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Optimization of a Mechanical Part using Finite Element and Taguchi

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***Abstract*: The developed analysis was based on the optimization of a mechanical part. Which will be designed in a CAD software (SolidWorks) that allows to perform simulations (Finite Element) to determine the deformation and stresses when a force is applied to it. Some variables will be changed to identify which is the most optimal simulation and thus obtain the best results, and by the orthogonal arrangement method of Taguchi, a results comparison will be made to determine which is the most optimal model of all the simulations that were obtained so in this way we demonstrate that by making changes to the design we can improve its performance, in order to have the most optimal mechanical part.**

***Keywords*: Finite element, stress, deformation.**

1. Introduction

Design of experiments is an application of the scientific method, which generates knowledge about a process or system through appropriately planned tests. This methodology has been strengthened as a set of statistical techniques and engineering tools to help understanding complex cause and effect situations (Gutiérrez & De la Vara, 2003). The design of experiments has been proven as a very powerful tool to solve manufacturing, science, technology, research, product and process optimization problems. The experimental design has two main approaches, the classical approach, and the Taguchi's approach, also known as robust design methods.

The classical approach is a design strategy where experimentation is used for the purpose of studying the performance of a process or product. The Taguchi method emphasizes the appropriate selection of control factor levels to minimize the variability transmitted by noise factors and thus generate a robust product or a robust process. Montgomery (2009) mentions two objectives of robust design methods: (i) ensure that the average of the responses reaches a target value and (ii) that the variability around the target value is as small as possible. The present investigation proposes to fractionate Taguchi's experimental designs.

The fundamental reason is that it was observed that Taguchi orthogonal arrangements are designed in such a way that the same arrangement can be used for different listed factors, but the number of runs remains the same. For example, the L32 arrangement allows estimating up to 31 factors with 32 runs; If the number of factors were smaller, 16 for example, the number of runs remains as a constant. When a mechanical part is required to be manufactured for any reason, the type of material and an appropriate design must be considered, which efficiently meets the requested requirements. The sketch can be drawn by some design software. In this kind of software, mechanical tests of the part can also be developed to determine some design errors, and others. This is why this research will be focused on the optimization of a specific mechanical part. It will be modified in some of its dimensions in different proportions, with which a deformation and displacement analysis will be applied on each of its modifications through the SolidWorks design software to obtain varied results that will be used to determine which piece will obtain the greatest disturbance.

2. Problem Statement

Taguchi orthogonal arrangement were designed in such a way that a specific arrangement can be used for different numbers of factors. For example: L32 is used when there are 16 to 31 factors and requires 32 experiments. When the number of available columns exceeds the number of factors to be investigated, the remaining columns are commonly used to estimate the interactions. However, in cases where the researcher is only interested in the main effects, running the entire arrangement could be unnecessary and expensive. It is that why the suggested proposal includes to analyze the tests in which there are less factors than the tests in which there are several to maximum factors that the arrangement can handle. From that problem, the initiative arises to generate more compact designs for the main effects with two additional degrees of freedom for different numbers of factors and not to run the complete Taguchi orthogonal design methods.

3. Methods

Applying the equation of the Taguchi orthogonal design methods through a mathematical calculation software called MatCad, to each value obtained in the deformation and displacement analysis of different several factors and showing different results, will be possible to compare and determine which of them has the least deformation and displacement.

At the end of the investigation, it will be demonstrated that by performing small modifications to the design of the

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mechanical part, a more efficient result can be obtained in terms of the analyzes performed.

The mechanical part to be studied in figure 1 has established variables.

