at high angles of attack. The advantage of using flat-plate characteristics is that the aerodynamic coefficients depend only on the aspect ratio of the plate.

The coefficient of lift is normally obtained by experimental work using wind tunnel tests. Many tests were run by the NACA, in order to establish the relation of coefficient of lift, coefficient of drag, pressure and moment coefficient for many different types of airfoil.

3. The design of the experimental model for generating the blade's surfaces

The coefficients of lift, drag and moment depend upon the angle of attack, the Mach number and the Reynolds number. For subsonic speeds, normal airfoils have a linear relationship between angle of attack and coefficient of lift until just before stall occurs, the airfoil or wing experiences a loss of lift. For higher speeds, the Mach number is higher than 0.3.

The lift coefficient is also dependent on Reynolds number. The Reynolds number determines the type of flow whether laminar or turbulent, which in turn determines where the flow separates from the blade. This affects the lift, drag and moment coefficients. When the Reynolds number increases, the maximum lift coefficient increases. Also when flows become very turbulent, the maximum lift coefficient begins to drop.

The main goal of this research is to design a wind generator with a 1000 W electrical power. We consider a starting speed of 2.7 m/s, a working speed of 10 m/s and a cut off speed of 15 m/s.

The calculated radius of the propeller is :

$$R = \sqrt{\frac{P}{0.6 \cdot \eta_1 \cdot \eta_2 \cdot \pi \cdot V_1^3}} \quad (1)$$

where:
R – the radius of propeller (m)
P – effective power of the wind generator (W)
η_1 – the efficiency of the electric generator
η_2 – the efficiency of the propeller
V_1 – the speed of the wind (m/s)

In the design was considered a propeller with three blades. The electric generator will produce the nominal electrical voltage when the rotational speed is 600 RPM.

The tip speed ratio of the blade is:

$$T = \frac{V_2}{V_1} \quad (2)$$

with

$$V_2 = \omega \cdot R \quad (3)$$

and

$$\omega = 2 \cdot \pi \cdot \upsilon \quad (4)$$

where:
T – the tip speed ratio factor (TSR)
V_1 – the wind speed (m/s)
V_2 – the speed of the tip of the blade (m/s)
ω - the angular speed (rad/s)
R – the radius of the propeller (m)
ν - the rotational speed (s^{-1})

In order to generate the blade it is necessary to choose a low Reynolds number airfoil. It was selected the NACA2410 which will be the reference airfoil. The airfoil is described with two sets of numbers, one set for the upper face of the blade and the other set for the lower face of the blade. In this article, these numbers are interpreted as two sets of coordinates,

$\{(y_{1u},z_{1u}), (y_{2u},z_{2u}),\ldots\ldots\ldots\ldots\ldots\ldots\ldots, (y_{nu}, z_{nu})\}$
$\{(y_{1l},z_{1l}), (y_{2l},z_{2l}),\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots, (y_{nl}, z_{nl})\}$.

This because it will be simple to understand how the blade is machined by the cutter.

Knowing the airfoil type it is possible to determinate the lift coefficient and the attack angle from the (Cl, α) diagram. It will consider the pair of parameters Cl = 0.85 and α = 6 ° since these are a good compromise between chord dimension and blade efficiency.

The blade is divided into small sections, with the assumption that a section will correspond to the diameter of the cutter which will machine the blade. A smaller diameter of the cutter means a higher precision of the blade profile.

The number of the sections of the blade is:

$$N_r = INTEGER(\frac{R}{i}) \quad (5)$$

where:
R – the length of the blade (m)
i - the diameter of the cutter (m)

It is necessary to define the radius of the hub of the propeller and to take out from the sections of the blade the points that correspond to it:

$$N_b = INTEGER(\frac{R_b}{i}) \quad (6)$$

where:
R_b – the radius of the hub of the propeller (m)
i - the diameter of the cutter (m)

Starting from the tip of the blade, the radius of each section is:

$$R_j = R - i \cdot j \quad (7)$$

where: $j \in \mathrm{N}^*$, $j = 1,2,...,(N_r - N_b)$

The chord of the blade at the point that correspond to R_j is:

$$C_{hj} = \frac{5.6 \cdot R^2}{C_l \cdot N \cdot R_j \cdot T^2} \quad (8)$$

where:
C_h – the chord (m)
R – the length of the blade (m)
N – number of blades of the propeller
R_j – the length of the blade at j point (m)
T – tip speed ratio
C_l – the lift coefficient

