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# INVESTIGATION OF TEMPERATURE DURING MACHINING PROCESS BY HIGH SPEED TURNING

**Abstract:** *This paper presents the results and obtained mathematical models of temperature during machining process by high speed turning as a function of processing parameters* v, f, a *and* $r_e$. *The machining process by turning is performed on lathe type "Prvomajska TVP 250" with power P=11,2 kW and step change of number of revolutions between n=16 and 2240 rev/min, by using ceramic cutting tool inserts type SNGN 120712- 120716-120720 made from mixed ceramics type MC 2 ($Al_2O_3$ + TiC) and manufactured by HERTEL and tool holder type IK.KSZNR -064 25x25 manufactured by KENNAMETAL. Workpiece material is* **C** *1630 (DIN C 55). Cutting tool holder is reconstructed to provide transimission of the voltage signal from the cutting tool insert. Processing parameters are varied in range interval between* v *=300 and 500 m/min,* f *=0,16-0,30 mm/rev,* a*=0,5-1,0 mm and* $r_e$*=1,2-2,0 mm. Average temperature is determined by using of natural thermocouple method and computer aided research equipment. Experiments and the mathematical processing of the results are performed at the Faculty of Mechanical Engineering in Skopje using the program CADEX combined with MATLAB. Four factorial first order experimental plan was used.*
**Key words:** *Machining by turning, average cutting temperature, natural thermocouple, factorial experiments*

## 1. INTRODUCTION

It is known that during the transformation of workpiece machined layer into chips, because of energy transformations in the cutting zone it is released significant quantities of heat. Created heat in the cutting process is directly dependent on the applied processing parameters *(v, f, a, .....)*, workpiece material condition and cutting tool stereometry $(\chi, \lambda, \gamma, r_\varepsilon, ...)$. The heat reflected through the maximum temperature is an important factor which has a dominant influence to: the mechanism of transformation of the workpiece machined layer into chip; on the phenomenon that occur in the process of cutting tool wear (abrasive, adhesive, diffusive, heat, oxidative); the magnitude of the cutting force components, which is in close correlation with thermal model of creation residual stresses; and thus to the creation of the resultant characteristics of the new constituted technological surface layer /TSL/ [1]. Therefore, in the machining process it is important accurately to know the magnitude of the temperature that occurs in the cutting zone as function of machining parameters. The temperature in the cutting process can be determined in an analytical and experimental way, which are developed many methods [2]. From the experimental methods, the most widespread is the method of natural thermocouple, where the natural thermocouple consists of the cutting tool and the workpiece. Methods of natural thermocouple are simple to implement, but require knowledge of the thermoelectric characteristics of the natural thermocouple, and its determination is only by experimental way [3]. The emergence of modern cutting materials, especially cutting ceramics, creates conditions for the application of significantly higher cutting speeds.