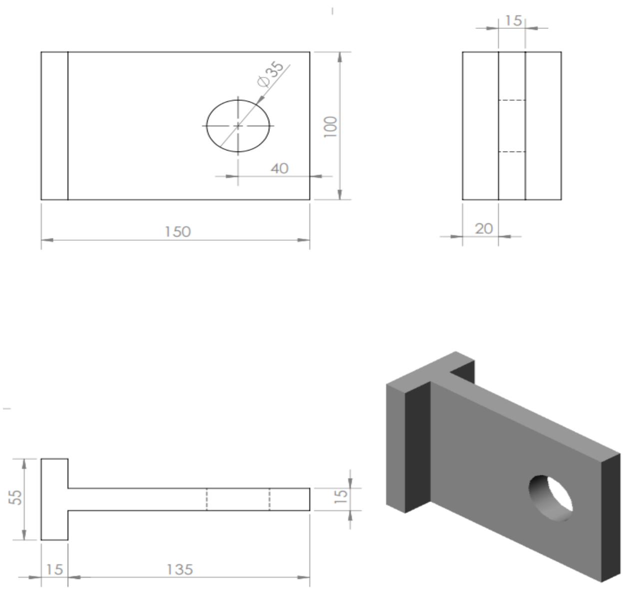

Fig. 1. Mechanical part with the initial part in figure 1 will be made the variable changes shown in the following Table 1

Table 1
Parameters

PLATE PARAMETERS AND ITS PLANES USED IN THE EXPERIMENT			
Parameters	Drawing 1	Drawing 2	Drawing 3
b/a	35/35 = 1	30/35 = 0.86	34/35 = 0.97
X (Drilling location)	40	45	35
Final Finish	No Radius	Radius at the base = 1.5	Radius at the base = 3
Mesh hole	3 Global	2 Local y 3 Global	1 Local y 3 Global

The following study to be performed we be done by using the Orthogonal arrangement which is the most applied method in the modeling of experiments Table 2 and where the data of the runs will be obtained. Table 3.

Table 2
Orthogonal arrangement

	1	2	3	4
RUN	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

Through SolidWorks software, the first run will be carried out on the mechanical part with the initial conditions, where a load of 1500 N will be applied, and the material type will also be selected for our study as an annealed 4340 steel which can be seen in the following figures.

Table 3
Data in the orthogonal arrangement

	FACTORS			
Run	b/a	X	Final Finish	Mesh
1	1	40	No Radius	3
2	1	45	1.5	2
3	1	35	3	1
4	0.86	40	1.5	1
5	0.86	45	3	3
6	0.86	35	No Radius	2
7	0.97	40	3	2
8	0.97	45	No Radius	1
9	0.97	35	1.5	3

The figure 2 showed the clamping of the piece and where the load is applied.

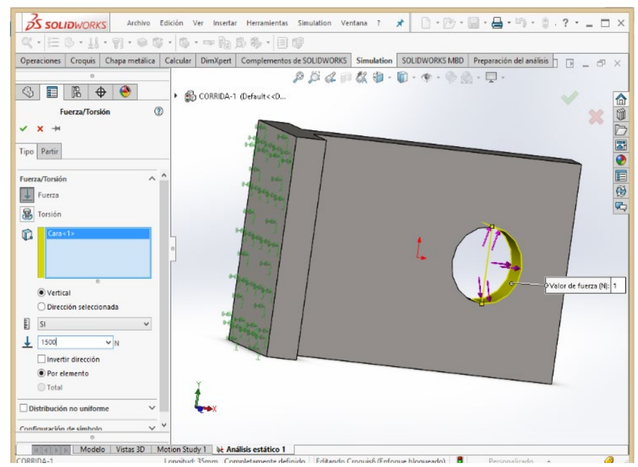

Fig. 2. Clamping of the piece

When the simulation is carried out (Finite Element) we obtain the results of stresses and deformations as presented in figure 3.

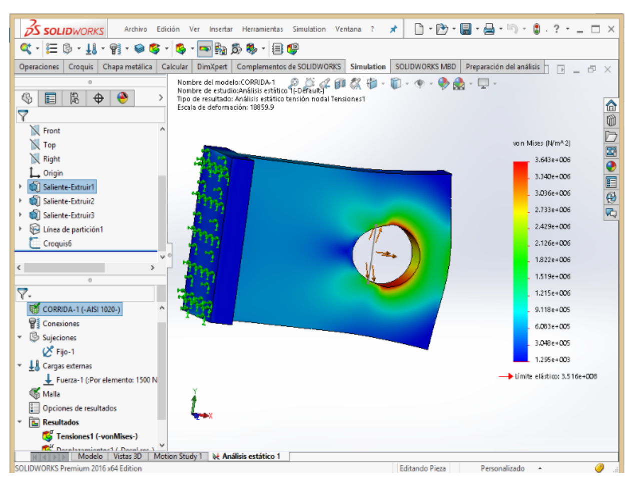

Fig. 3. Present deformations

This procedure is applied to the remaining 8 runs to obtain the stresses and deformations from all the simulations. We record the values obtained in the following Table 4.

