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Application of Taguchi Method in process improvement of turning of a Superalloy NIMONIC 80A

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Abstract

In this article was used the Taguchi Method as a tool to improve a turning of superalloy NIMONIC 80A, using a cemented carbide TNMG 160408-23 C standard H10A (ISO S10) and a holder PTGNR K16, in order to optimize the cutting length (Lc). Was used the L8 orthogonal array with three factors: cutting speed, feed rate and cutting depth, operating in two levels and three interactions, setting yet the value of flank wear in 5 mm as final goal for each experimental condition. The analysis of variance (ANOVA) of the response variable cutting length showed a significant influence of the process of variable: cutting speed and depth of cut, as well as their interactions. The Taguchi Method showed to be very useful in process improvement, because provides confident information about influence of factors on a response variable and require less number of experiments than traditional methods to improve the process.

Keywords: Taguchi Method, Machining, Design of Experiment

1. Introduction

Economic globalization and the rapid and continuous appearing of new technologies mobilized organizations to obtain the maximum degree of competitiveness, high quality products in short time in order to ensure their survival and growth in the market (Benardos,&Vosniakos, 2002; Besseris, 2009) .

In this scenario, companies started to look for quality not only in their products, but also in its production process, thus increasing considerably their production, and launching on the market at a higher quality product to meet consumer is increasingly demanding.

For this purpose, this study proposes the use of the technique Design of Experiments (DOE), more specifically, the Taguchi Method to optimize the process of turning on CNC (Computer Numerical Control) in this case for the super alloy Nimonic 80A.

2. DOE - Design of Experiment

The concept of Design of Experiment was first introduced in early 1920 in a small station of Agricultural Research in England, by a scientist called Sir. Ronald Fisher. He showed as a valid experiment could be conducted in the presence of many natural conditions variables, such as: temperature, soil conditions and rainfall. The principles of experimental design first used in agriculture have been adapted successfully in industry and in military applications since 1940 (Franceschini & Macchietto, 2008 ; Kim & Kalb, 1996).

The DOE is a technique used to define what data, in what quantity and conditions should be collected during an experiment, trying to satisfy two major goals: the statistical accuracy of the response and lower cost (Gunasegaram et al., 2009).

Benardos,&Vosniakos (2002) The most efficient method of experimental planning is DOE, offer even greater opportunities for improving the quality and increase productivity.

The benefits of DOE include the possibility of improving performance in the process, avoiding the trial and error to find solutions (Kleijnen et al., 2005). For Antony (2006) DOE emphasizes the development and use of regression models to predict process behavior under different process conditions to a certain level of confidence.

Montgomery (1997) states that before starting the experimentation is important to establish the planning of experiments. The author emphasizes the importance of the problem domain by all those involved in the experiment, and recommends that during the implementation process is carefully monitored to ensure that everything be done according to plan.

The application of DOE has gained acceptance around world as an essential tool for improving the quality of goods and services. This recognition is partly due to the work of Genichi Taguchi, a Japanese expert in Quality, which promoted the use of DOE in designing robust products - relatively insensitive to environmental variations (Antony 2006; Padke 1989; Rosa et al. 2009).

3. Taguchi Experimental Design

"The experimental design is widely used to optimize process parameter values in order to improve the quality properties of a product for example" (Rosa et al. 2009). Conventional experimental design methods are generally complex and not always reach the desired objectives. Moreover, these methods require a large number of experiments when the number of process parameters increases.

Taguchi developed the foundations of Robust Design introduced in the 1950s and 1960s and the application of his method in electronics, automotive, photographic and many others industries has been an important factor in the rapid industrial growth of Japanese industries (Padke, 1989). Taguchi method uses a special design of orthogonal arrays that allows studying the whole parameter space with a limited number of experiments (Ross, 1996). Besides, this method provides other advantages: it reduces economically the variability of the response variable, shows the best way to find out the optimum process conditions during laboratory experiments, it is an important tool for improving the productivity of the R&D activity and it can be applied to any process.