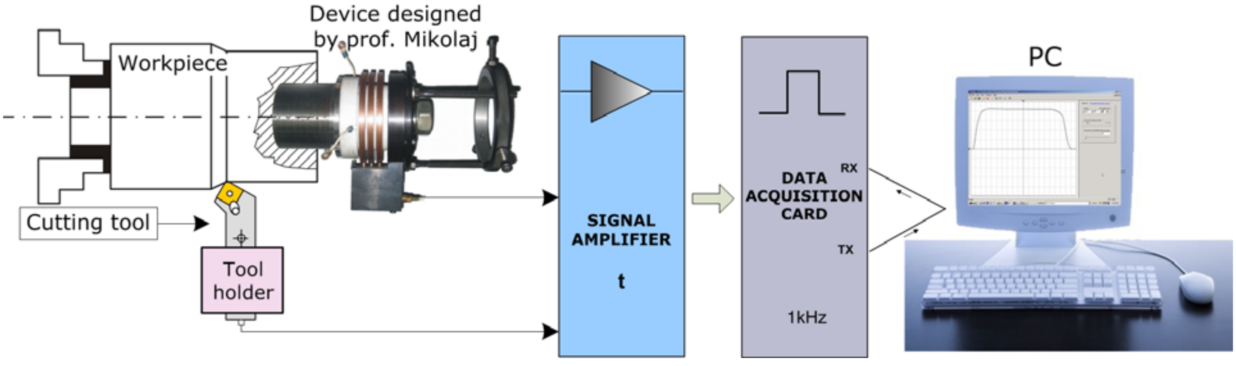


Fig. 1. Schematic view of the research experimental setup

The high temperatures and material removal dynamics in such conditions more intense influence on the mechanisms of chip creation and on the cutting tool wear, as well to technological effects in /TSL/. Increased stiffness is required from the system Machine - Device - Workpiece - cutting Tool (MDWT). The system for measuring the temperature is required: to reduce errors that occur in the transmission of the signal from the workpiece-cutting tool thermocouple; be able to record increased quantity of information in relatively short interval; application of computer technology for reliable determining of the temperature in the cutting process. The goal is to reduce the interval of measuring uncertainty of the results obtained from measurements performed. The creation of computer aided research equipment for measuring temperature in the cutting process is the result of joint research realized on the Faculty of Mechanical Engineering and the Faculty of Electrical Engineering in Skopje, in cooperation with the Institute of Production Engineering and Automation of the Wroclaw University of Technology, Poland. Using the research equipment, investigations of dependence of the temperature from the machining parameters *v, f, a* and $r_\varepsilon$ are carried out.

## 2. EXPERIMENTAL CONDITIONS

### 2.1 Cutting tool

The processing is performed by use of ceramic cutting tool inserts type SNGN 120712- 120716- 120720 made from mixed ceramics MC 2 ($Al_2O_3$ + TiC) manufactured by HERTEL and cutting tool holder type IK.KSZNR -064 25x25 manufactured by KENNAMETAL. Cutting tool stereometry is:

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$$\chi = 85°,\ \chi_1 = 5°,\ \gamma = -6°,\ \alpha = 6°,\ \lambda = -6°,$$

$$\gamma_f = -20°,\ b_f = 0{,}2\,\mathrm{mm},\ r_\varepsilon = 1{,}2 - 1{,}6 - 2{,}0\,mm$$

Cutting tool holder was previously reconstructed to provide transmission of the voltage signal from the cutting tool insert, which is presented on Fig. 2.

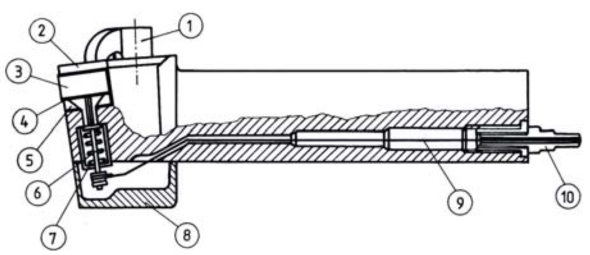



Fig. 2. Cutting tool holder cross-section, 1 - thumb, 2 - chip breaker made from $Al_2O_3$, 3 - cutting tool insert made from mixed ceramics MC 2, 4 - mica, 5 - washer, 6 - mechanism, 7 - isolation bushing, 8 - protective cap, 9 - signal conductor, 10 - connector.

To reduce the impact of disruption factors during transmission of the generated signal and thus to increase the accuracy of measurements, cutting tool insert is completely isolated in the nest of cutting tool holder, by using of mica. To obtain the required chip shape, a chip breaker made from zircon-oxide ceramics is used.

### 2.2 Workpiece

Material C 1630 (DIN C 55), normalized to the hardness of 200 HB.

### 2.3 Metal cutting machine

Lathe type "Prvomajska" TVP 250, with power P = 11,2 kW with step change in the numbers of revolutions between n=16 and 2240 rev/min.

### 2.4 Cutting parameters

Cutting speed *v* = 300-500 m/min, feed *f*=0,16-0,30 mm/rev, depth *a*=0,5-1,0 mm, cutting tool insert tip radius $r_\varepsilon$ =1,2-1,6-2,0 mm.

