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THERMOCOUPLE AND INFRARED SENSOR-BASED MEASUREMENT OF TEMPERATURE IN METAL CUTTING

Milan IVKOVIĆ[1], Bogdan NEDIĆ[1*], Suzana PETROVIĆ SAVIĆ[1]
[1]Faculty of engineering University of Kragujevcu, Serbia,
*Corresponding author: nedic@kg.ac.rs

Abstract: *The high temperature that occurs during metal cutting processing has a negative impact on the durability of the cutting tool and can also have a negative effect on the object of processing. Therefore, it is very important to have information about the temperature in the cutting zone and the workpiece. Accurate real-time temperature measurement is still a challenge. Efforts to accurately measure the cutting temperature today are directed in two directions. One direction refers to placing artificial thermocouples as close as possible to the cutting zone, and the other direction is the application of infrared thermography and thermovision. The paper presents the results of temperature measurement using an artificial thermocouple placed directly under the top of the cutting tool insert of the turning knife and using an IR non-contact thermometer to measure the temperature on the surface of the workpiece at different cutting speeds of two different materials.*

Key words: *temperature metal cutting, turning, thermocouple, IC thermometer*

INTRODUCTION

The processing of metals by cutting is highly non-linear in nature, where complex processes take place in an extremely small cutting zone with high cutting temperatures and high specific pressures [1, 2].

During the cutting process, most of the mechanical work (approximately 90%) is converted into thermal energy in a very narrow cutting zone directly at the tip of the cutting tool. High temperature significantly affects tribological processes on the cutting tool, wear of the tool and reduction of its service life. In addition, high cutting temperatures and tool wear affects the quality of the machined surface (inaccuracy of measurements and surface roughness increases). Also, high temperature can lead to structural changes in the surface layer of the processing object [1, 3, 4]. Cutting speed has the greatest influence on heat generation in the cutting zone, followed by depth and pitch. In addition to processing parameters, the cutting temperature is influenced by the type of material being processed. An increase in hardness and tensile strength leads to an increased cutting temperature. Also, when processing more difficult to process alloy steels, higher cutting heat is generated.

In order to efficiently select and use adequate cutting parameters, it is necessary to measure the cutting temperature in real time. On-line measurement of the cutting temperature can prevent high cutting temperatures at the very beginning of processing, and also stop the cutting process in case of unwanted changes (eg tool wear, unplanned changes in cutting depth, etc.) [5, 6].

In addition to the impact on tool durability, the heat generated in the cutting process also affects the productivity of the machining process, the quality of the machined surface, machining accuracy and other output factors of the machining process. Hence, examination, measurement and knowledge of the size and distribution of the cutting temperature in the tool and the workpiece is of first-rate practical importance. On the basis of this knowledge, optimal processing conditions and regimes, quality, productivity and economic efficiency of the process, durability of tools, etc. can be determined.

So far, a number of different cutting temperature measurement methods have been developed, but precise measurement in real time is still a challenge. The reason for this is the movement of tools and workpieces, frequent changes in cutting depth, the creation of chips whose course cannot be controlled, very small cutting zones, complex geometry of the cutting tool, etc. [7, 8].

The cutting temperature measuring methods can be divided into two groups, based on:

- thermal conductivity and
- thermal radiation.

In the case of thermal conductivity, thermal energy leads to the creation of a thermal voltage that can be measured by suitable measuring systems. Thermocouples are most often used, because they have a low price, can work in a wide temperature range, and can be easily installed. They are used to measure the mean temperature in the immediate environment of the thermocouple [9].

Artificial thermocouple. Pre-formed thermocouples made of special materials are implanted in places close to the cutting zone. This is achieved by drilling holes in the workpiece [10, 11] or the tool [12, 13, 14, 15] at one or more points at the same time, or by placing the tip of the thermocouple on the outer surface of the tool. The accuracy of measurement using this method primarily depends on the proximity of the set measuring point to the cutting zone [16, 17, 18].

Methods based on thermal radiation (infrared pyrometer to measure the temperature at a point, and thermography, thermovision to measure the temperature of the surface). These methods are non-contact methods that have a number of advantages over the previously described contact methods. The main disadvantage is that the method depends on the optical properties of the measured object, i.e. shavings or cooling and lubricating agents can cover the surface whose temperature is measured or damage to the measuring equipment can occur [19, 20]. Also, the problem is the necessity of knowing the exact value of the thermal emission coefficient of the surface whose temperature is measured [21, 22, 23, 24].

TEMPERATURE MEASUREMENT DURING TURNING PROCESSING

In order to test the possibility of measuring the temperature on the cutting tool and the object of processing and the influence of the cutting speed and the type of material of the object of processing, appropriate measurement systems were formed, Figure 1.

