The optimization of cutting parameters at turning, using electrical current at cutting, in order to increase the durability of the cutting tool

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Abstract. The optimization of the turning cutting parameters was a permanent concern for research but also for production. The emergence of new metal materials to be processed as well as the development of new cutting edges has always led to new optimizations of the cutting regime. The appearance of coated plates, single layer or multilayer, determined the companies producing them to indicate information about the cutting parameters, but the values are given in a certain interval. In order to reduce the necessary experiments to indicate the optimal cutting regime, the paper proposes the analysis of the electrical current at cutting and its use for optimization. The processing of the experimental data obtained as well as the optimization of the cutting parameters was performed using Design Expert software.

1. Introduction

In case of machining metals with cutting tools that conduct electricity, heat is released in the cutting area, which leads to a higher temperature than the cold end of the cutting tool. This causes the appearance of the electrical current at cutting, which in the literature is also known as thermocurrent.

If the temperature difference between the cutting area and the cold end of the cutting tool increases, the current voltage also increases [1-8].

In research [9] it is shown that when drilling metals with high speed steel drills, there is a dependence between the quality of the drill edge and the voltage of the occurred thermocurrent. Research [10] proposes an algorithm for acquiring drills depending on the size of the thermocurrent voltage that occurs when cutting metals.

Research [11-13] present several approaches for using the thermocurrent that occurs during turning process, involving determination of quality differences between cutting edges and an algorithm for acquiring cutting inserts.

The mentioned previous research attests the direct connection between the voltage of the thermocurrent and the imperfections of the cutting edge. The more and larger these imperfections, the higher the temperature in the cutting area, which leads to an increased voltage and finally to a low durability of the cutting edge.

Based on the presented facts, this paper proposes the use of the thermocurrent for optimization, by analyzing the influence of the cutting parameters.
2. The influence of the cutting regime on the thermocurrent value when turning with coated plates

To study the influence of the cutting regime on the thermocurrent value as well as to optimize its values in order to increase the durability of the tool, it was used a three-factor model, each having three levels, according to table 1, and the response was introduced as the thermocurrent voltage.

Table 1. Input parameters for the complete factorial model.

| Factors | Name             | Unit | Levels | Level 1 | Level 2 | Level 3 |
|---------|------------------|------|--------|---------|---------|---------|
| A       | Cutting speed    | m/min| 3      | 86      | 107     | 137     |
| B       | Cutting feed     | mm/rev| 3      | 0.151   | 0.208   | 0.25    |
| C       | Cutting depth    | mm   | 3      | 1       | 1.5     | 2       |

Having three factors with three levels each, according to the complete factorial plan, the number of experiments is, $3^3$, which means 27 experiments.

2.1. Performing experiments

For the experiments it was used the configuration presented in figure 1, defined by the next elements: 1 – lathe; 2 – part; 3 – cutting tool; 4 – collector for the electrical current; 5 – multimeter; 6 – computer.

![Figure 1. The configuration used to measure the voltage of the thermocurrent.](image1)

![Figure 2. The interface of the digital multimeter.](image2)
Table 2. Experimental results using the complete factorial model.

| No. of experiment | Speed [m/min] | Feed [mm/rev] | Depth [mm] | Voltage [mV] |
|-------------------|---------------|---------------|------------|--------------|
| 1                 | 86            | 0.208         | 2          | 2.6          |
| 2                 | 137           | 0.151         | 2          | 3.5          |
| 3                 | 137           | 0.151         | 1.5        | 3.8          |
| 4                 | 107           | 0.208         | 2          | 3.4          |
| 5                 | 137           | 0.25          | 2          | 5            |
| 6                 | 86            | 0.208         | 1.5        | 3            |
| 7                 | 107           | 0.208         | 1          | 3.2          |
| 8                 | 107           | 0.151         | 2          | 3.3          |
| 9                 | 137           | 0.151         | 1          | 3.9          |
| 10                | 86            | 0.25          | 1.5        | 3.2          |
| 11                | 107           | 0.151         | 1.5        | 3.4          |
| 12                | 137           | 0.25          | 1          | 3.5          |
| 13                | 137           | 0.208         | 1          | 3.2          |
| 14                | 107           | 0.25          | 1          | 3.5          |
| 15                | 86            | 0.25          | 1          | 3.1          |
| 16                | 107           | 0.208         | 1.5        | 3.2          |
| 17                | 107           | 0.25          | 2          | 3.7          |
| 18                | 107           | 0.25          | 1.5        | 5.5          |
| 19                | 107           | 0.151         | 1          | 3.3          |
| 20                | 137           | 0.208         | 2          | 4.8          |
| 21                | 86            | 0.25          | 2          | 3.5          |
| 22                | 137           | 0.25          | 1.5        | 4.6          |
| 23                | 86            | 0.208         | 1          | 2.9          |
| 24                | 86            | 0.151         | 1          | 3.3          |
| 25                | 137           | 0.208         | 1.5        | 3.9          |
| 26                | 86            | 0.151         | 1.5        | 2.9          |
| 27                | 86            | 0.151         | 2          | 2.4          |

With the help of the configuration presented in figure 1, the 27 experiments that are centralized in table 2 were performed.

The experiments were performed when turning C45 steel with titanized metal carbide plate, type WNGB080408.