The rotation angle of each section of the blade that correspond to R_j is:

$$\alpha_j = \frac{180}{\pi}.\arctan(\frac{R}{1.5 \cdot R_j \cdot T}) - \alpha \quad (9)$$

where:
α - the attack angle of the blade (degree)
α_j – the rotation angle (degree)

Using these formulae was calculated each point of the blade. An arbitrary point of the blade situated on the upper face is described as $P_{ju}(X_{ju}, Y_{ju}, Z_{ju})$ and an arbitrary point situated on the lower face of the blade is described as $P_{jl}(X_{jl}, Y_{jl}, Z_{jl})$. The X_{ju} and X_{jl} are defined as:

$$X_{ju} = X_{jl} = R_j \quad (10)$$

where:
R_j – the length of the blade at j point (m)
X_{ju} – the X coordinate of the upper face at point j (m)
X_{jl} – the X coordinate of the lower face at point j (m)

The Y_{ju} and Z_{ju} coordinates are calculated starting from x_{ju} and z_{ju} coordinates using the rotational and scale matrices.

The initial point from the airfoil, $p_{ju}(y_{ju}, z_{ju})$ is represented as:

$$p_{ju} = \begin{bmatrix} y_{ju} & z_{ju} & 1 \end{bmatrix} \quad (11)$$

The final corresponding point on the blade, $P_{ju}(Y_{ju}, Z_{ju})$ is represented as:

$$P_{ju} = \begin{bmatrix} Y_{ju} & Z_{ju} & 1 \end{bmatrix} \quad (12)$$

It was considered that the initial airfoil starts from the origin. The rotation of the blade sections takes place counter clockwise. The general form of counter clockwise rotation matrix about origin is:

$$R_M = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (13)$$

where:
θ - the rotation angle

The scale matrix is:

$$S_M = \begin{bmatrix} S_X & 0 & 0 \\ 0 & S_Y & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (14)$$

where:
S_M – scale matrix
S_X – x axis scale factor
S_Y – y axis scale factor

In our problem we have to make the following replacements:

$$S_X = S_Y = C_{hj} \quad (15)$$

and

$$\theta = \alpha_j \quad (16)$$

Using the matrix notation, the final coordinates are obtained as follows:

$$[P_{ju}] = [p_{ju}] \cdot [S_M] \cdot [R_M] \quad (17)$$

It were calculated all the points of the blade with a program written in Pascal language which generated the final NC file. It was also implemented a routine in order to apply corrections due to the radius of the tool.

The step describe earlier will be repeated for a new pair of the lift coefficient and the attack angle (C_{l2}, α_2), (C_{l3}, α_3), ..., (C_{ln}, α_n) obtained from the (C_l, α) diagram at the same tip speed ratio coefficient.

The second set of blades will be obtained at a new tip speed ratio coefficient T_2, and (C_{l1}, α_1), (C_{l2}, α_2), ..., (C_{ln}, α_n), and will be machined and tested in the wind tunnel (under construction). Using the results from the wind tunnel it is possible to conclude which blade suits the start at low speed, 2.5 m/s and have the best efficiency. In the table 1 are shown the data of the upper side of the NACA 2410 airfoil**.**

Table 1. NACA 2410 selected data

j	y_u	z_u
1	1.00000	0.00105
2	0.95041	0.00990
3	0.80097	0.03296
4	0.70102	0.04551
5	0.60085	0.05580
6	0.50049	0.06356
7	0.29875	0.06875
8	0.24814	0.06668
9	0.19761	0.06276
10	0.14722	0.05665
11	0.09710	0.04766
12	0.04742	0.03420
13	0.02297	0.02411
14	0.00000	0.00000

Considering R = 1200 mm, C_l= 0.85, α = 6°, T = 7, N = 3, i = 3 mm, R_b = 125 mm, the tip of the blade, the calculated chord is C_{h1} = 0.053 and the twist angle of the profile is u1 = -0.55 °. In the table 2 are presented the calculated values of the final points that represents the blade geometry.

