ORTOGONAL EXPERIMENTAL PLANS FOR A WIND TURBINE BLADE DESIGN

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Abstract. This paper presents the theoretical model of the experiment to find the main input parameters that can bring the best solution for the output parameter take into account – displacement. This research should have the smallest numbers of experiments for the maximum representation.

Keywords: Taguchi method; orthogonal experiment; wind turbine blade; displacement.

1. Introduction

Companies involved in the industrial construction of cars and airplanes may change activities such as the design and construction of assembly complexes. They were the first to change their structure and integrated the new tools and sets of information related to the travel cycle for products, for an optimization of the triptych: cost, delivery terms, and quality.

Each deviation from this optimization has like results an increased cost for a lower quality and a delay of delivery terms.

G. Taguchi's research and ideas, known since 1980, have shown that, on the one hand, the technique of experimental plans (provided that orthogonal

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plans are limited to a few simple plans) could be widely implemented in industry and on the other hand, experimental plans will play a central role in the design of products and manufacturing processes.

Those different types of energy needs will force the society to change and requires the implementation of alternatives means of energy conversion, mostly in electricity.

Taking a look at the future, through the open window of needs that will push society to produce electricity in a completely changed environment; we find that the locomotive of this change will be the propulsion of vehicles, which brings to the same table electricity producers and consumers – the auto industry.

The reality of this complex change will produce effects in all strata of society. From those who work directly to design and develop the technologies needed to produce electricity, either for its storage, or for transportation or for the devices that use it.

Renewable energy production technologies are multiple, but energy control should or is usually the priority before any development of new production technologies, because it is often less expensive to save one kWh than to produce an additional kWh. Saving energy (through technology or in a much responsible way by changing the behavior) is generally cheaper than investing in new means of production. This must constantly remain in the minds of those responsible.

One of these types of renewable energy that can be used is the wind energy. It might be an alternative to the hydrocarbon energy, but this energy is more depending by the climate changing over the time.

2. Experimental Plans Employed for Wind Turbine Blade Design

The main output parameter for the wind turbine blade is the displacement of the blade.

The method of programming the experiments allows the determination of the significant parameters, of the significant interactions between the parameters and leads to the obtaining of the relation that expresses the phenomenon according to the effects retained as influential (Jackson and Amano, 2017).

One of the aspects pursued in the design and execution of products and/or processes is that of total quality, and one of the approaches of total quality is to change the way of solving the problems that appear, in order to achieve the objectives with the same quality, cost and delays (Gupta, 2015). The use of the method of experimental plans is part of this approach to achieve the objectives of total quality.

Table 1
Parameters and Value Levels

Parameter	Description	Level 1	Level 2	Level 3	Measure unit
P	Pressure	95	383	862	N/m²
S	Structure	Shell (Fig. 1*a*)	Grid (Fig. 1*b*)	Full (Fig. 1*c*)	–
Mesh_D	length of the mesh elements	1	3.5	6	mm
Mesh_P	quantity of mesh elements included in a circle	3	6	9	–
DM	Density	1020 (ABS)	1120 (PA6)	1410 (Delrin 2700)	kg/m³

The approach of experimental plans not only leads to the optimization of system performance (product, process, …) but must ensure that the system is as sensitive as possible to the variation of various parameters that are not controlled by the designer, but which may affect performance.

The parameters that are involved in experimental plans for wind turbine blade design are as followed (Table 2).

| *a* | *b* | *c* |
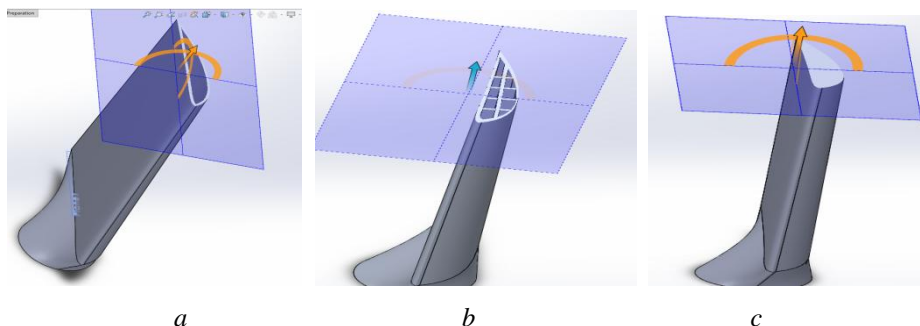
Fig. 1 – The blade representation for experiments.

