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PREDICTING CUTTING PARAMETERS BY APPLYING DEVELOPED NEURAL NETWORK AND LINEAR REGRESSION MODELS

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Abstract: *The paper presents the methods for prediction of the cutting parameters. In order to test the workability of the material by process of scraping, from the aspect of the cutting temperature, an natural thermopar was placed just below the cutting edge of the plate. In this way, a simple, reliable, accurate and economical method for determining the workability of material by cutting is obtained. The feasibility study of several semi-finished products by applying the realized experiments was carried out. Different materials in processing with cutting discs with different coatings give different results, which are used to form neural network and linear regression models.*

Keywords: *cutting parameters, prediction model, neural networks, linear regression.*

1. INTRODUCTION

Scraping is a very widespread type of processing in the metalworking industry. It takes place in conditions that are very complex and to date completely undefined. Tribological phenomena on the cutting pin affect the reduction of the tool's stability, and this affects the increase in processing costs [1].

As a result of the complexity of occurrences on cutting tools, wear appears, and it is the main cause of the short life of tools. Defining the wear process can be based on: changes that occur on the tool, the object of processing, change of resistance or cutting temperature. Since many physical and chemical reactions occur in the cutting process and how they are directly related to the wear of the tool, and how they are highly dependent on the cutting temperature [2, 3], this is a study of the possible prediction model creation for cutting process parameters.

The aim of this paper is to establish a reliable prediction models through the application of the appropriate tools for prediction and measuring of the cutting parameters at the points in the body of the knife, and by determining the data necessary for studying the machining process. Checking the method and measuring chip for measuring the parameters in the knife body is done by parallel measurements of the mean temperature of the cutting by a natural thermopar. In this way, conditions are created for the development of adaptive prediction models for machining by cutting [4].

2. THE PREDICTION MODELS OVERVIEW AND INFLUENCE OF THE PROCESSING FACTOR ON THE CUTTING TEMPERATURE PARAMETER

In the last few decades, the application of computer systems and software tools, particularly those based on artificial intelligence, had a great influence on integration and general availability of the individual knowledge and experience of experts in the field of production engineering. This led to the development of expert systems intended for expert reasoning, evaluation and optimization of parameters within preparation and production activities [5].

For creation of the prediction model, various methods can be used that are grouped into several general categories [6]:

- mathematical (linear regression, statistical methods). The best known is the linear regression to link the values of different independent and dependent variables using a linear expression to predict the "new" values of the dependent variables.
- distant (distance learning). Distant methods are based on the concept of "distance between cases". Any two cases in the data set can be compared to determine the similarity measure, this is the equivalent of the distance (s) to the corresponding value, which is the case, the distance is smaller.
- Logical (decision tables, decision trees, classification rules). The most used logical decision-making method is the decision tree. In order to forecast a new case, the root of the tree is examined; the appropriate testing is carried out, based on the result of which the case moves to the lower to the corresponding branches of the tree. The process continues until the last node ("tree list") is completed, the value of the last node represents the estimated outcome of the tree.
- modern heuristic methods (neural networks (NN), fuzzy logic, genetic programming). These methods are based on the principles of heuristics, i.e. based on experience. They accelerate foresight processes and find a solution that are good enough in situations where the implementation of a detailed forecast is not practical and can require a longer search time.

In this paper, the developed models use neural networks as an artificial intelligence method and linear regression as a statistical method. NN have proven to be a very promising artificial intelligence method in many prediction applications [7, 8, 9], due to their ability to learn from the data set, their nonparametric nature and the ability to generalize [10, 11, 12]. Having this in mind, NN and linear regression have been applied to predict cutting temperature. Since, there are a number of factors that affect the cutting temperature, which are:

- the characteristics of the machining material (M) and tools (A),
- treatment with refrigerant and lubricant (H) and without refrigerant and lubricant (BH),
- Cooling system (SH) and type of coolant and lubricant (VS),
- Processing mode (RO) - step, cutting depth, cutting speed,
- Tool geometry (GA) - geometric elements and coordinates that define the shape and position of the cutting wedge and processing objects, and
- other processing conditions.

Knowing the character and degree of influence of the mentioned factors on cutting temperature θ i.e. the dependency (formula 1):

$$Q = f(M, A, H, BH, SH,\ VS, RO, GA) \quad (1)$$

This dependency creates the possibility of developing practical algorithms for optimization and adaptive management of production processes based on thermodynamic characteristics and temperature signals.