The steps of the Taguchi experimental design (Barrado et al., 1996) are: (a) to select the output variable(s) (response(s)) to be optimized; (b) to identify the factors (input variables) affecting output variable(s) and to choose the levels of these factors; (c) to select the appropriate orthogonal array; the arrays are found in literature (Taguchi & Konishi, 1987); (d) to assign factors and interactions to the columns of the array; (e) to perform experiments; at this step it is important to randomize the trials in order to minimize the systematic error; (f) to analyze the results using analysis of variance (ANOVA); (g) to determine the optimal process parameters; (h) to perform confirmatory experiments, if it is necessary.

The analysis of variance (ANOVA) is applied in order to test the equality of several means, resulting in what process parameters (factors) are statistically significant. The results of ANOVA are presented in a table that displays for each factor (or interaction) the values of:

• SS: sum of squared deviations from the mean. For n values of y_i and the mean value $\overline{y}$.

$$SS = \sum_{i=1}^{n} (y_i - \overline{y})^2 \qquad (1)$$

• d.f.: degree of freedom which is the number of levels for each factor minus 1.

• MS: mean of squares.

$$MS = \frac{SS}{d.f} \qquad (2)$$

• F: F is the ratio between the mean of squares effect and the mean of squares error.

$$F = \frac{\mathbf{MSeffect}}{\mathbf{MSerror}} \qquad (3)$$

F-test is used to see the significance of each factor (or interaction) on the response variable or signal-to-noise ratio.

4. Machining

Kitagawa et al (1997) relates that due to the difficulty in the cut of superalloy the demand for machining in higher speeds is increasing in order that reaches high productivity and lower cost of machining.

Aeronautical industries manufacture components of motors with alloys of titanium, nickel alloys and also special stainless steels. These industries are characterized by a great cost in the production of these workpieces machining and one of the great reasons of this elevated cost is the cost hour/machine. For this reason, it is interesting to reduce the times of workpieces machining and to increase the tool life, because the costs hour in the industry aeronautics they are higher than in the conventional industries (RIBEIRO, 2003; López De Lacalle et al. 1998).

In research of good achievements, the machine CNC (Computer Numerical Control) had as initial objective to solve the machining of the components of the high complexity, and afterwards came support the reduction of unproductive time (Tzeng et al., 2009). However the utilization of these machines only become economically feasible when guaranteed the proper employment of these machines and tools during the machining process, that is, the efficiency of machining process depends of the utilization of optimized cutting data, updated and adequate to the real work conditions.

Good results in machining operation are related with an achievement of the component wished measurements, selection of cutting tools and cutting conditions is an essential element in process planning for machining, because each material would be influenced by different machining parameters (Wang et al. 2007; Yih-fong, 2006).

The optimization of machining process have been one of the options for manufacturing industries, looking for better achievements, represented mainly by the cost reduction or manufacturing time (Diniz et al, 2001).

5. Experimental Procedures

Based on the analysis of the experiments and their results, it intends to guide the choice of production parameters, which will permit a greater cutting length possible, evaluating the best arrangement between the chosen parameters and the effect of the interaction between them.

5.1. Machining tests

The external cylindrical turning tests were carried out considering machining parameters (semi-rough).

The tests were performed on a CNC lathe MACH-9-CENTUR 30S, 25 to 3500 rpm, with power of 10 hp, brand ROMI from the Department of Materials and Technology, Faculty of Engineering, Guaratinguetá Campus, UNESP. Was used a chip carbide uncoated TNMG 160408-23 Class H10A (ISO S10) and a support, PTGNR 2020 K16 (Sandvik).

After each step of turning, to the measures of the diameters of the components was used a Mitutoyo caliper from 0 to 150 mm with a sensitivity of 0.05 mm.

