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THE EFFECT OF THE CIRCULAR SAW BLADE BODY STRUCTURE ON THE CONCENTRIC DISTRIBUTION OF THE TEMPERATURE ALONG THE RADIUS DURING THE WOOD CUTTING PROCESS

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ABSTRACT

The paper presents the experimental results of a research aimed at the distribution of the temperature on thecircular saw blade body. The temperature was measured at four distances from the centre of the circular saw blade body (60 mm, 70 mm, 80 mm, 90 mm) by means of an infrared thermometer. Three circular saw blades with the diameter of 350 mm and a variable adjustment of the body (without slots and coating, with slots and without the coating, with both slots and coating) were used for the longitudinal sawing of the spruce wood (*Picea excelsa*) with the thickness of h = 25 mm. Feed speed vf = 12 m•min^{-1} and cutting revolutions n = 4000 min^{-1} were constant. The measured temperature was in the range from 22°C to 30°C. The highest measured temperatures were recorded on the circular saw blade with the slots and coating.

KEYWORDS: Circular saw blade, infrared thermometer, temperature, wood cutting.

INTRODUCTION

The sawing process by the circular saws is the most used process in woodworking, where circular saw blades are the cutting tools. The basic problems of tool instability in the cutting process are vibration and noise of the circular saw blade (Ukvalbergiene and Vobolis 2007, Krilek et al. 2016). The most significant obstruction during cutting is its aberration (deformation) in a plane (Kopecký and Rousek 2012). The effect is only caused by compressive stress in the circular saw blade which is dependent on the temperature distribution status inside. Knowing the accurate temperature distribution is one of the main points to solve the problem. The measurement of the tool surface temperature during a high cutting speed (vc = 50 m•s^{-1} ÷ 100 m•s^{-1}) is not easy. Some results have been brought by the experimental works of the authors. (Konov 1982, Danielson and Schajer 1993, Ratnasingam et al. 2010) used at the experimental measuring the method of thermocouple (copper – konstantan) with the diameter wire d = 0.125 ÷ 0.15 mm. The measuring of the temperature on the saw blade body with the infrared thermometer is published by authors (Mote and Rahimi 1983, Li et al. 2002, Sheik-Ahmad et al. 2003, Lehmann 2007, Li et al. 2007, Ishihara et al. 2010, Khviyuzov and Galashev 2013, Khviyuzov et al. 2015). The simulation of the cutting process by means of a digital computer was used by authors (Martinez and Hankele 2015).

The formation of the temperature and its gradient in the circular saw blade body is caused by the heat generated at its periphery due to the cutting power, the friction between chips and the frontal area during the cutting process and as a result of the heat generated by the side friction between the saw blade and the cutting material. Moreover, the circular saw blade rotates in specific conditions; a circular trajectory made in the air is longer than in the wood. A heat dissipation (dispersion) from the circular saw blade surface into the surrounding air is considered as a factor affecting the heat gradient. Three factors generate the heat on the circular saw blade periphery which are represented as the functions r, φ, and τ. In this case, the temperature is concentrically divided and the temperature distribution status is expressed as a function of radius r and time τ. The temperature distribution in the circular saw blade is determined by the following factors: friction in the cutting process and heat dissipation from the saw blade surface. The diagram of the circular saw blade in polar coordinate system is shown in Fig.1.

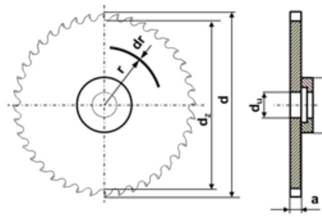

Fig. 1: The circular saw blade calculation model.