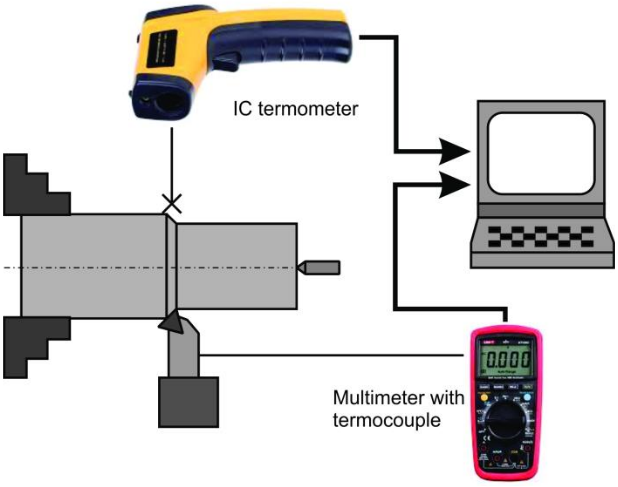


Figure 1. Measuring systems for measurement of the cutting temperature

During turning processing, a special artificial thermocouple is formed, placed between the cutting plate and the base plate immediately below the top of the cutting plate. The tool is a turning knife CSDNR 2020K12 with an interchangeable insert SPMX 12T3AP-75. A cutting insert without coatings was used for the tests. Figure 2 shows the position of the measuring point and the method of placing the thermocouple. A groove was formed on the base plate by drilling, in which the thermocouple was placed.

The special thermocouple was formed using a type 2 AB AC 15 thermocouple from the "Termocoax" series of the "PHILIPS" company. Thermocouple elements are NiCr(+) and Ni(-) wires. The thermocouple is pre-calibrated.

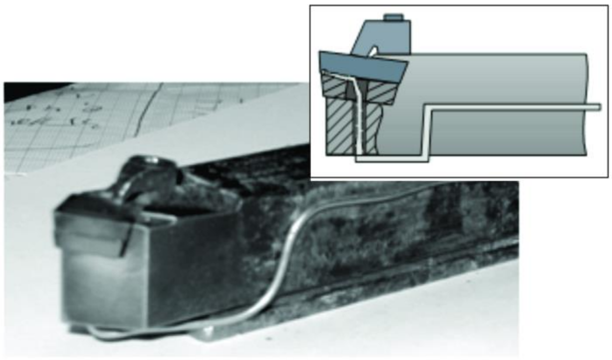


Figure 2. Position and measuring spot for artificial thermocouple at turning tools

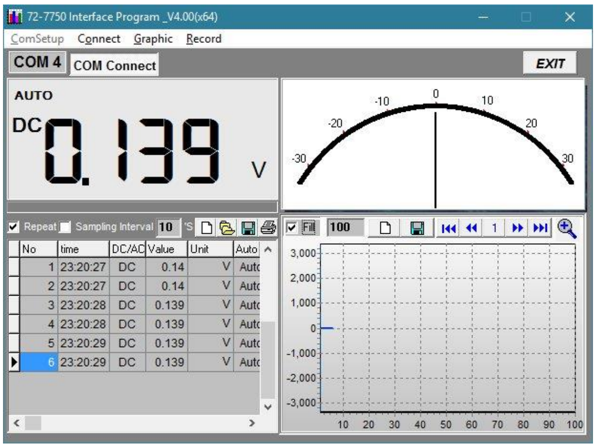
A TENMA 72-7750 digital multimeter was used to measure the temperature

The 72-7750 multimeter has the standard measurement modes (voltage, current capacitance, resistance, conductivity), also measures frequency, temperature, and TENMA has an opto-coupled RS-232 cable with connector and datalogging software, figures 3 and 4.

The temperature measurement range is

-40°C to +1000°C with resolution 1°C. Measurement speed - updates 2 times/second.

Figure 3. Digital multimeter TENMA 72-7750



☑ Repeat ☐ Sampling Interval 10 'S

No	time	DC/AC	Value	Unit	Auto
1	23:20:27	DC	0.14	V	Autc
2	23:20:27	DC	0.14	V	Autc
3	23:20:28	DC	0.139	V	Autc
4	23:20:28	DC	0.139	V	Autc
5	23:20:29	DC	0.139	V	Autc
6	23:20:29	DC	0.139	V	Autc

Figure 4. 72-7750 Interface Program

IR thermometer DT-8855 was used to measure the temperature of the surface of the workpiece on the newly processed surface on the opposite side from the place of the cutting, Figure 5. Infrared temperature range -50 to 1050°C with resolution 0.1°C. The Model DT-8855 is supplied with a Wireless USB (RF 433 MHz) datalogging system for use with a PC and software, interface to figure 6.