In the test was used a cutting fluid designed to meet the machining operations for ferrous metals and aluminum alloys, the Tapmatic - type ME-1. This fluid consists of a concentrated microemulsion of 10% in water. It contains in its composition a mixture of mineral oils, esters, amides boric, surfactants, biocides and defoamers. The fluid was applied to conventional way (abundant).

To calculate the cutting length was used the Equation 3 (Diniz et al., 2001):

$$Lc = \frac{Lf.\pi.D}{f.1000}(m) \quad (3)$$

where Lf is the length of advance of the operation, equal to 185 mm, D is the diameter obtained in the pass in question (in mm) and f is the feed rate used (mm/rev).

5.2. Determination of the factors to be investigated

The aim is to evaluate the influence of the following factors on the characteristics of the machined components, that is, the best arrangement of factors and levels that provide a greater cutting length (Lc). The levels and the factors are showed on Table 1.

Table 1: Factors and their levels

Level	Factors of Variation		
	A: Cutting Speed (Cs)	B: Feed (f)	C: Depth of Cut (ap)
1	75 (m/min)	15 (mm/rev)	0,8 (mm)
2	90 (m/min)	18 (mm/rev)	1,6 (mm)

5.2. Selection of the Orthogonal Array

The sequence of experiments with the combination of factors and levels is determined by an orthogonal array. This array will determine the number of experiments to be performed, ensuring that all levels of all factors will be tested an equal quantity. The appropriate array is selected according to the number of factors, levels and resolution intended.

In this case, for 3 factors at two levels was selected L8 orthogonal array. This array includes the implementation of eight runs showed on the Table 2.

Table 2: Orthogonal Array L8

Runs	Factors						
	1	2	3	4	5	6	7
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

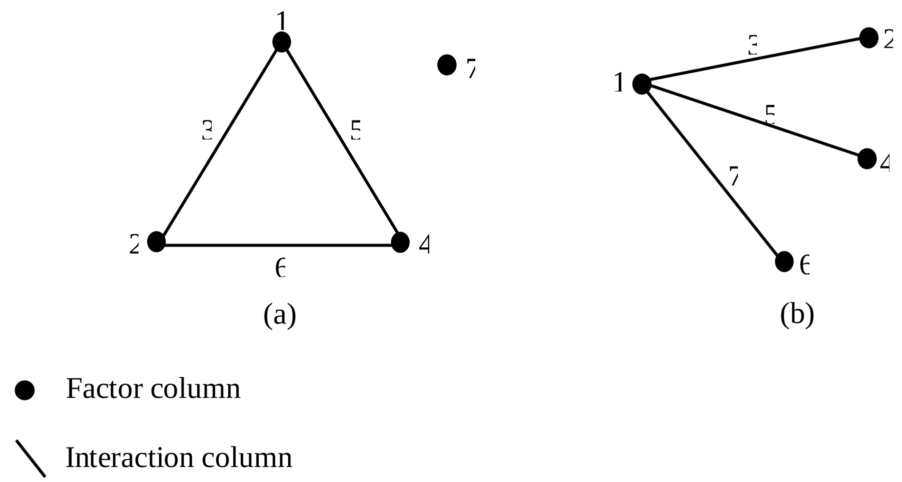

Figure 2: Linear graphs of the orthogonal array L8 (a) and (b)

Source: Adapted from (Ross, 1996)

6 Results and Discussion

6.1. Taguchi Array and Results

With the array planned and the experiments made, was constructed the Table 3 where A, B and C are the factors to be studied and Lc is the result of the cutting length for each configuration of input factors in their respective array for the flank wear set at 0.5 mm.

