

USE OF TAGUCHI METHODS IN DESIGNING AN EXPERIMENTAL MODEL OF WIND TURBINE WITH VERTICAL AXIS WITH CURVED SHEET BLADES

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ABSTRACT

Increasing the efficiency of the conversion of electricity into light energy (UV LEDs) has made possible a new stage in the development of vertical axis wind turbines by compensating for the small wind energy conversion efficiency (14.81%). The work is based on the use of Taguchi methods (TM) in increasing the efficiency of a wind turbine with vertical axis blades made of deformed aluminium foil. Experiments were carried out in the wind tunnel to confirm the models selected by the QE procedure.

KEYWORDS: Taguchi methods, TM, VAWT, microWT

1. Introduction

Over time, wind turbines have undergone continuous development. Wind energy (WE) is among the first forms of energy that have been used by humans, along with solar energy [1]. The last 150 years have marked a continuous development of wind turbines in the two important directions: water pumping and electricity generation [2].

Today, many wind turbines are destined for the production of complementary electricity (RES) and in decentralized systems (out grid) [2]. This is also possible due to the evolution of the electrical and electronic equipment of domestic utility towards the reduction of the energy consumption which has attracted the decrease of the consumed currents and the decrease of the working voltages. For example, the microprocessors that are used today usually use 3.3V less than 5V or 12V. Also, the lighting systems have evolved in order to increase the conversion efficiency by using LEDs so that for the same lighting the energy required decreases and makes it possible to use RES for local lighting. But overall, energy consumption has increased due to the increase in the number of people living in modern comfort.

In other words, alternative energy sources (RES) such as solar or wind energy (WE) can be used separately or in combination to charge a battery when it is sunny or blowing so that during the night the stored energy will discharge to the LED- the lighting of a lighting system. The system can be independent

or complementary to the consumption from the mains [2].

The paper aims to optimize with the help of Taguchi Methods (TM) the shape and dimensions of the blades of a VAWT, intended to obtain electricity from wind energy. Because drag force VAWTs are not only driven by the resistive force, it is possible to use this gate to look for constructive variants that use other forces that are involved in the rotational motion and which increase the conversion efficiency over the Betz limit of these (14.81%) [3]. Simple structures from accessible materials are preferred that reduce the costs of implementation by focusing on VAWT design.

$$E = \frac{1}{2}mv^2 \quad (1)$$

The volume flow and the mass flow are:

$$\dot{V} = A \cdot v \quad (2)$$

$$\dot{m} = \rho \cdot A \cdot v \quad (3)$$

The power of wind is:

$$P = \frac{1}{2}\rho \cdot A \cdot v^3 \quad (4)$$

For VAWT, like "S-rotor" the Betz limit is 4/27 (14.81%) [3]. The drag force (3) is:

$$D = C_D \frac{1}{2} \rho (v - u)^2 A \quad (5)$$

And the power to each blade is:

$$p = Du = C_D \frac{1}{2} \rho v^3 (1 - \lambda)^2 \lambda \quad (6)$$

The proposed conceptual model considers a wind turbine with a vertical axis, which the blades are made of sheet and which is brought to its semi-cylindrical shape. You can use 2...6 blades of different width and with different seating angles.

For experiments, a part of the Taguchi concepts is used (TM).

Taguchi concepts. Three concepts are important to understand Taguchi's approach and method. Product variability is present for all products. Variability is determined by different factors that are located at producer and also to consumer.

Robust Quality (RQ) [4]. This method calls for making products and processes that are quality robust. Quality robust products are products that can be produced uniformly and consistently in a variety of adverse manufacturing and environmental conditions. The basic idea is to remove the effects of adverse condition instead of removing the causes. Taguchi suggest that removing the effects is often chapter that removing the causes and more effective in producing a robust product.

Notation:

E - energy, *J*
v - wind speed, *m/s*
m - mass of air, *kg*
ρ - air density, *kg/m³*
u - tip blade speed, *m/s*
 \dot{V} - volumic debit *m³/h*
 \dot{m} - mass debit, *kg/m³*
A - swept aria, *m²*
p - wind power, *W*
ρ - air density, *kg/m³*
n - rotation speed, *rpm*
C_D - drag coefficient
λ - specific speed

Abbreviations:

WE - Wind Energy
RES - Renewable Energy Sources
microWT - micro Wind Turbine
TM - Taguchi Methods
QE - Quality Engineering
VAWT - Vertical Axis Wind Turbine
HAWT - Horizontal Axis Wind Turbine
QLF - Quality Loss Function
RQ - Robust Quality
LED - Light Emitting Diode

Quality Loss Function (QLF) [4]. Taguchi has also defined what he calls a quality loss function. A quality loss functions (QLF) identifies all costs connected with poor quality and shows these costs increase as the product moves away from being exactly what the customer wants. These costs include not just the cost to the customer in terms of satisfaction but also warranty and service costs; internal inspections, repairs, and scrap costs; and costs that can best described as cost to society.