### 2.5 Device for transmission of the signal from workpiece

For measuring the average temperature in the cutting process by using method of "natural thermocouple", for transmission of generated signal from the workpiece a specially designed device is constructed, Fig. 3. This device after screwing into workpiece, allows transmission of generated signal through three rotating rings and fixed brushes. Particular attention is paid to the choice of material for rings and brushes, which in this case is black-lead bronze. The thermocouple ring - brush when heated to 373,16 K (100 ° C) generate thermovoltage of 0,3 mV.

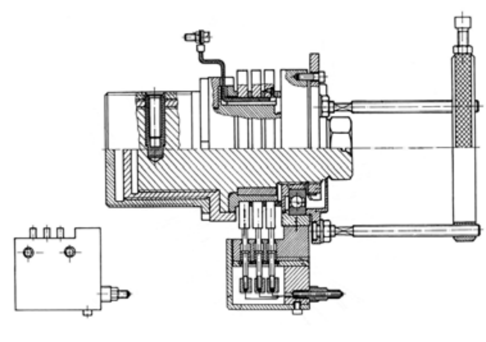


Fig. 3. Device for transmission of the signal from workpiece, cross-section [4]

### 2.6 Experimental plan

It is used first-order full four factorial plan of experiments ($2^4$ + 4), presented in Table 1. Power function is accepted for the mathematical model to describe the changes of the temperature. Mathematical processing is performed at the Faculty of Mechanical Engineering in Skopje with the application of program *CADEX* in connection with *Model-Based Calibration (MBC) Toolbox Version 1.1,* contained in the *Matlab* software package, which is intended for design of experiments and statistical modeling. Using the advanced features of *Matlab* and *MBC* provides significant advantages in the realization of experimental studies, with an option for graphic interpretation of results.

## 2.7 Research equipment

Monitoring of the thermovoltage (temperature) in the cutting process is done with computer aided research experimental setup, presented on Fig. 1 [5, 6]. Part of the research setup is specially designed PC interface that consist of signal amplifier and data acquisition card [7]. Measurements are done at the Faculty of Mechanical Engineering in Skopje. Graphical interpretation of monitored quantities by the software FORTMON is shown on Fig. 4.

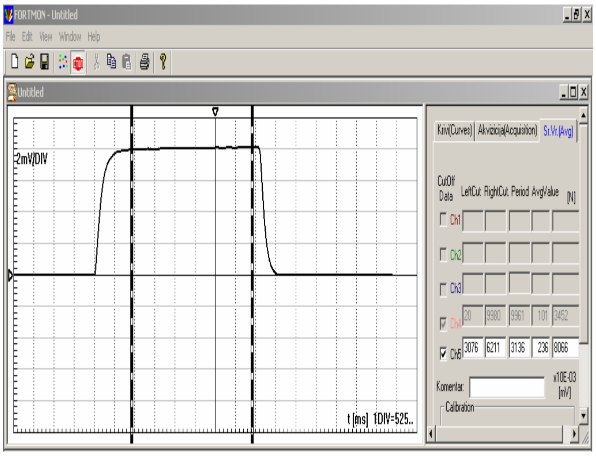



Fig. 4. Graphical interpretation of monitored quantities by the software FORTMON

Determining the average temperature by the method of natural thermocouple request to define of correlation between the thermovoltage measured by mV and the temperature expressed in °C. In this case, thermocouple is C 1630 - MC 2. For this purpose, a calibration installation is created. After regression analysis on the results obtained from the calibration measurements, the dependence between temperature $T$ and thermovoltage $u$ is obtained and represented as a polynomial of fourth degree [6]:

$$T = 104{,}426 - 42{,}646 \cdot u + 44{,}734 \cdot u^2 - 4{,}937 \cdot u^3 + 0{,}17 \cdot u^4 \cdots \quad (1)$$

By using of the equation (1) in the software of the research experimental installation, showed on Fig.1, it is enabled direct transformation of the measured thermovoltage into temperature.

