RESEARCH ON THE USE OF TAGUCHI’S METHOD TO MODEL THE MILLING PROCESS OF SOME METAL MATERIALS

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Abstract - The paper is based on an applied scientific research carried out within a doctoral thesis. It is proposed to use the Taguchi Method in order to model the cutting regime factors to obtain the best quality of the surface machined by the end-milling, considering experimental statistical modelling. The orthogonal matrix, the signal-noise ratio and the variance analysis are used to study the performance conditions in the milling operation of an aluminum workpiece using a standard cutting tool. Three end-milling factors, namely, cutting speed, cutting depth and feed rate, are modelled considering the surface roughness. The tests results obtained are disseminated to illustrate the effectiveness of the analyzed process.

Keywords: Taguchi’s Method, Cutting Parameters, Surface Roughness, End-Milling, Experimental Statistical Modelling.

1. Introduction

The experimental design is one of the most important tools used for modeling and at the same time analyzing the influence that control factors can have on the performance of the production.

In this context, the classical experimental design approach presents a high level of difficulty when it is necessary to carry out a considerable number of experiments, and the number of factors is increasing [1,2,3].

An essential stage in the design of the experiment is the selection of control factors [4,5,6].

Taguchi’s method includes an experiment plan aimed at acquiring a data package in a controllable manner, performing the necessary tests and collecting the analysis information to gain data on the behavior of the analyzed process [7,8,9].

In accordance with Taguchi’s approach, the quality of a product implies a definition focused on the terms of the loss offered by the product to the company from the moment of delivery to the customer [10,11,12].

In this scientific research, the design of parameters according to Taguchi’s methodology is the most important phase and implies the achievement of the objective of determining their optimum values in the cylinder-front milling process in order to reach the lowest surface roughness values for an aluminum alloy, chosen with properties superior to other alloys of this material.

2. Research Methodology

Conduct the experiments

The experimental research will be carried out considering the following aspects:
- Cutting process: end-milling;
- CNC: 3 axis - HAAS VF2;
- Workpiece material: aluminum alloy 7136;
- Cutting tool: SECO type R217.69-1616.0-09-2AN, with two indexable cutting inserts X0EX0903O8FR-E05, H15;
- The cutting process parameters: cutting speed, cutting depth, feed per tooth;
- Direction of research: Ra surface roughness;

Choosing the method

The research related to this work will be performed with Taguchi method and ANOVA analysis.

The stages of the experimental plan using Taguchi’s method
- The factors identification which are involved in the analyzed process;
- Selecting and defining the parameters to be studied;
- Choosing the levels for each parameter;
- The orthogonal array;
• Carrying out the research according to the Taguchi experiments plan;
• Data analysis and interpretation;
• Determining the best level of each control parameter.

The objective of the research
This paper aim is to determine the optimum values of some cutting parameters to increase the performance of the end-milling process, and to obtain a minimum sensitivity to the uncontrollable factors and a surface roughness as small as possible.

Statistical application
The software application used in the research is Statistica®. This application offers the possibility to perform a series of data analyzes, to manage them, to view them as well as a package of procedures for extracting them along with a data variety, predictive modeling, clustering, and classification and exploration techniques.

Design and Analysis of experiments
A first step in this analysis involves generating the design of experiment. In this case, Taguchi robust design experiments (orthogonal array) was chosen.

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Experiment design analysis (DOE)
Since it is desired to obtain a roughness of the machined surface (Smaller-the-better), the dependent and independent variables are established, as follows:
• Dependent variables: surface roughness Ra med;
• Independent variables: cutting speed, cutting depth and feed rate.

Table 1. The adjustment parameters and the values of the related levels
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Parameter</th>
<th>Parameter name</th>
<th>Value 1 - min</th>
<th>Value 2 - max</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Parameter 1</td>
<td>Cutting speed</td>
<td>495,00 [m/min]</td>
<td>660,00 [m/min]</td>
</tr>
<tr>
<td>B</td>
<td>Parameter 2</td>
<td>Cutting depth</td>
<td>2 [mm]</td>
<td>4 [mm]</td>
</tr>
<tr>
<td>C</td>
<td>Parameter 3</td>
<td>Feed per tooth</td>
<td>0,04 [mm/tooth]</td>
<td>0,14 [mm/tooth]</td>
</tr>
</tbody>
</table>

Table 2. The measured values of roughness Ra according to the parameters established for the 8 tests
<table>
<thead>
<tr>
<th>Trial number</th>
<th>Adjustment parameters</th>
<th>Ra results [μm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>v [m/min]</td>
<td>ap [mm]</td>
</tr>
<tr>
<td>1</td>
<td>495</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>495</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>495</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>495</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>660</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>660</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>660</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>660</td>
<td>2</td>
</tr>
</tbody>
</table>
Using the statistical application, the averages were calculated (for Eta, the S/N signal-noise ratio) for each level for each parameter and the parameter estimates - that is, the average deviations of the respective factor level from the total average (μ).

Considering that it is desired to obtain a minimum roughness of the end-milled surface, in this sense it is necessary that the S/N ratios be maximized.

Figure 2 shows a summary of these averages, in a graphical form.

Fig 2: Average Eta by Factor Levels

In this graph, the best levels for each factor can be easily identified, that is, those that lead to obtain the highest S/N ratio. Specifically, for all the cutting factors in this study, the highest S/N ratio appears at level 2.