Table 4
The remaining 8 runs to obtain the stresses and deformations

	Variable de Entrada		Variable de Salida	
	SIN S/N		CON S/N	
Corrida	σ	δ	S/N σ	S/N δ
1	3.164e+006	9.401e-004		
2	3.658e+006	3.416e-004		
3	1.624e+008	2.441e-003		
4	2.442e+006	5.160e-004		
5	3.663e+006	3.413e-004		
6	3.738e+006	6.000e-004		
7	3.022e+006	4.363e-004		
8	3.653e+006	3.423e-004		
9	3.735e+006	5.992e-004		

4. Methodology of Taguchi

There are two main approaches to robust experimentation: The Taguchi approach and the traditional approach (Box & Bisggard, 1987). The Taguchi methodology for RPD was introduced in the early 1980s. This methodology revolves around the use of orthogonal designs where an orthogonal array involving control variables is crossed with an orthogonal array containing the noise variables. The Taguchi orthogonal design methods have been implemented in various areas of engineering, manufacturing, and many other areas, for example: in the manufacturing of medical devices (Limon, Tlapa, Baez, Maldonado, & Rivera, 2016) obtaining improvements in indicators such as the work capacity index. It is also widely used in the optimization of processes such as plastic injection (Oktem, Erzurumlu, & Uzman, 2007) and within the field of research in the construction of neural networks (Ortiz, Martínez, & Vega, 2006). Within the methodology for the analysis of the design with external and internal arrangement, Taguchi proposed a performance statistic, which he called the signal/noise quotient or signal/noise rate, which is calculated in each combination of the controllable factors and is analyzed like any variable of answer. The most robust combination of the levels of the controllable factors is the one that maximizes the statistical signal/noise rate (Roy, 2010). The signal/noise rate is expressed as shown in equation 1.

$$\frac{S}{N} = -10\, log\left[\frac{1}{n}\sum_{i=1}^{n} Y_1^2\right] . . . \;(1)$$

Are substituted the values of the stress σ and the deformation δ in the variable Y to obtain the following results shown in Table 5.

Table 5
Results of all runs

	Input variable		Output variable	
	WITHOUT S/N		WITH S/N	
Run	σ	δ	S/N σ	S/N δ
1	3.164e+006	9.401e-004	130.005	60.537
2	3.658e+006	3.416e-004	130.67	69.33
3	1.624e+008	2.441e-003	64.212	52.249
4	2.442e+006	5.160e-004	134.253	65.747
5	3.663e+006	3.413e-004	130.663	69.337
6	3.738e+006	6.000e-004	131.453	64.437
7	3.022e+006	4.363e-004	129.606	67.204
8	3.653e+006	3.423e-004	131.253	69.312
9	3.735e+006	5.992e-004	135.551	64.449

5. Results

From the data obtained by the software study (SolidWorks with finite element) which appears in table 4, runs 6 and 9 are the most optimal runs, because they both are the ones that support the most stresses applied and the deformation in runs 6 and 9 are very similar, therefore is taken the run number 9 as the most optimal run. These results are shown in Table 6.

Table 6
Optimum results with finite element

	Input variable	
	WITHOUT S/N	
Run	σ	δ
6	**3.738e+006**	**6.000e-004**
9	**3.735e+006**	**5.992e-004**

Comparing the applying equation 1 in the Taguchi methodology, we obtain the results shown in table 5 where the most optimal is run 9. The results are shown in table 7.

Table 7
The Taguchi methodology results

	Output variable	
	WITH S/N	
RUN	S/N σ	S/N δ
9	**135.551**	**64.449**

Therefore, is concluded that with the results obtained by the methods applied, it is evident that run 9 is the best run for the mechanical part studying, where the values are shown in Table 8.

Table 8
Optimal mechanical part results

	Input variable		Output variable	
	WITHOUT S/N		WITH S/N	
Run	σ	δ	S/N σ	S/N δ
9	3.735e+006	5.992e-004	135.551	64.449

6. Conclusion

This paper presented an analysis based on the optimization of a mechanical part using finite element and Taguchi.

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