## 3. RESEARCH RESULTS ANALYSIS

Changes of average cutting temperature $T_C$ as function of machining parameters are investigated during researches. Power function was adopted for describing of these changes:

$$T_c = C\, v^x f^y a^z r_\varepsilon^{\,q} \cdots\cdots\cdots\cdots \quad (2)$$

Experimental plan and results are presented in Table 1. Obtained results processing includes analysis of mathematical models with and without mutual effect, determination of 95% confidential interval for analyzed models, evaluation of significance of coded polynomial coefficients, determination of experimental error and determination of multiple regression coefficient. Performed analysis, after complete computer processing, showed adequacy of obtained mathematical model (3).

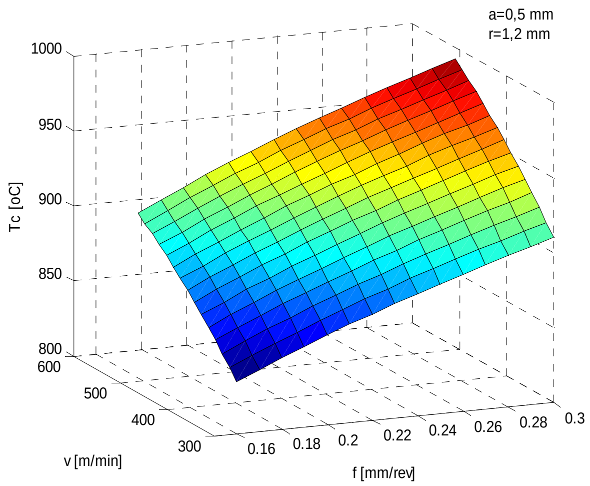
$$T_C = 444{,}662 \cdot v^{0{,}164} \cdot f^{0{,}138} \cdot a^{0{,}054} \cdot r_\varepsilon^{-0{,}088} \quad (3)$$

| Obs No | Independent variables - Real matrix | | | | Result |
|---|---|---|---|---|---|
| | $v$ [m/min] | $f$ [mm/rev] | $a$ [mm] | $r_\varepsilon$ [mm] | $T_{Cav}$ [°C] |
| 1 | 300,00 | 0,16 | 0,50 | 1,20 | 821,69 |
| 2 | 500,00 | 0,16 | 0,50 | 1,20 | 895,41 |
| 3 | 300,00 | 0,30 | 0,50 | 1,20 | 915,16 |
| 4 | 500,00 | 0,30 | 0,50 | 1,20 | 970,23 |
| 5 | 300,00 | 0,16 | 1,00 | 1,20 | 891,37 |
| 6 | 500,00 | 0,16 | 1,00 | 1,20 | 951,23 |
| 7 | 300,00 | 0,30 | 1,00 | 1,20 | 919,21 |
| 8 | 500,00 | 0,30 | 1,00 | 1,20 | 1043,63 |
| 9 | 300,00 | 0,16 | 0,50 | 2,00 | 819,56 |
| 10 | 500,00 | 0,16 | 0,50 | 2,00 | 845,19 |
| 11 | 300,00 | 0,30 | 0,50 | 2,00 | 879,32 |
| 12 | 500,00 | 0,30 | 0,50 | 2,00 | 961,36 |
| 13 | 300,00 | 0,16 | 1,00 | 2,00 | 819,57 |
| 14 | 500,00 | 0,16 | 1,00 | 2,00 | 887,23 |
| 15 | 300,00 | 0,30 | 1,00 | 2,00 | 873,42 |
| 16 | 500,00 | 0,30 | 1,00 | 2,00 | 998,38 |
| 17 | 387,30 | 0,22 | 0,71 | 1,55 | 909,53 |
| 18 | 387,30 | 0,22 | 0,71 | 1,55 | 917,18 |
| 19 | 387,30 | 0,22 | 0,71 | 1,55 | 903,37 |
| 20 | 387,30 | 0,22 | 0,71 | 1,55 | 901,28 |