Table 2. The calculated coordonates of the blade

j	Y_{uj}	Z_{uj}
1	0.000	-2.580
2	0.746	-1.794
3	2.815	-1.218
4	4.171	-1.028
5	5.518	-0.904
6	8.199	-0.764
7	13.528	-0.711
8	16.184	-0.741
9	21.497	-0.844
10	26.850	-0.990
11	32.211	-1.177
12	42.965	-1.583
13	48.362	-1.788
14	53.778	-1.998

The blade has to be machined in small steps in order to obtain the correct geometry. The sequence of the NC file generated by the Pascal program, which will produce in steps of 0.75 mm the profile from table 2 is:

```
G0X1200
G0Z1.00
G1Y0.00 Z-0.75
G1Y0.75 Z-0.75
G1Y1.44 Z-0.75
G1Y2.81 Z-0.75
G1Y4.17 Z-0.75
G1Y5.52 Z-0.75
G1Y8.20 Z-0.76
G1Y10.87 Z-0.71
G1Y13.53 Z-0.71
G1Y16.18 Z-0.74
G1Y21.50 Z-0.75
G1Y26.85 Z-0.75
G1Y32.21 Z-0.75
G1Y37.58 Z-0.75
G1Y42.97 Z-0.75
G1Y48.36 Z-0.75
G1Y51.07 Z-0.75
G1Y53.78 Z-0.75
G0Z1.00
G0X1197
G0X1200
G0Z1.0
G1Y53.78 Z-1.50
G1Y51.07 Z-1.50
G1Y48.36 Z-1.50
G1Y42.97 Z-1.50
G1Y37.58 Z-1.38
G1Y32.21 Z-1.18
G1Y26.85 Z-0.99
G1Y21.50 Z-0.84
G1Z-0.74
………..
………..
………..
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4. The CNC experimental stand for generating complex surfaces

In order to generate complex shapes and surfaces similar to the blade's ones, a CNC stand was designed and made. This includes a CNC milling machine, the software and the hardware.

4.1. The CNC milling machine

In figure 2 is presented the designed of CNC milling machine.

The main characteristics of the milling machine are:

1. table size: 800 mm X 500 mm
2. X,Y,Z working area: 750mm×450mm×100mm
3. X,Y,Z feed per pulse: 0.025/0.0125 mm
4. X,Y,Z travelling positioning accuracy ±0.05/300mm
5. X,Y,Z axis: round linear fully supported bearings, ball screw
6. base structure: steel
7. maximum speed: 0 - 2000mm/min

8. maximum working speed: 0-1000mm/min
9. maximum power consumption:2 kW
10. spindle: 0.55 kW variable speed, air cooled motor
11. spindle speed: 0-14000 RPM
12. the maximum mass of the load is 20 kg.

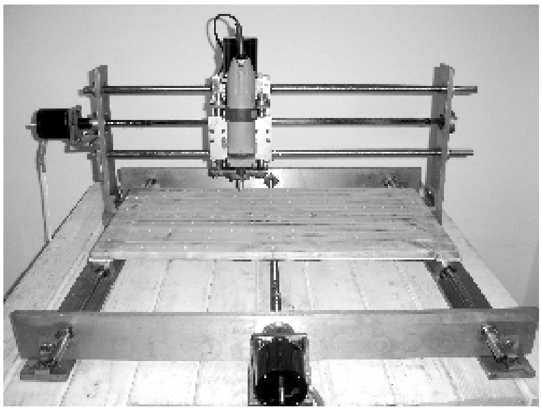
Figure 2. The CNC milling machine

The machine uses three SH8618M7508 double shaft hybrid stepping motor made by Nanotec Gmbh. Their specifications are: 1.73 V voltage / winding, 7.5 A current / winding, 0.22 ohm resistance / winding, 0.95 mH inductance / winding, 4.23N.m holding torque, 0.09 N.m detent torque, 1100 g.cm^2 rotor inertia, 1.8° step angle, 5% non accumulating step accuracy and a mass of 2.65 kg. The maximal permissible axial force is 25 N. Depending on the distance from the front motor’s bearing, the maximal permissible radial force decrease from 228 N to 100 N.

The maximal axial shaft play is 0.075 mm and the radial maximal shaft play is 0.025 mm. The mounting of the motors is the standard NEMA 34.

These motors have four coils. These coils can be connected, two by two, in parallel or in serial. The parallel connection will increase the current in the coils to 10.3 A which implies expensive drivers.

We use the serial connection of the coils because the holding torque remains the same like parallel connection but the current decrease to 5.3 A while the voltage increase to 2.33 V.

The motors can be drive at constant voltage or constant current. These modes are subdivided in unipolar and bipolar and also in full-step, half-step and micro-step. Because the unipolar mode achieve only 0.707 from holding torque we drive the motors in the bipolar mode.

The motor’s translator is made with three L297 integrated circuits, one for each axis and can work in full step or half step mode. These circuits provide load constant current control in the form of two PWM choppers, one for each phase of a bipolar motor.

The driver is designed with two L6203 integrated circuits for each motor. The L6203 is a full bridge driver for motor control applications which can deliver 5 A peak current and 4 A continuos current. The maximum supply voltage supported by the driver is 48 V and.