3. Determining the Type of Experiment

The theoretical model has the following expression:

$$Y \approx M + P + S + Mesh_D + Mesh_P + DM + P - DM + S - Mesh_D + P - Mesh_P$$

For the displacement suffered by the part when applying the pressures mentioned above (Rădulescu *et al*., 2006).

As shown, the conditions for choosing the simplified experiment type must be met (Taguchi, 1987):

a) The rule of degrees of freedom, according to which the minimum number of experiences is equal to the number of degrees of freedom of the studied model; thus, in this case the number of degrees of freedom of the chosen model can be determined;

$$Y \sim = 1+2+2+2+2+2+4+4+4 = 23$$

So the minimum number of experiences to be considered should be greater than or equal to 23.

b) The orthogonality rule, according to which the minimum number of experiences of a plan must be less than the least common multiple of disjoint levels and interactions. For this, the calculation table of the least common multiple is made (Table 2):

Table 2
The Least Common Multiple

Parameters / Levels		P	S	Mesh$_D$	Mesh$_P$	DM	P-DM	S-Mesh$_D$	P-Mesh$_P$
		3	3	3	3	3	3^2	3^2	3^2
P	3	#							
D$_s$	3	3*3	#						
v$_s$	3	3*3	3*3	#					
v$_l$	3	3*3	3*3	3*3	#				
HB	3	3*3	3*3	3*3	3*3	#			
P-DM	32	#	3^2*3	3^2*3	3^2*3	#	#		
S-Mesh$_D$	32	3^2*3	#	#	3^2*3	3^2*3	#	#	
P-Mesh$_P$	32	#	3^2*3	#	3^2*3	3^2*3	#	#	#
CMMMC		27							

As a result of the above, it can be said that the experiment is orthogonally divided into type 3n (35 = 243 tests), from which the L27 plane was selected, based on the Taguchi tables.

4. Experimental Research on the
Displacement that Can Be Supported by a Wind Turbine
Blade without Plastic Deforming

Experimental research on the displacement that can be supported by a wind turbine blade without plastic deforming (Table 3).

Table 3
Experimentation Plan

| Nb	Parameter for testing							
	P	S	Mesh_D	Mesh_P	DM	P-DM	S-Mesh_D	P-Mesh_P
1	1	1	1	1	1	1	1	1
2	1	1	2	2	2	2	2	2
3	1	1	3	3	3	3	3	3
4	1	2	1	2	3	3	2	1
5	1	2	2	3	1	1	3	2
6	1	2	3	1	2	2	1	3
7	1	3	1	3	2	2	3	1
8	1	3	2	1	3	3	1	2
9	1	3	3	2	1	1	2	3
10	2	1	1	1	1	2	1	2
11	2	1	2	2	2	3	2	3
12	2	1	3	3	3	1	3	1
13	2	2	1	2	3	1	2	2
14	2	2	2	3	1	2	3	3
15	2	2	3	1	2	3	1	1
16	2	3	1	3	2	3	3	2
17	2	3	2	1	3	1	1	3
18	2	3	3	2	1	2	2	1
19	3	1	1	1	1	3	1	3
20	3	1	2	2	2	1	2	1
21	3	1	3	3	3	2	3	2
22	3	2	1	2	3	2	2	3
23	3	2	2	3	1	3	3	1
24	3	2	3	1	2	1	1	2
25	3	3	1	3	2	1	3	3
26	3	3	2	1	3	2	1	1
27	3	3	3	2	1	3	2	2
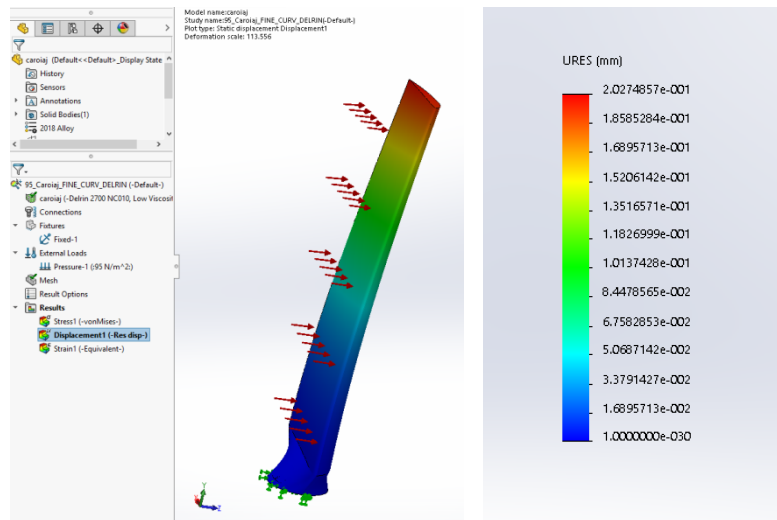
Fig. 2 – The disposal of pressure, fixtures and the displacement
values (for the line 4, Table 4).