Heat conduction differential equation is derived on the basis of a term that we consider a circular area with an infinitesimal width dr as it is shown in Fig. 1. The amount of heat that flowsinside in the positive direction of the radius r through the inside wall on the radius r at the time dτ (Sugihara and Sumiya 1955) is given by the Eq. 1:

$$Q = -\lambda \cdot \frac{\partial T}{\partial r} \cdot 2\pi r \cdot a \cdot \mathrm{d}\tau \tag{1}$$

where: λ - thermal conductivity of steel in W· m^{-1} K^{-1}, (for steel = 50),
T - temperature of this place in Kelvin degrees,
r - radius of circular saw blade in m,
a - thickness of circular saw blade in m,
τ – time in sec.

The negative sign in the Eq. 1 expresses the direction of the temperature gradient $\frac{\partial T}{\partial r}$ from the peripheral region into the middle of the circular saw blade.

The differential equation determining the temperature distribution, according to (Sugihara and Sumiya 1955) is given by the expression:

$$\frac{1}{\kappa}\cdot\frac{\partial\phi}{\partial\tau}=\frac{\partial^2\phi}{\partial r^2}+\frac{1}{\kappa}\cdot\frac{\partial\phi}{\partial r}-n\cdot\phi+B \qquad (2)$$

In the Eq. 2, the terms:

$$\kappa=\frac{\lambda}{c\cdot\rho}\,,\qquad n=\frac{2\cdot\alpha}{\lambda\cdot a}\,,\qquad B=\frac{2\cdot Q_1}{\lambda\cdot a}\,, \qquad (3)$$

where: c – specific heat in J·kg^{-1}·K^{-1} (for steel ≈ 469),
ρ – density in kg·m^{-3} (for steel ≈ 7800),
α – coefficient of heat transfer in W·m^{2}·K^{-1} (for air 10÷500),
κ – thermal diffusivity in m^{2}·h^{-1} (for circular saw blade' steel ≈ 0.049),
Q_1 – the quantity of heat generated at the unit surface area by friction in unit time
$\phi = T - T_0$,
T - the temperature of the place and T_0 is the temperature of the air.

MATERIALS AND METHODS

Researching the temperature distribution in the cutting process, three circular saw blades from Stellite Trenčín, Ltd. Company were used at the experimental measurements. The first examined tool was all the metal (PK1), the second one was with compensation and radial slots (PK2) and the third one contained compensation and radial slots with the spray paint RAL 9006 made by the K-system, Ltd. in Kosorín, district Žiar nad Hronom (PK3). Used circular saw blades are shown in Fig. 2.

a) b) c)

Fig. 2: The circular saw blades used for the experimental measurements.

The basic parameters of the circular saw blades used in the experiment are given in Tab. 1.

Tab. 1: The basic parameters of used circular saw blades.

Parameters	**PK1**	**PK2**	**PK3**
Saw blade diameter (mm)	350	350	350
Clamping hole diameter (mm)	30	30	30
Number of teeth (-)	36	36	36
Body thickness (mm)	2.4	2.4	2.4
Length of the cutting edge (mm)	4	4	4
Tooth height(mm)	13	13	13
Pitch of teeth (mm)	equable pitch of teeth	unbalanced pitch of several teeth	
Tooth geometry	α_f = 15°		
	β_f = 65°		
	γ_f= 10°		

The sawing process was performed on acircular saw with a continuous feed through a belt conveyor and top clamp by a roller feeder. The circular saw is located in the laboratory of the Department of Manufacturing Technology and Quality Management at the Technical University in Zvolen. A block diagram of the experimental apparatus for measuring the temperatures of the circular saw blade during the cutting is shown in Fig. 3. The cutting plates from spruce (*Picea excelsa*) with dimensions: thickness h = 25 mm, width b = 400 mm, length L = 1500 mm, w = a moisture content of 12% were used. Overhang of the circular saw blade was 60 mm over the belt conveyor. The slats of 15 mm width were gradually cut off from the boards. The cutting conditions ofthe performed cutting are shown in Tab. 2.

Tab. 2: The cutting conditions.