Experiments with orthogonal array [4, 5]. One of the most important elements of TM is the use of partial-factorial experiments, based by orthogonal matrices.

2. Experimental conditions

The maximum wind speed in the open wind tunnel on which the experiments were performed is 9 m/s. The other factors have the value range according to the limits imposed on the realization of the experimental model (EM).

The maximum area of the model in cross-section is 10% of the area of the working section of the wind tunnel. the order of the factors is according to the degree of knowledge of the investigated phenomenon [6-8]. Other details regarding the experimentation conditions:

- The maximum section of the wind tunnel measuring area is 0.25 m², which leads to a maximum section of the experimental model (EM) of 10%, respectively 0.025 m²;
- The maximum diameter of the model should not exceed 0.178 m;
- The objective function is the speed of the model *n* (rot/min, rpm) which must be as high as possible;
- The blades are made of sheet metal and have the dimensions 0.225 m x 0.07 m, respectively, 0.225 m x 0.035 m, and 0.225 m x 0.0175 m;
- The number of blades is 2, 3 or 6;
- There is no other task than rubbing in the bearings (peaks).

The existing wind tunnel offers conditions for experimenting with the behaviour of the aerodynamic profiles having the following characteristics: wind speed 0...9 m/s, measuring section: 0.5 m x 0.5 m (0.25 m²), electronic balance (drag force), and balance two-point electronics (Lift and Drag). LC6000 anemometer was used for wind speed measurement. An Atmel 328U microprocessor-based data acquisition system was used for data acquisition [10].

3. Experimental models (EM)

They were made after selecting the level of the factors and were updated for each experiment, by changing the blades and adjusting the positioning angles. In Fig. 1, Fig. 2 and Fig. 3 the models used in experiments 3, 6 and 9 are shown. A detail for fixing the blades is shown in Fig. 4.



Fig. 1. Experimental model for experiment no. 3



Fig. 2. Experimental model for experiment no. 6

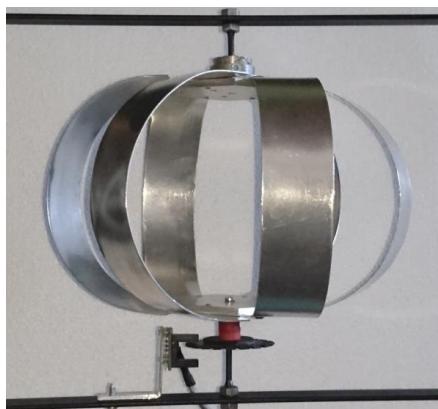


Fig. 3. Experimental model for experiment no. 9

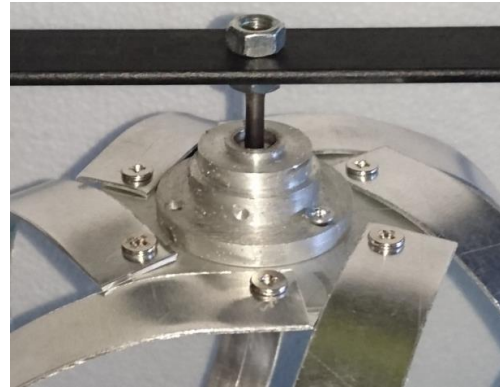


Fig. 4. Detail with fixing the blades

Table 1. Factors influencing the experiment

n.o.	factor	m.u.	range of values
1	wind speed	m/s	0... 9
2	number of blades	m2	2...6
3	blade width	m	0...0,1
4	settlement angle	grd	0 ... 90
5	air temperature	°C	- 35 ... + 45
6	air pressure	Pa	9050...1080hPa
7	air relative humidity	%	30...80
8	etc.		