Table 3: Set of factors for a Taguchi Array L8

Runs	Number of columns, position of the factors, their interactions and their levels							
	1	2	3	4	5	6	7	
	A	**B**	**AxB**	**C**	**AxC**	**BxC**	**empty**	**Lc(m)**
1	1	1	1	1	1	1	1	1811,60
2	1	1	1	2	2	2	2	227,50
3	1	2	2	1	1	2	2	914,42
4	1	2	2	2	2	1	1	253,11
5	2	1	2	1	2	1	2	255,72
6	2	1	2	2	1	2	1	193,72
7	2	2	1	1	2	2	1	134,32
8	2	2	1	2	1	1	2	124,63

6.2. Calculating the Effects

From the results obtained in the experiment the effects of factors on the response was calculated with the aid of statistical software Minitab®, as showed on Table 3.

Table 4: Factors Effect on the Response

Level	Effects of factors and their interactions					
	A	B	C	AxB	AxC	BxC
1	801,7	622,1	779,0	574,5	761,1	611,3
2	177,1	356,6	199,7	404,2	217,7	367,5

6.3. Analysis of Variance

On the Table 5 presents the analysis of variance (ANOVA) of the effects of factors on the response variable cutting length (Lc).

Table 5: ANOVA to the Mean				
Source of Variation	SS	d.f	MS	F
A	780150	1	780150	8,24
B	140996	1	140996	1,49
C	671119	1	671119	7,09
A*B	57984	1	57984	0,61
A*C	590632	1	590632	6,24
B*C	118853	1	118853	1,25
Residual Error	94717	1	94717	
Total	2454451	7		

SS: sum of squares; d.f.: degree of freedom. MS: mean of squares (equal to SS/d.f.); F: MSeffect/MSerror

In order to obtain the most significant variables, was used the judgment proposed by Phadke (1989), which considers influent those variables that present $F \geq 2.0$. Performed this analysis, it is observed that the factors A, C and the interaction between AxC are the most significant variables in the process.

6.4. Influence of factors on the cutting length

With the results on Table 4 and Figure 3, taking into account that the objective is reaching the largest possible value of cutting length, can be observed the great importance of the factors A and C and their interaction AxC, being confirmed by the values F on Table 5.

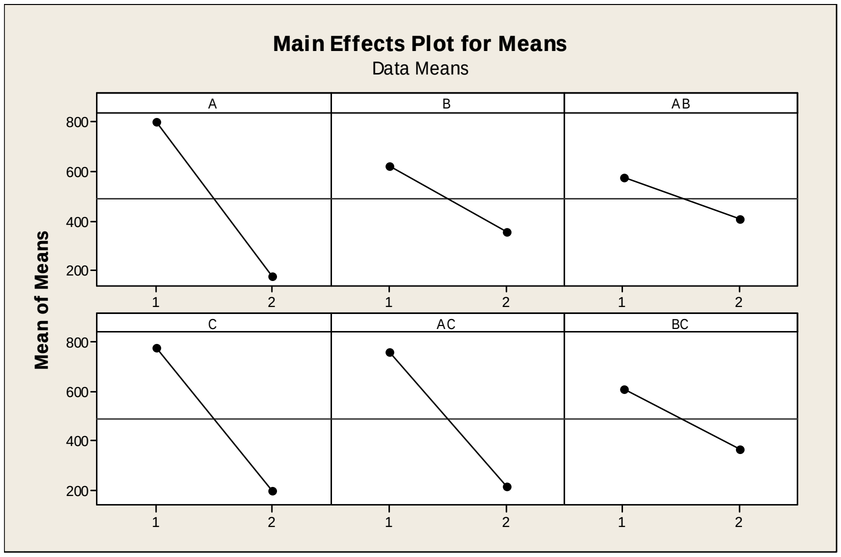

Figure 3: Effects of levels of factors

Thus, the optimum condition of the adjust of control factors, deduced from analysis of the response of cutting length, in order to achieve longer life of the tool is to put all the factors in its lower levels.

Analyzing the best fit for the cutting speed (factor A) at level 1, that is, working with lower speeds there is a gain in tool life thus increasing the response variable cutting length. This best setting is due to the studied components (Nimonic 80A), they have a high heat resistance as a characteristic, making the increase of cutting speed, increases the friction between tool and material, and much of that heat is absorbed by the tool making its life decreased.