The test results are summarized in Table 4; thus, the average value of
the displacements that are calculated when is used the FEM module from
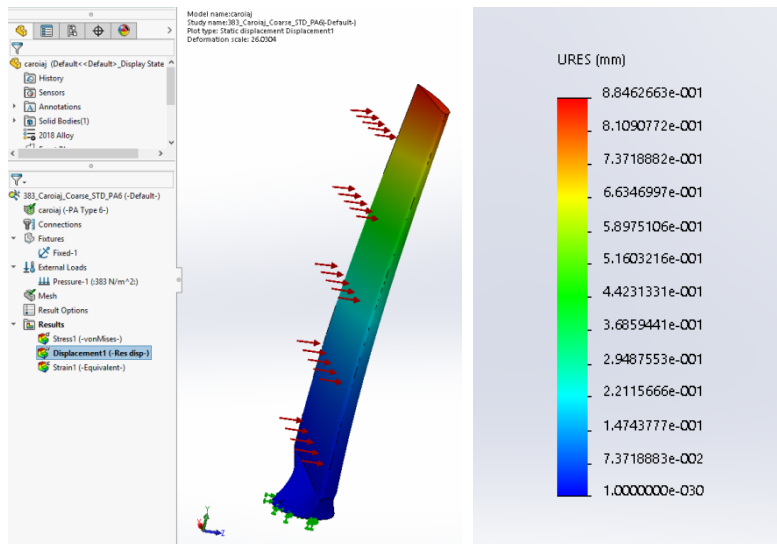SolidWorks. Some results are presented in Fig. 2, Fig. 3 and Fig. 4.

Fig. 3 – The disposal of pressure, fixtures and the displacement values
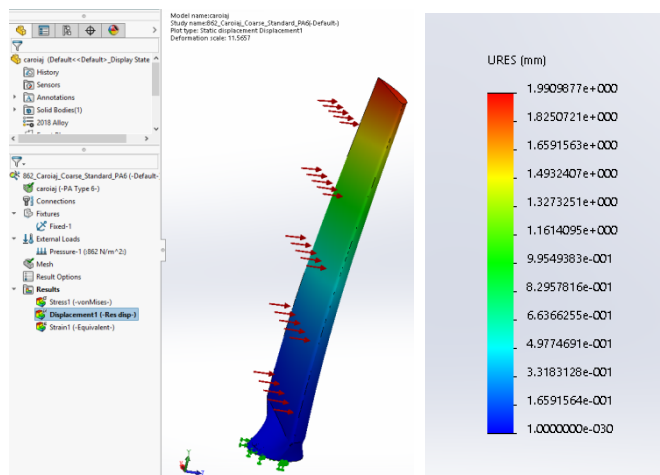(for the line 15, Table 4).

Fig. 4 – The disposal of pressure, fixtures and the displacement values
(for the line 24, Table 4).

There are 27 tests to do according to the Table 3 and the results of these experiments with the conditions of simulations from the Table 3 are presented in the Table 4.