Table 1. First order four factorial experimental plan

Some graphical interpretation of the influence of cutting speed - $v$, feed - $f$, cutting depth - $a$, and cutting tool insert tip radius - $r_\varepsilon$ on the changes of average temperature $T_C$ are shown on Fig. 5. It can be noticed that most significant effect on average temperature increase has cutting speed increase, then cutting feed, and, the least, cutting depth. Cutting tool insert tip radius increase results in temperature decrease. Average temperature increase as result of cutting speed increase is explained, mainly, by decreasing contact between chip and face surface of cutting tool insert, resulting with chip ramming decreases, chip sliding speed against face surface increases, heat discharge is worse and friction is increased. Heat created in cutting area is, mainly, a sum of heat of machined layer deformation, which decreases, due to cutting speed increase, till certain limit as well as of heat generated by chip friction against face surface of cutting tool, which increases by cutting speed increase, which is basic reason for average temperature increase. Average temperature increase due to feed increase is results of higher deformation, which alternatively causes higher heat quantity. However, feed increase also means increase of contact surface between chip and cutting tool, which results by conditions for improved heat discharge.

Therefore, de facto, there is smaller effect of feed onto average temperature. Similar is cutting depth effect. Namely, this means that deformation work increases by cutting depth increase, thereby generating higher heat quantity, however also increasing contact surface between chip and cutting tool and improving heat discharge. In addition, cutting blade active length directly increases. This provides much better conditions for heat discharge thereby smaller temperature gradients. The cutting tool insert tip radius $r_\varepsilon$ effect is much interesting. Average temperature decreases by $r_\varepsilon$ increase. This is due, mostly, to increased active length of cutting blade, which provides much better heat discharge. Besides this, reduction of angle $\chi$, as result of increase of $r_\varepsilon$, is, also, a reason for smaller cutting forces, smaller deformation work and thereby smaller heat quantity. It should also be stated that increase of measured average cutting temperature is result of temperature increase on rear side of cutting wedge due to increased friction of rear main surface and auxiliary rear surface with machined surface.



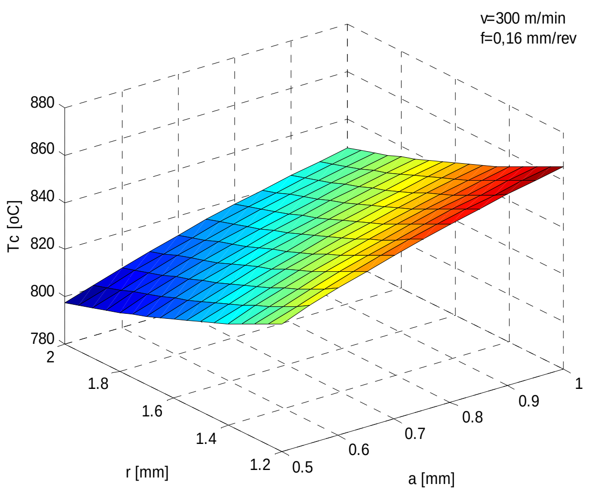




Fig. 5. Graphical interpretation of the influence of cutting speed - *v*, feed - *f*, cutting depth - *a*, and cutting tool insert tip radius - $r_\varepsilon$ on the changes of average temperature $T_C$

## 4. CONCLUSIONS

Following remarks and conclusions can be reached from performed experimental researches, obtained mathematical models, as well as results analysis:

- Statistical analysis indicated that describing changes of average cutting temperature $T_C$ as function of machining parameters *v, f, a* and cutting tool insert tip radius $r_\varepsilon$, by means of power function, is correct;

- All factors adopted in models are significant, and their effect is as follows:

- Average cutting temperature mostly depends upon cutting speed and feed, while from cutting depth, the least. The increase of these parameters causes average temperature increase, which reached highest value of 1043°C in the investigated domain.

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