Table 2. Factors that are considered in the experiment

symbol	Factor	m.u	levels		
			1	2	3
A	wind speed	m/s	5	7	9,5
B	number of blades	-	2	3	6
C	blade width	m	0,070	0,035	0,0175
D	settlement angle	grd.	30	45	60

Table 3. Orthogonal array experiment (standardized L9)

experiment	factors			
	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 4. Experimental matrix

experiment	specified factors and levels			
	A	B	C	D
m.u.	m/s	-	m	grd.
1	5	2	0,070	30
2	5	3	0,035	45
3	5	6	0,0175	60
4	7	2	0,035	60
5	7	3	0,0175	30
6	7	6	0,070	45
7	9,5	2	0,0175	45
8	9,5	3	0,070	60
9	9,5	6	0,035	30

Table 5. The measured results of the target function and the conversion into dB

experiment	EM	
	rotation speed	target function
u.m.	rpm	dB
1	0	-40.00
2	0	-40.00
3	0	-40.00
4	0	-40.00
5	0	-40.00
6	165	22.17
7	0	-40.00
8	126	21.00
9	66	18.20

Table 6. Calculating the average effect of the level of each factor

the average effect of each level	relation	value, dB
$m_{A1} =$	$1/3(n_1+n_2+n_3) =$	-40.00
$m_{A2} =$	$1/3(n_4+n_5+n_6) =$	-19.28
$m_{A3} =$	$1/3(n_7+n_8+n_9) =$	-0.27
$m_{B1} =$	$1/3(n_1+n_4+n_7) =$	-40.00
$m_{B2} =$	$1/3(n_2+n_5+n_8) =$	-19.67
$m_{B3} =$	$1/3(n_3+n_6+n_9) =$	0.12
$m_{C1} =$	$1/3(n_1+n_6+n_8) =$	1.06
$m_{C2} =$	$1/3(n_2+n_4+n_9) =$	-20.60
$m_{C3} =$	$1/3(n_3+n_5+n_7) =$	-40.00
$m_{D1} =$	$1/3(n_1+n_5+n_9) =$	-20.60
$m_{D2} =$	$1/3(n_2+n_6+n_7) =$	-19.28
$m_{D3} =$	$1/3(n_3+n_4+n_8) =$	-19.67
	average =	-19.85

Table 7. The average effect of the level of each factor

factor	UM	levels		
		1	2	3
A wind speed	dB	-40	-19.28	-0.27
B number of blades	dB	-40	-19.67	0.12
C blade width	dB	1.0595	-20.60	-40.00
D settlement angle	dB	-20.6	-19.28	-19.67
			m	-19.85

4. Experimental regimes

The experiments were performed following an L9 orthogonal matrix with nine experiments [4, 5]. The factors considered with notable influence are shown in Table 1 and the selected ones (A, B, C and D) are shown in Table 2. Also, in Table 2 the levels selected for the experiment, for each factor are shown.

The orthogonal matrix L9 [5] used in the experiments is shown in the Table 3 and the updating of this matrix with the factor levels and its transformation into the matrix after which the experiments were actually performed is shown in Table 4. For each experiment the levels of the considered factors were respected, which is one of the difficulties of using orthogonal matrices: from one experiment to another it is possible that all the factors can be reset.

In order to calculate the objective function with the relation:

$$\eta = 10 \log n \quad (7)$$

We considered the speed at a reasonable value of 0.0001 rpm. The objective function is in the "Larger the better" category because it wants the highest value, respectively the highest rotational speed for the experimental model (EM).