The contact temperature of the tool, sawdust and processing object is referred to as the mean cutting temperature θ_{mean}. The empirical term for the calculation of temperature in the cutting zones of the tribo-mechanical systems in which the cutting in the scraping process is realized as [13, 14] (formula 2):

$$\theta = C_\theta \delta^{xt} s^{yt} v^{zt} \prod_1^n K_i \tag{2}$$

where:

C, k, i, z - are constants and exponents that depend on the type and state of the processing material,

δ - cutting depth (mm),

s - step (mm / o), and

v - cutting speed (m / min).

Thermal phenomena (cutting temperature, heat generation, etc.) that occur in the narrower and wider area of the cutting zone are in direct and narrow correlation with the tool wear rate, the degree of workability of the machining material, the stability of the tools and a number of other characteristics, and effects of the production process. Almost the entire cutting force is transformed, as experimental testing shows, into heat energy. The generated heat passes from the cutting area to the sawdust, the tool, the processing object and the surrounding environment, and thus under the influence of a part of the heat passing on the tool, the hardness of the material of the cutting elements of the tool decreases, and leads to a gradual plastic deformation of the cutting blades, loss of cutting ability of the tool and sharpness reduction. (The process of gradual loss of cutting ability stimulates even intensive wear and periodic friction of cutting tool elements.)

Distribution of generated heat in the workpiece, the tool, material chip, and therefore the temperature of the elements on the working part of the tool, on the treated surface and in the sawdust, depends on the machining material (mechanical and chemical properties), cutting speed, cutting depth, tool geometry, cooling and lubricating means and a number of other factors [15, 16, 17].

In addition to the impact on tool durability, the generated heat or cutting temperature also affects the production process, the overall quality of the treated surface, the processing accuracy and other output effects of the process. Hence, testing, measuring, understanding and possible creation of prediction models of the size and arrangement of cutting temperatures in the tool and workpiece are of primary importance, since on the basis of these findings, optimal conditions and processing regimes, quality, productivity and cost-effectiveness of the process, stability of the tools can be determined.

The significance of measuring technique and the method of measuring cutting temperatures is primarily that these methods and techniques form the basis of the experimental method, which, in addition to analytic, is another general method for researching and detecting thermodynamic (temperature) laws in the narrower and wider cutting zone and the processing system in continent. One of the major goals, achieved by knowing these laws, is optimization and adaptive management of production processes.

3. FORMING A MEASURING CHAIN FOR THE TEMPERATURE MEASUREMENT IN THE KNIFE BODY

Measuring chain (system) includes a set of measurement devices and auxiliary devices interconnected, through the link channels, into one functional entity and connected to the measurement object, a control object, a control object, an object of analysis, or an object of research for generating, converting, displaying, storing, and use for certain purposes of measurement signals (measurement results) of one or more measuring sizes.

From this definition, two basic tasks of any measurement system arise:

- measuring the value of one or more given physical or other sizes and displaying the measurement results on an analog or digital display, a registry (printer or printer), or a signalizer.
- generation of signals or information on measured values in a form suitable for use for other purposes (automatic management and control of processing

processes, memory and storage of metering information, statistical processing of results, etc.).

3.1 Measuring instrumentation for the cutting temperature measurement

Measurement of cutting temperature (natural thermopar) was carried out on a turn according to the scheme of the measuring chain given in Figure 1.

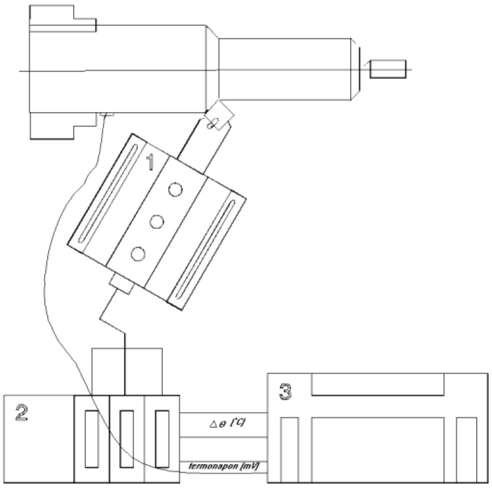

Figure 1. Measuring chain for measuring the cutting temperature

A four-channel printer "R-54" (position 3, figure 1) was used to record the signals. In the tool holder measurements, the KISTLER-9441 dynamometer (position 2 of Figure 1) was used, with the corresponding amplifier (position 2, figure 1).