For the Factor B is observed on Table 4 which has no great influence on the process, because there is a good distribution of heat for both levels of feed rate used, so that there isn't great significance in the variation, what is not observed with Factor C, that with the increasing of the depth there is no time enough to dissipate heat through the material, causing heating of the tool and reducing its hardness and consequently the tool's life.

Analyzing the Figure 4 (a) can be observed that the cutting length decreases while that there is a increasing in the depth of cut (ap). This behavior is presented in the same way with the cutting speed (Cs).

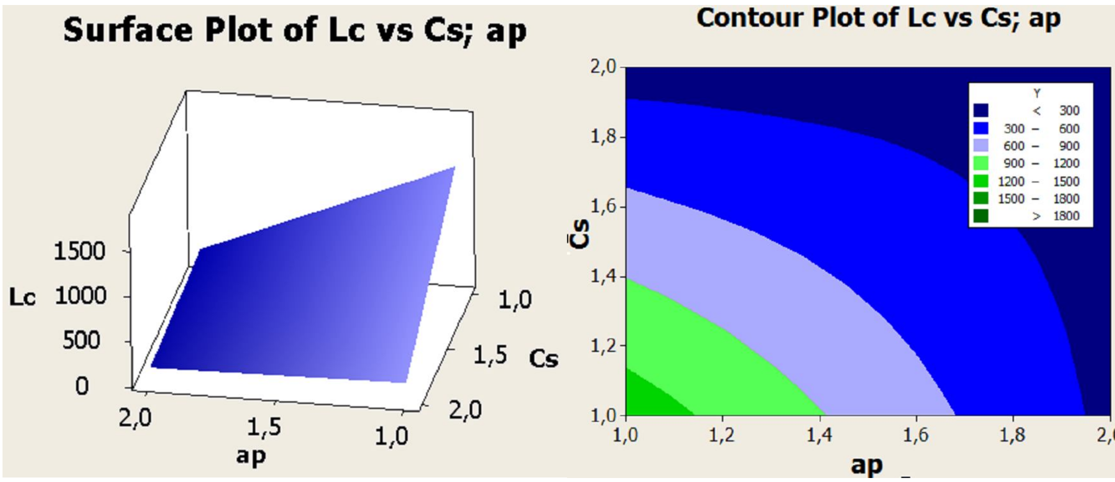

Figure 4: Response surface (a), Contour (b) to the cutting length (Lc) depending on the depth machined and cutting speed.

The Figure 4 (b) presents on a similarly graphs with the contours of that same arrangement, being the part in dark shade of blue the lowest values of cutting length and the darker green the highest values. This make an evident conclusion that the higher cutting speed and Lc, shorter the length of material being machined, thus proving the explanations of the behavior of factors.

It can be pointed out from the Figure 4 (a) the presence of interaction, not by the flatness of the response surface, which does not happen on the Figures 5 (a) and 6 (a) where there is no evidence that there is a presence of interaction between the factors.