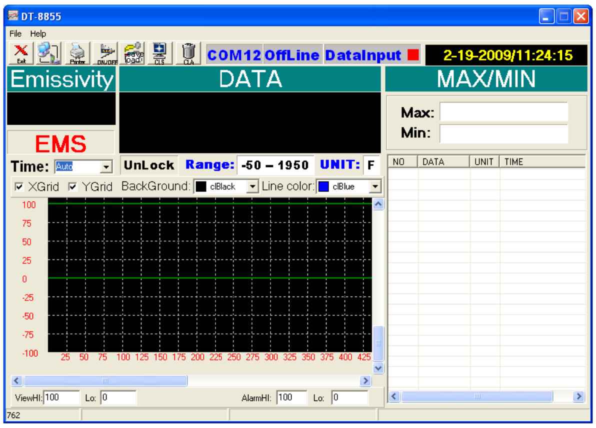
Experimental tests in turning processing were carried out under the following conditions:

- cutting speeds v = ~60, ~80 i ~100 m/min,
- step s = 0,2 mm/o
- cutting depth a = 0,3 mm,
- the material of the processing object

- 25CrMo4 (Č4730), diameter 45 mm, processing length - 300 mm,

- C45 (Č1530), diameter 30 mm. processing length - 320 mm,

Figure 5. IC termometer DT-8855



Time: Auto
UnLock
Range: -50 – 1950
UNIT: F
☑ XGrid ☑ YGrid BackGround: clBlack Line color: clBlue
ViewHI: 100 Lo: 0
AlarmHI: 100 Lo: 0

Figure 6. Interface IC thermometer

MEASUREMENT RESULTS

Longitudinal machining by turning was performed on a universal lathe Prvomajska TNP-480, power 10 KW. Figure 7 shows the position of the processing object, tool with thermocouple and IR thermometer.

Figure 7. Position of the turning knife and IR thermometer during longitudinal turning

Figure 8 shows a monitor with active software for temperature measurement using the methods described.

Temperature measurements were always performed with the initial ambient temperature: 23.6 °C.

Figure 9 shows the change in the measured temperature in the tool and on the workpiece from C45. It can be seen that the temperature in the tool rises and that after processing the 320 mm object, it is 107°C. Measuring the temperature on the surface of the object to be processed with an IR thermometer showed that there was very little heating, i.e. from the initial 23.6°C the surface reached 28.2°C. However, it can be seen that there are significant deviations in the value of the measured signal, which occurs due to the accumulation of continuous chips on the tool and the object in the immediate vicinity of the processing zone. Its breakage in a short period of time enables measurement with an IR thermometer.

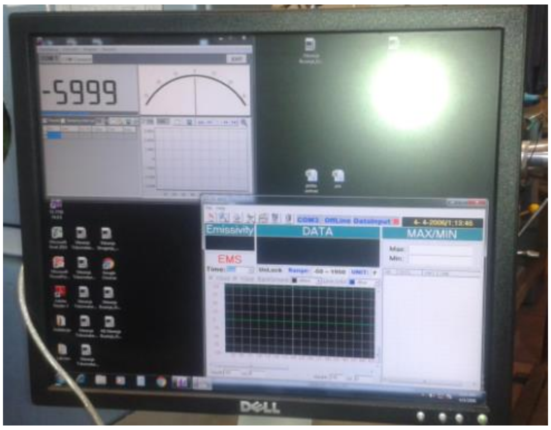


Figure 8. Temperature measurement applications

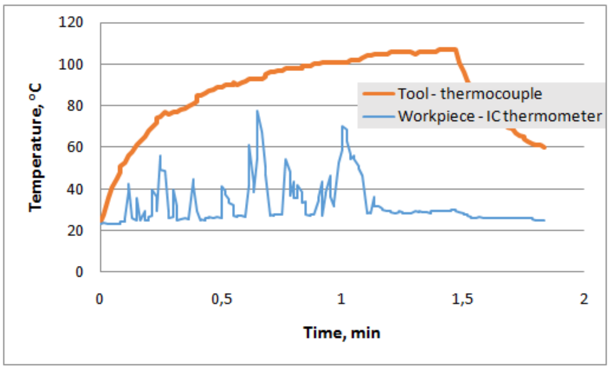


Figure 9. Cutting temperature when processing steel C45 and cutting speed 80 m/min

Figure 10 shows the temperature change during processing of 25CrMo4 material at the same cutting speed. It can be seen that after processing a length of 300 mm, a higher temperature was reached: 120°C. In this case too, the established maximum temperature was not reached. The temperature signal on the workpiece shows that the chip removal flow is more favorable and that it does not accumulate on the tools and the workpiece. The temperature of the surface of the processing object increased from 23.6°C to 28.5°C.

Figures 11 and 12 show the changes in cutting temperatures for two different steels and three cutting speeds.