To measure the temperature using a natural thermopar, the tool and the machining object were isolated from the machine. The natural thermocouple is not calibrated, due to its large complexity, the results of the temperature measurements by a natural thermocouple are expressed in mV.

The tool is a cutting knife CSDNR 2020K12 with a removable plate SPMX 12T3AP-75. Figure 5 shows a cutting board with basic dimensions. Tiles are coated with TiN, TiAlN, TiZrN, ZrN coatings.

All tests were carried out on the universal "Prvomajska" D-480lathe, with a power of 10 kW in the metal processing laboratory at the Faculty of Mechanical Engineering in Kragujevac.

4. PRELIMINARY MEASUREMENT OF THE TEMPERATURE IN THE SCRAPING WITH THE FORMED MEASURING CHAINS

Experimental tests were aimed to determining the change in cutting temperature in the knife body, depending on:

a - cutting speed in (m / min), respectively the corresponding speed n (rpm),

b - steps with (mm / o),

c - cutting depth δ (mm),

d - material processing objects,

e - coating of the cutting board.

The cutting mode parameters are:

a - cutting speed or corresponding speeds of 355, 450, 560, 710 rpm.

b - step 0.14, 0.2, 0.25 mm / o.

c - cutting depth 0.3, 0.5, 0.7 mm.

d - the largest part of the test was performed on the processing object of the C4730 in the improved state (273-300 HB). The workpiece obstruction is a half covertube (Material 1). Due to the inability to perform the same operation and measure resistance in laboratory conditions, external longitudinal treatment was performed. In order to ensure the same geometric parameters or an angle of attack, the dynamometer turning is also performed, which at the same time represents the tool carrier. In addition to this processing object, in order to compare the workability of materials in concrete conditions with different coatings on the tools, the surface treatment of the C4731.6 was performed, in the improved hardness of 230-280 HB (Material 2), and the head gears of the C5421, isothermal glow HB-120 forgings) (Material 3). All items of processing are pre-tested "bark" removed.

e - on the cutting plates of the corresponding geometry in the "Copper Institute" - Bor, application of a number of coatings was done, namely TiN, TiAlN, TiZrN, ZrN. The conducted tests were supposed to give a recommendation for the selection of the appropriate coating on the tool for carrying out a specific operation.

The experiment plan with the results of measuring the temperature rise ΔΘ (˚C) in the body of the knife and the thermonaphon of the natural thermo power (mean cutting temperature) are shown in the following tables.

Table 1 shows the results of the measurement of the temperature rise ΔΘ (˚C) for Material 1 (half cover) and all types of coatings. Cutting speed varies, i.e. number of revolutions n at a constant step (s = 0.2mm / o) and constant cutting depth (δ = 0.5mm). Cutting time is 0.5 min. The table also shows the temperature after cutting length (l) of 2 and 3 cm, due to comparison with the results of measurements in operations whose cutting time or cutting length is in this range. The results of the measurement of thermonaphones of a natural thermocouple are also shown for the coated TiAlN plate.

Table 1. Measurement of the temperature rise ΔΘ for material 1

coating type		t [min]	l [cm]	n [rPM]	temp [ΔΘ]
Without coatings	1	0.5	0	355	146
	1	0.5	0	450	151
	1	0.5	0	560	152
	1	0.5	0	710	154
	1	0.5	2	355	127
	1	0.5	2	450	132
	1	0.5	2	560	122
	1	0.5	2	710	112
	1	0.5	3	355	136
	1	0.5	3	450	140
	1	0.5	3	560	127
	1	0.5	3	710	121
ZrN	2	0.5	0	355	138
	2	0.5	0	450	145
	2	0.5	0	560	150
	2	0.5	0	710	156.5
	2	0.5	2	355	106
	2	0.5	2	450	108
	2	0.5	2	560	106
	2	0.5	2	710	102
	2	0.5	3	355	118
	2	0.5	3	450	119
	2	0.5	3	560	118
	2	0.5	3	710	115.5
TiN	3	0.5	0	355	143
	3	0.5	0	450	155
	3	0.5	0	560	158
	3	0.5	0	710	160
	3	0.5	2	355	109
	3	0.5	2	450	116
	3	0.5	2	560	112
	3	0.5	2	710	109
	3	0.5	3	355	125
	3	0.5	3	450	132
	3	0.5	3	560	127
	3	0.5	3	710	125
TiZrN	4	0.5	0	355	145
	4	0.5	0	450	147
	4	0.5	0	560	150
	4	0.5	0	710	152
	4	0.5	2	355	117
	4	0.5	2	450	119
	4	0.5	2	560	115
	4	0.5	2	710	114
	4	0.5	3	355	126
	4	0.5	3	450	128
	4	0.5	3	560	126
	4	0.5	3	710	124
TiAlN	5	0.5	0	355	146
	5	0.5	0	450	149
	5	0.5	0	560	151
	5	0.5	0	710	157
	5	0.5	2	355	117
	5	0.5	2	450	119
	5	0.5	2	560	115
	5	0.5	2	710	114
	5	0.5	3	355	126
	5	0.5	3	450	128
	5	0.5	3	560	126
	5	0.5	3	710	124