Eta expresses the intensity of the connection between a nominal variable and an ordinal or scalar variable.

ANOVA

The following is the ANOVA analysis which is closely related to the obtained results, as the standard errors reported depend on the interpretations made previously.

Table 3 summarizes the results obtained from this analysis.

<table>
<thead>
<tr>
<th>Effect</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)Cutting speed [m/min]</td>
<td>9.6475</td>
<td>1</td>
<td>9.64752</td>
<td>0.303024</td>
<td>0.611289</td>
</tr>
<tr>
<td>(2)Cutting depth [mm]</td>
<td>75.6719</td>
<td>1</td>
<td>75.67191</td>
<td>2.376816</td>
<td>0.198006</td>
</tr>
<tr>
<td>(3)Feed per tooth [mm/tooth]</td>
<td>42.2941</td>
<td>1</td>
<td>42.29414</td>
<td>1.328437</td>
<td>0.313276</td>
</tr>
<tr>
<td>Residual</td>
<td>127.3501</td>
<td>4</td>
<td>31.83751</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In table 3 the symbols represent:
- SS - sum of squares;
- df - Degrees of freedom;
- MS - Average of squares;
- F is the value of the Fisher (Fratio) test coefficient;
- P - Each ratio F is calculated as the ratio of two MS values. Each of these MS values has an appropriate number of degrees of freedom. Thus the ratio F is associated with a number of degrees of freedom for the numerator and another for the denominator;
- Residual - Typically, to obtain a more stable estimate of error variation, small and insignificant effects are combined within the error term. Even if this procedure exploits the chance (and the resulting p values are suspect), it produces several stable predictions later.

Perform optimization of the equation state

The combination of the insignificant effects in the error term exploits its occurrence and, significant factors can be identified.
One way to "verify" the results obtained is by first predicting Eta under optimal conditions, based on the factors identified as significant, that is, in our case the cutting depth having the greatest influence.

Then we can run a verification experiment, that is, a few runs using these real settings. If significant differences occur between predicted and observed values, then factors that were unimportant, or unexpected interactions between factors, were erroneously included.

The Signal / Noise ratio, used to measure the results, simultaneously takes into account the average of the relative measurements of each test on the one hand, and their dispersion, the average of the standard deviations, on the other. Therefore, the higher the algebraic value of the Signal / Noise ratio, the lower the recorded loss and the better the cutting process performance.

By default, all factors are set to their optimal level, that is, to the levels that produce the highest S/N ratio.

Table 4 presents the signal-to-noise ratio results obtained under optimal conditions.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Level</th>
<th>Effect size</th>
<th>Standard error</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Cutting speed [m/min]</td>
<td>1</td>
<td>1.09815</td>
<td>2.821237</td>
</tr>
<tr>
<td>(2) Cutting depth [mm]</td>
<td>1</td>
<td>3.07555</td>
<td>2.821237</td>
</tr>
<tr>
<td>(3) Feed per tooth [mm/tooth]</td>
<td>1</td>
<td>2.29930</td>
<td>2.821237</td>
</tr>
<tr>
<td>Expected S/N</td>
<td></td>
<td>23.27127</td>
<td></td>
</tr>
</tbody>
</table>

The conclusion is that factors and their levels should be reviewed so that no meaningful interactions remain. In this respect, traditional factorial designs on two levels (with sufficient resolution) can be used to detect the interactions in the research data.

In more detail, the results obtained can be viewed through bar graphs with cumulative proportions (figure 3). In this graph, the relative frequencies (proportions) of each category (Ra1, Ra2, Ra3) for each level of each factor are displayed in stacked columns. For example, for the first factor (cutting speed), we can immediately recognize that the largest coverage area appears below level 1.

This information for this factor can also be displayed by a linear graph with the cumulative proportions between categories (figure 4).
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![Figure 4: Cumulative Percent – factor – cutting speed [m/min]](image)

As shown in the illustration above, the line indicating the cumulative proportion at which the highest roughness is recorded is the one for level 1.

Finally, following the optimization, the results presented in table 5 were obtained.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Level</th>
<th>Ra₁</th>
<th>Ra₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Cutting speed [m/min]</td>
<td>1</td>
<td>-2.27565</td>
<td>3.772794</td>
</tr>
<tr>
<td>(2) Cutting depth [mm]</td>
<td>2</td>
<td>-2.54581</td>
<td>3.243579</td>
</tr>
<tr>
<td>(3) Feed per tooth [mm/tooth]</td>
<td>2</td>
<td>-2.66328</td>
<td>3.236961</td>
</tr>
<tr>
<td>Mean S/N</td>
<td></td>
<td>-2.54998</td>
<td>2.910702</td>
</tr>
<tr>
<td>Expected S/N</td>
<td></td>
<td>-2.38378</td>
<td>4.431931</td>
</tr>
</tbody>
</table>

### 3. Conclusions

In this paper, the subject of the surface quality during milling of an aluminum alloy was debated.

This theme was chosen due to the fact that in the cutting process industry and in the manufacturing industries, surface finishing and product strength are essential in determining quality.

The best surface finish also ensures a high quality of the final product.

The effect and optimization of the cutting parameters on the surface roughness was investigated using the Taguchi and ANOVA methods.

Following the optimization of the equation of state it is found that in order to obtain the best quality of the processed surface and therefore a small roughness, it is necessary that the cutting speed be as high as possible and the cutting depth and the advance on the tooth, small.

### References


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