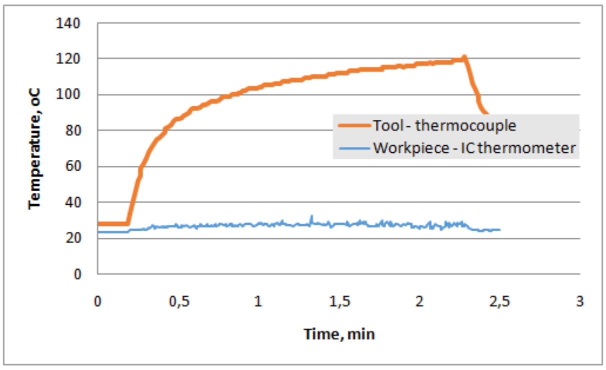


Figure 10. Cutting temperature when processing steel 25CrMo4 and cutting speed 80 m/min

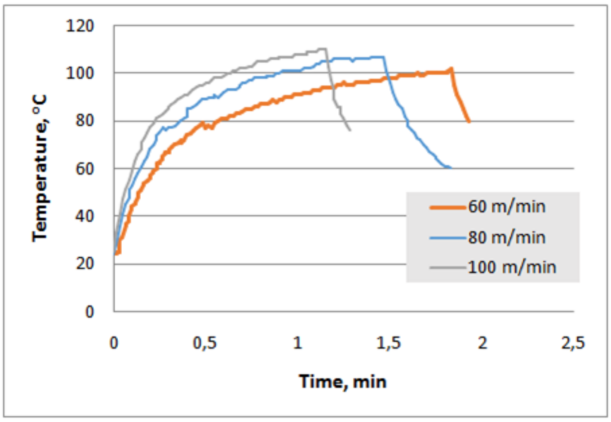


Figure 11. Temperature in the cutting tool when processing C45 with different cutting speeds.

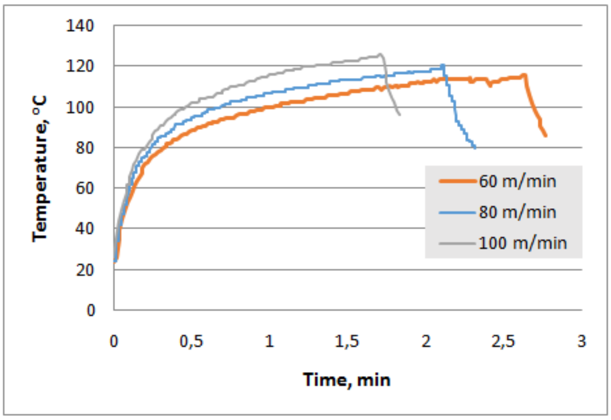


Figure 12. Temperature in the cutting tool when machining 42CrMo4 with different cutting speeds.

CONCLUSION

The tests carried out in this work are a continuation of long-started tests aimed at the development of methods for monitoring the cutting process, in which the resistance and temperature of cutting and tool wear are measured, and the formation of a database on material machinability and tool wear.

Based on the obtained measurement results, the following conclusions can be drawn:

- the presented methods for measuring the cutting temperature during turning processing using a thermocouple placed on the surface of the substrate immediately below the cutting edge of the insert and measuring the temperature of the object being processed using an IR thermometer are: simple, reliable, economical and sufficiently sensitive methods,
- these methods enable direct examination of the influence of technological processing parameters (processing mode, tool material and processing object, cutting geometry, etc.) on the cutting temperature,
- with the developed method of temperature measurement, it is possible to compare the machinability of the material of the processing object,
- the obtained results show that in order to draw general conclusions, it is necessary to continue the tests, where it is necessary to expand the area of the processing mode and prevent the penetration of chips between the processing object and the IR thermometer.

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PRIMENA VEŠTAČKOG TERMOPARA I IC TERMOMETRA ZA MERENJE TEMPERATURE PRI OBRADI METALA STRUGANJEM

Apstrakt: *Visoka temperatura koja nastaje prilikom obrade metala rezanjem ima negativan uticaj na postojanost reznog alata a može imati i negativan uticaj na predmet obrade. Zbog toga je od velike važnosti imati informacije o temperaturi u zoni rezanja i predmetu obrade. Precizno merenje temperature u realnom vremenu je i dalje izazov. Napori za precizno merenje temperature rezanja danas su usmereni u dva pravca. Jedan pravac se odnosi na postavljanje veštačkih termoparova što bliže zoni rezanja, a drugi pravac je primena infracrvene termografije i termovizije. U radu su prikazani rezultati merenja temperature primenom veštačkog termopara postavljenog neposredno ispod vrha rezne pločice strugarskog noža i primenom IC beskontaktnog termometra za merenje temperature na površini predmeta obrade pri različitim brzinama rezanja dva različita materijala.*

Ključne reči: *temperatura rezanja, struganje, veštački termopar, IC termometar, monitoring rezanja*