Based on the presented table application of prediction models is possible in order to predict cutting temperatures changes and degree of workability. Since degree of workability is calculated according to following (formula 3):

$$I_O = \frac{\theta_{ref}}{\theta_i} \qquad (3)$$

where in:

Θ_{ref} - temperature of the etalon material,

Θ_i - temperature of the test material.

For the purpose of determining the workability index of the processing object material, a part of the obtained measurement results was obtained in the processing of various materials of the processing object with plates with different coatings. By accepting that the material is a reference material, it is easy to reach the workability index according to the previously defined form.

5. PREDICTION MODELS APPLICATION

Without involvement in the problem of the formation and development of the scarping process, it can be assumed that knowledge about cutting temperatures as well as their dependence on the processing conditions, and in combination with other factors, can determine the degree of workability of a material with sufficient precision by application of prediction models.

Based on a defined NN (Figure 2), the correlations coefficient R for the training, validation, testing group and the overall correlation coefficient between the predicted output values and the measured target values of cutting temperature are determined (see Figure 3).

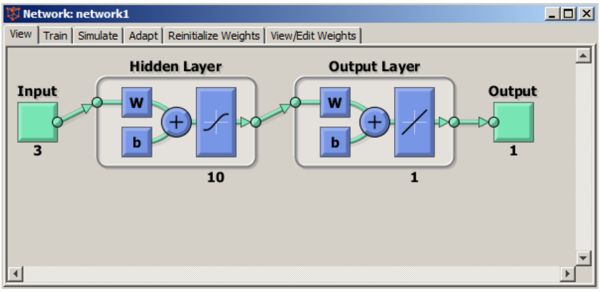

Figure 2. Defined neural network

According to the Figure 2, it may be concluded that in the input layer there are three neurons which correspond to the number of input parameters (coating type, cutting length, number of revolutions). Hidden layer has ten neurons and the output layer has only one layer, according to the output parameter (cutting temperature). Transfer function between hidden and output layer is tan-sigmoid, while transfer function between output layer and output is linear.

In the training set, with its regression line, linear correlation coefficient value is satisfactory equal to R = 0.99754. The same applies to the value of the correlation coefficient in the case of validation R = 0.97832. The value of the correlation coefficient in the case of testing is R = 0.95829, therefore the NN may be accepted as reliable for prediction of the cutting temperature and therefore prediction of workability index, since the total value of the correlation coefficient is R> 0.9. It may be concluded that there is a high correlation between the predicted output values and the measured target values.

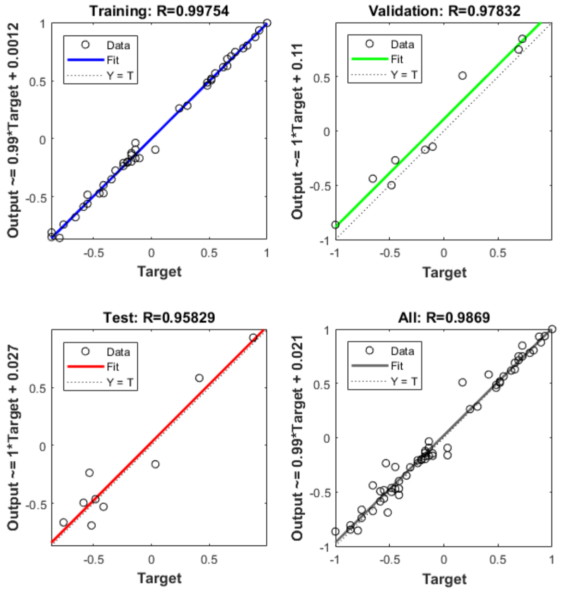

Figure 3. Correlation coefficients

Application of the linear regression model gave the following results presented in Table 2.