Table 4
*Experimentation Plan with the Values of the Input Parameters and
the Results of the Simulated Movements*

Nb	Parameters for testing								Displacement (mm)
	P	S	Mesh_D	Mesh_P	DM	P-DM	S-Mesh_D	P-Mesh_P	
1	95	3	1	3	1020	1	1	1	0.52655370
2	95	3	3.5	6	1120	2	2	2	0.40715951
3	95	3	6	9	1410	3	3	3	0.37140179
4	95	2	1	6	1410	3	2	1	0.20274857
5	95	2	3.5	9	1020	1	3	2	0.29009452
6	95	2	6	3	1120	2	1	3	0.21942441
7	95	1	1	9	1120	2	3	1	0.11071455
8	95	1	3.5	3	1410	3	1	2	0.10012028
9	95	1	6	6	1020	1	2	3	0.14407973
10	383	3	1	3	1020	2	1	2	2.12290800

Table 4
Continuation

Nb	Parameters for testing								Displacement (mm)
	P	**S**	**Mesh_D**	**Mesh_P**	**DM**	**P-DM**	**S-Mesh_D**	**P-Mesh_P**	
11	383	3	3.5	6	1120	3	2	3	1.64195800
12	383	3	6	9	1410	1	3	1	1.49789190
13	383	2	1	6	1410	1	2	2	0.81740409
14	383	2	3.5	9	1020	2	3	3	1.16900000
15	383	2	6	3	1120	3	1	1	0.88462663
16	383	1	1	9	1120	3	3	2	0.44635451
17	383	1	3.5	3	1410	1	1	3	0.40364283
18	383	1	6	6	1020	2	2	1	0.58086938
19	862	3	1	3	1020	3	1	3	4.77875190
20	862	3	3.5	6	1120	1	2	1	3.69842200
21	862	3	6	9	1410	2	3	2	3.38024330
22	862	2	1	6	1410	2	2	3	1.83969260
23	862	2	3.5	9	1020	3	3	1	2.63222580
24	862	2	6	3	1120	1	1	2	1.99098770
25	862	1	1	9	1120	1	3	3	1.00458910
26	862	1	3.5	3	1410	2	1	1	0.90845990
27	862	1	6	6	1020	3	2	2	1.30733530

4. Conclusions

First of all, we think it is important to mention that several strategies are possible to solve the same problem. All these strategies do not have the same effectiveness and optimality criteria can be used to find the best solution.

The use of an experiment plan aims to reduce the number of experiments needed to study the behavior of a system, without significantly affecting the accuracy of observations.

An experimental plan represents a series of tests organized beforehand in order to determine, with a minimum of tests and with maximum precision, the possible influences of the different parameters, in order to optimize the performances of the studied system.

The purpose of this experiment is to find the best formula for the input parameters to obtain the desired results, in the most reliable and economical conditions possible.

The use of the three types of internal constructions of the wind turbine blades, which have in view the reduction of their weight, implicitly the decrease of the manufacturing time and hence the production cost, allows us probing different types of materials.

For these internal structures to succeed in stating that there is the possibility that certain combinations of materials and structures of wind turbine blades allow their operation even if the wind is gusting or if it has higher intensities.

Therefore, the proposed method for making wind turbine blades is related to 3D printing.

More precisely, the proposal for further studies is related to the possibility of making blades by 3D printing.

The main advantage is that the thickness of the blade walls or their internal structure can be achieved regardless of its complexity.

Another major gain, even if this manufacturing process is quite slow, is that it does not require continuous assistance, the printer can be turned on, and then it can work without an operator following it throughout the manufacturing process.

The deformation characteristics of the turbine blades under the influence of a pressure applied constantly on the entire face of the blade, allowed us to take into account different types of blade structures, but also different materials that can be used.

The lift and drag forces, that are depending by the design of the turbine blade, should be take into account in the future research to be able to increase the power generation.

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UTILIZAREA PLANURILOR EXPERIMENTALE ORTOGONALE ÎN PROIECTAREA PALETELOR TURBINELOR EOLIENE

(Rezumat)

Această lucrare prezintă modelul teoretic al unui experiment pentru a găsi principalii parametri de intrare care pot conduce la cea mai bună soluție pentru parametrul de ieșire luat în considerare - deplasarea. Această cercetare ar trebui să aibă cel mai mic număr de experimente posibil a fi realizate pentru o reprezentabilitate maximă.