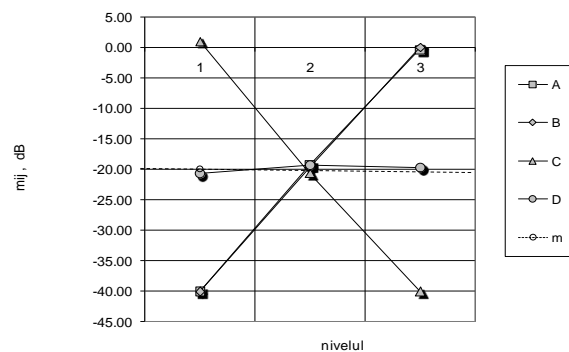


Fig. 5. Allure of the influence of each factor

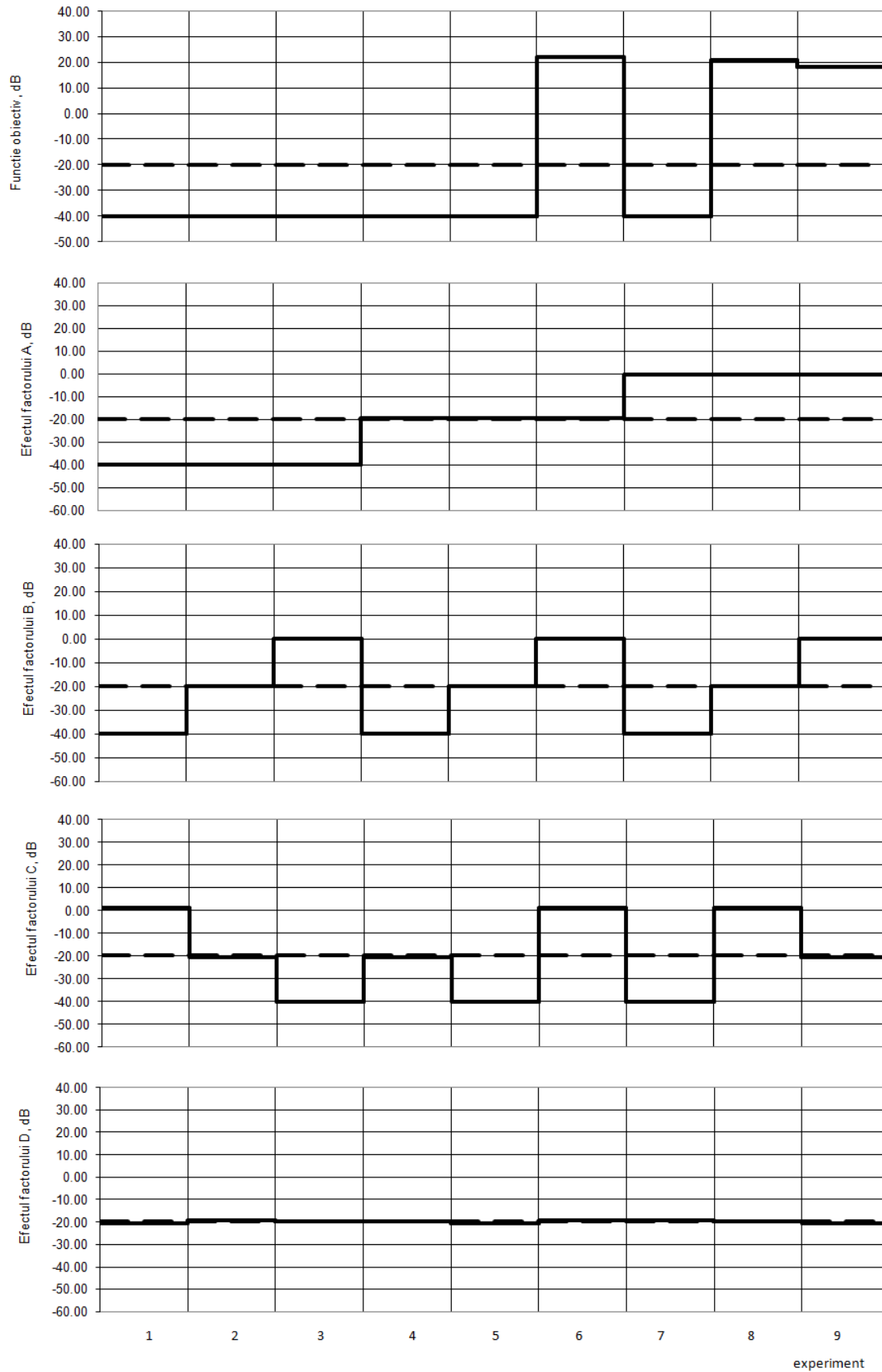


Fig. 6. The influence of factor levels on all experiments

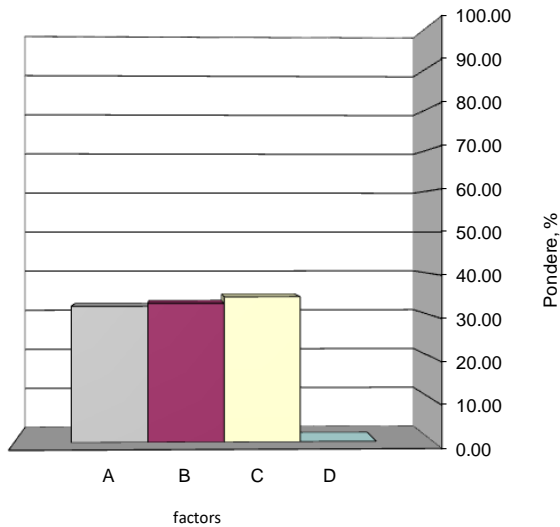


Fig. 7. Weight of factors

5. Results and Discussions

The measured result of the experiments was transformed into objective function with the relation (7). The results are rearranged in Table 7.

The best values obtained for the objective function, under the given experimental conditions correspond to the highest values of the average effect of each factor. Hence, the optimal recommended regime: A3B3C1D2. This corresponds to the practical situation where the experimental model was tested at the highest wind speed (A) (9 m/s), has the most blades (B) respectively 6 blades, has the width (C) the

largest, respectively 70 mm and tilt angle (D) of 45 degree. The effect of each level of each factor was showed in Fig. 6.

6. Conclusions

The weight of the factors considered is shown in Fig. 7 and indicates that the factors A, B and C have an approximately equal weight and in sum they give 99.96%. The allure of influence of each factor is shown in Fig. 5.

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