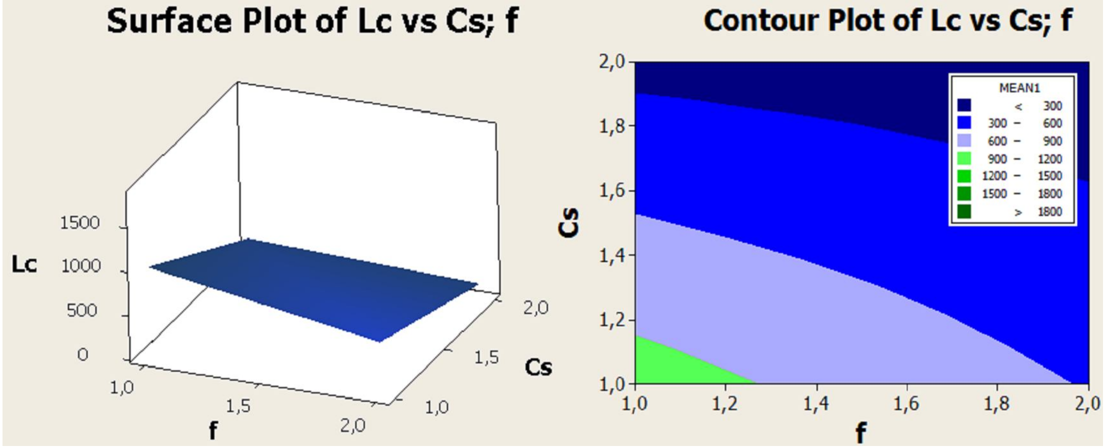

Figure 5: Response surface (a), Contour (b) the cutting length (Lc) depending on the feed rate and cutting speed.

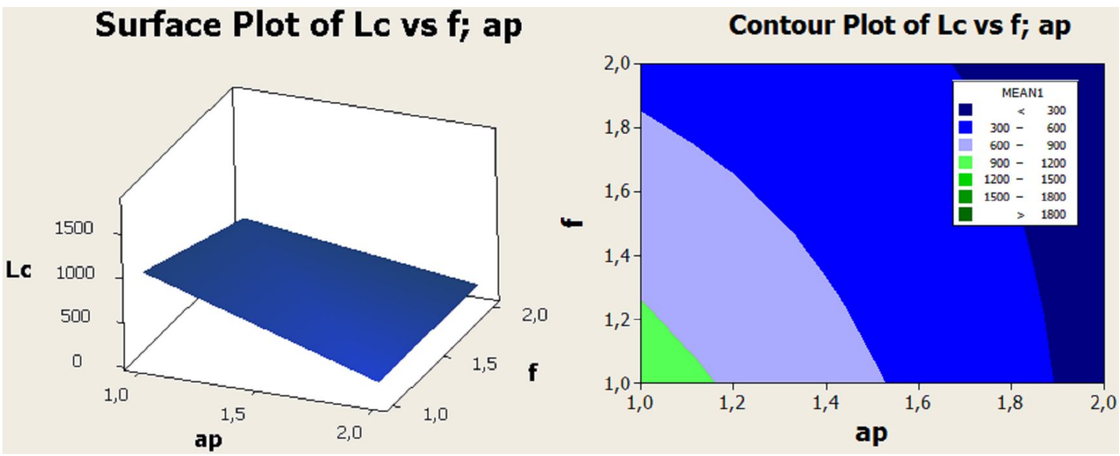

Figure 6: Response surface (a), Contour (b) the cutting length (Lc) depending on the feed and depth of cut

Comparing the figures 4 (b), 5 (b) and 6 (b) can be proved that the parameters Cs and ap produce a much greater effect on the Lc once it reaches the greatest variations in Lc and therefore on the life of the tool, ensuring the analysis of the Table 4.

7. CONCLUSIONS

The use of Taguchi orthogonal array has helped in the choice of factors and parameters of the test application, defined the sequence of experiments performed and the properties measured. After the experiments, it was possible to identify the influence of factors on the characteristics of measures and identify the parameters that gave the best results about the Lc.

Before these conditions, the maximum response in the cutting length according the parameters of forward cutting speed, feed rate and depth of cut, is obtained when these three parameters have their values adjusted in the minimum experimental levels, meaning bigger productivity for the process, by a greater rate of material removal.

In the present study can be seen that there was a strong influence of the parameters cutting speed and depth of cut as well as their interaction, so that there was a correlation between these parameters and the life of the tool, that is, increasing either of these two parameters, Vc, or ap, there will be a decrease in life of the tool, possibly due to the low abrasion of the alloy that increases the temperature of the tool, because the alloy has low thermal conductivity.

Taguchi Method showed to be efficient and suitable for the process improvement, proposing adjustments that will provide an improvement in the productivity.

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