Table 2. Linear regression model summary

Model Summary		
Model	R	R Square
1	.743^a	.552
a. Predictors: (Constant), coating type, l [cm], n [rev/min]		

Coefficients^a						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	146.635	6.881		21.309	.000
	coatings type	-.125	1.021	-.011	-.122	.903
	l [cm]	-9.609	1.158	-.743	-8.298	.000
	n [rev/min]	.000	.011	-.002	-.020	.984
a. Dependent Variable: temp [ΔΘ]						

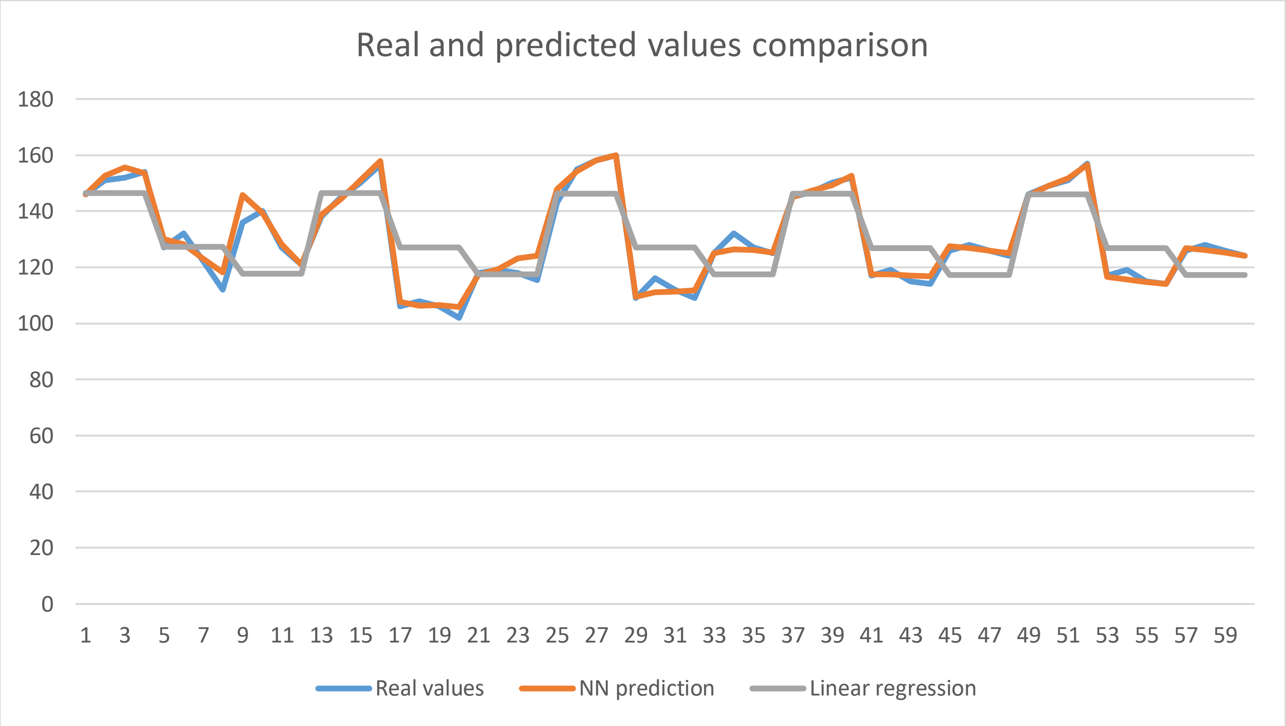

Figure 4. Comparisons between real and predicted values

Model show that the correlation coefficient between real and predicted values is R = 0.743.

Equationfor the prediction of cutting temperature values may be presented as (formula 4):

$$temp = 146.635 - 0.125 * c.t. - 9.609 * l + 0.0 * n \qquad (4)$$

Comparisons of prediction results for both NN and linear regression models and real values have been presented on the Figure 4.

From the Figure 4 it may be concluded that NN prediction model gave better prediction results than the linear regression model. Based on this results NN may be used to predict degree of workability.

6. CONCLUSION

In this paper, authors have analyzed the possibility of application of NN and linear regression models for prediction of cutting temperatures, based on the few cutting parameters.

Based on the presented obtained prediction results, it can be concluded that the developed application provides the ability to predict the values of cutting temperature.

Information collected from natural thermopar may be used in order to obtain appropriate real temperature values, which are used for application of the NN and linear regression. Accordingly, decisions can be made, for the input parameters of cutting parameters, in order to obtain expected degree of workability.

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