The multimeter is used as an acquisition system and it has a sample rate of three values/second. The acquisitioned values can be visualized in real-time, as presented in figure 2, and they also can be saved.
2.2. Data processing. ANOVA Analysis.

To see how each parameter of the cutting regime influences the value of the thermocurrent voltage, an ANOVA analysis was performed using Design Expert version 11. Also, experiments no. 18 and 21 were eliminated from the analysis. They were identified as aberrant values by studying DFFIT indicator.

The final results for ANOVA are presented in table 3, and table 4 shows the resulted statistical indicators.

### Table 3. ANOVA analysis.

| Source | Sum of squares | Freedom degrees | Mean square | F Value | P value |
|--------|----------------|-----------------|-------------|---------|---------|
| Regression | 8.39 | 7 | 1.20 | 24.71 | < 0.0001 |
| A-Speed | 5.02 | 1 | 5.02 | 103.44 | < 0.0001 |
| B-Feed | 0.0034 | 1 | 0.0034 | 0.0708 | 0.7933 |
| C-Depth | 0.6865 | 1 | 0.6865 | 14.15 | 0.0016 |
| AB | 0.1596 | 1 | 0.1596 | 3.29 | 0.0874 |
| AC | 1.24 | 1 | 1.24 | 25.59 | < 0.0001 |
| BC | 0.0094 | 1 | 0.0094 | 0.1934 | 0.6656 |
| ABC | 0.2382 | 1 | 0.2382 | 4.91 | 0.0407 |
| Residual | 0.8249 | 17 | 0.0485 | | |
| Total | 9.22 | 24 | | | |

In order to interpret the results, there were used the specifications provided by Design Expert software.

The row of the Regression source shows how much of the variation of the response is explained by the model, the rest of the variation left unexplained being shown in the Residual row, the total variation around the average of the observations being calculated in the Total row.

The F value represents, in case of ANOVA analysis, the value of the effect and it is calculated as the ratio between the square mean of the analysed parameter and the residual square mean. For the analysed model, the F value of 24.71 represents that it is statistically significant.

It can also be seen that the cutting speed has the greatest influence on the voltage of the electrical current, being followed by depth and feed. But to find out if the model parameters have statistical significance on the analysed response, the p value, which must be less than 0.05, is analysed. In this case, the cutting speed and the cutting depth parameters are significant while the cutting feed has no statistical significance on the electric current voltage value.

### Table 4. Statistical indicator resulted from ANOVA analysis.

| Indicator | Value |
|-----------|-------|
| Standard deviation | 0.2203 |
| Mean | 3.46 |
| Coefficient of variation % | 6.36 |
| R2 | 0.9105 |
| Adjusted R2 | 0.8737 |
| Predictable R2 | 0.7507 |
| Signal to noise ratio | 20.9610 |
Predictable $R^2$ measures the variation of newly introduced experimental data, which can be explained by the current model. In order for the model to be used for optimizations and predictions regarding the variation of the response to new values of the input parameters, the difference between adjusted $R^2$ and predictable $R^2$ must be less than 0.2, which in this case it is fulfilled.

The signal-to-noise ratio must be greater than 4 for the model to be used in predictions. This requirement is also fulfilled.

The resulted linear mathematical function that models the experimental data is:

$$U = -0.276 + 0.0514202 \cdot v_c + 27.53036 \cdot f + 1.87008 \cdot a_p - 0.34882 \cdot v_c \cdot f -$$

$$\quad - 0.032826 \cdot v_c \cdot a_p - 23.22924 \cdot f \cdot a_p + 0.29698 \cdot v_c \cdot f \cdot a_p$$  \hspace{1cm} (1)

where:

- $U$ [mV] – thermocurrent voltage;
- $v_c$ [m/min] – cutting speed;
- $f$ [mm/rev] – cutting feed;
- $a_p$ [mm] – cutting depth.

3. The optimization of the cutting regime, using the thermocurrent, in order to increase the durability of the cutting tool

As it was mentioned in the introduction, a direct relationship is created between the wear of the cutting edge and the value of the thermocurrent voltage. For a high value of the voltage, the wear intensity will be high, so the durability will be low.

In this way the criterion chosen to increase the durability of the cutting tool is to minimize the value of the thermocurrent voltage. The solution generated by the previously created experimental model is presented in figure 3.

![Figure 3. The values proposed for the cutting parameters to obtain the minimum voltage.](image)

4. Conclusions

A first conclusion consists in the fact that the electric thermocurrent that appears when processing by cutting the nets with good electrically conductive edges can be used to optimize the cutting regime.

In this paper, it was determined how the cutting regime influences the thermocurrent voltage of the cutting by performing experiments according to a complete factorial plan. Using Deign Expert and using ANOVA analysis it was demonstrated that the cutting speed has the greatest influence on the voltage of the electrical current, being followed by depth and feed.
The obtained linear dependence was used to optimize the cutting regime in order to minimize the thermocurrent voltage, which leads to maximizing the durability of the cutting edge.

The values of the cutting regime that lead to the minimization of the thermocurrent voltage obtained when turning C45 steel with titanized metal carbide plate type WNMG080408 are: \( v_c = 86 \text{ m/min}, f = 0.151 \text{ mm/rev} \) and \( a_p = 2 \text{ mm} \).

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