All the signals for direction, step, feed control, spindle speed control and relays are galvanic separated from the controller and PC using four optocouplers CNY 74-4 from Telefunken Semiconductors which has a cut-off frequency of 100kHz. In figure 3 is presented the motor’s controller.

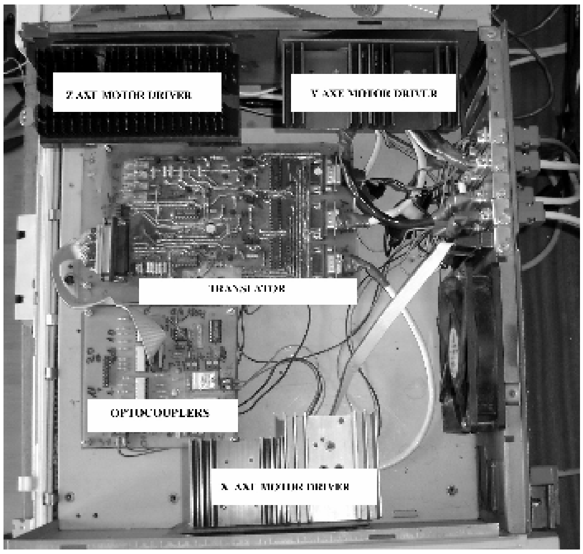

Figure 3. The motor’s controller

4.2. The hardware and software system

The minimal hardware for the CNC control is a Pentium III /800 Mhz computer class with 256 Mb RAM, two EPP parallel ports configurable at $278 and $378 addresses 2 Gb hard disk.

The parallel port work with electrical signal which has TTL level, high for voltage between +2.4 V and +5.0 V and low for voltage between 0 V and +0.8 V. The port can source up to 2.5 mA current and sink up to about 20 mA depending on the implementation.

For our application is important that the speed of the parallel port exceeds the speed of the drivers. A built-in parallel port, an ISA parallel port card or an PCMCIA card has a speed of about 700 kb/s while a PCI parallel card can achieve 1.5 – 4.5 Mb/s.

The first parallel port has the $278 address and is used to send the pulses for motion and direction for X,Y, and Z axes and to monitor the X,Y,Z limit switches and Home X, Home Y and Home Z switches.

The second parallel port has the $378 address and is used to receive the signals for override the spindle speed and the feed rate and to send the PWM signal to the electrical motor of the spindle.

As operating system we use Ubuntu 6.06, a version of Linux with 2.6 kernel and with real time extensions applied by RT-Linux or RTAI patches.

The CNC interpreter is the Enhanced Machine Controller 2 (EMC2), a descendent of the EMC developed by the U.S. National Institute of Standards and Technology (NIST). The EMC2 is free software released under the terms of the GNU GPL (General Public License). The main advantage of this software is that we have access to all the sources that are written in standard ANSI C and makes it ideal for research work.

EMC provides a graphical user interface, an interpreter for the RS-274 machine tool programming language (G code) and a real-time motion planning system with look-ahead. EMC2 operate at low-level machine electronics such as sensors and motor drives and can simultaneously move up to 6 axes. The control can operate true servo systems, analogue or PWM, with the feedback loop closed by the EMC software at the computer, or open loop with stepping motors.

Motion control features include: cutter radius and length compensation, path deviation limited to a specified tolerance, lathe threading, synchronized axis motion, adaptive feed rate, operator feed override, and constant velocity control.

We implement a system that can modify the feed rate and the spindle speed. For this we make modifications in the source code in order to obtain a feed override of 30 % and a spindle speed override of 20 %.

The spindle speed override is activated with the instruction M51 P1 and deactivated with the instruction M51 P0.

The feed rate override is activated with the instruction M51 P1 and deactivated with the instruction M51 P0.

Make modifications in the source code in order to obtain a feed override of 30 % and a spindle speed override of 20 %.

5. Conclusions

In order to generate complex shapes and surfaces was designed and made a CNC stand. This includes a CNC milling machine, the software and the hardware.

Starting from a reference airfoil, were analyzed blade shapes in order tot determine the optimum set of parameters, tip speed ratio *T*, lift coefficient C_l and attack angle, α.

It was realized the algorithm and the software in Pascal language for generating the NC files that correspond to the blades.

It was designed and realized a CNC stand for generating the complex shapes like the ones on the blade’s propeller.

The machined blades have to be tested in the wind tunnel.

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