	Feed speed v_f **(m·min^{-1})**	**Rotation** n **(min^{-1})**	**Cutting high** h **(mm)**	**Temperature of surround T (°C)**
PK1, PK2, PK3	12	4000	25	19

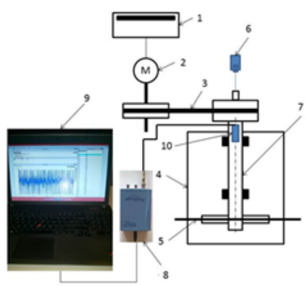

Fig. 3: The block diagram of the connecting instruments for measurement of the temperature in cutting process on the circular saw blade.

1. frequency converter Siemens A.6. MM550/3, 2. electric motor Siemens P = 5.5 kW, 3. belt drive, 4. circular saw frame, 5. circular saw blade mounted with clamping collars dp = 110mm, 6 . noncontact speedometer 2236, 7. shaft stored in the bearings, 8. PicoScope PC Oscilloscope 2205, 9. PC, 10. handheld Infrared Thermometer OmegaScope OS520.

The experimental measurement of the circular saw blades temperature on the circular saw in a cutting process was carried out at the measuring apparatus whose block diagram is shown above. For two circular saw blades that have not been surface-treated, the emissivity of 0.25 was set on the handheld infrared (IR) thermometer OmegaScope OS520. The circular saw blade which was treated by a spraying, the emissivity of 0.96 was set on the IR thermometer OmegaScope OS520. The measurement was performed at four distances from the centre of the circular saw blade. The sensor axis was adjusted at the distances of 90 mm, 80 mm, 70 mm and 60 mm from the centre of the circular saw blade. The sensor was located 250 mm from the side surface of the circular saw blade. Mounting of the OmegaScope OS520 and its screen and keyboard are shown in Fig. 4.

a) *b)*

Fig. 4: Mounting handheld Infrared Thermometer OmegaScope OS520 and of its the display and the keypad.

a) Mounting handheld Infrared Thermometer OmegaScope OS520 on frame of the circular saw, b) display and the keypad (1) mode displays, (2) Data associated with one of the Display Modes, (3) Backlighting Icon, (4) Displays the units of measure in either, (5) Main display- displays the current temperature, (6) Locks the trigger, (7) ▲ for incrementing data about 1; ○-● is for turning on/off the backlighting, (8) ▼ for decrementing data about 1; °F - °C is for changing the units of measure from °F to °C or vice versa, (9) Function key for scrolling through the display modes, (10) Display Icons : LCK Trigger lock.

The thermometer OmegaScope OS520 (Fig. 4) provides information very elegantly - via the backlit dual digital LCD display (Fig. 4) which shows the current measured temperature of the body. The infrared thermometer uses the law of Stefan - Boltzmann for the temperature calculation (Lévesque 2014), which is given bythe equation:

$$I = \varepsilon \cdot \sigma \cdot (T^4 - T_a^4) \qquad (W \cdot m^{-2}) \tag{4}$$

where: I – heat energy in $W{\cdot}m^{-2}$,
ε – emissivity,
σ – Stefan-Boltzmann constant in $W{\cdot}m^{-2}{\cdot}K^{-4}$, ($5.6703{\cdot}10^{-8}$),
T – temperature of themeasured body in Kelvin degrees,
T_a –surrounding temperature in Kelvin degrees.

This versatile instrument provides:

- Measurable target distances from 5 inches to approximately 200 feet.
- Emissivity adjustable from 0.1 to 1.00 in 0.01 steps provides ease at use when measuring variety of surface.
- An electronic trigger lock feature set via the keypad allows continuous temperature measurement up to 4 times per second.
- Audible and visual alarms. The high and low alarm points are set via the keypad.
- 1 mV per degree (°F or °C) analogy output which allows interfacing with data acquisition equipment (including chart recorders, data loggers and computers.

The parameters of the OmegaScope OS520 are shown in the following (Tab. 3).

Tab. 3: The parameters of the portable infrared thermometer OS520.

Accuracy	Range	Emissivity
± 2% of measured value	-18°C ÷ 400°C	adjustable

RESULTS

The data obtained during the experimental temperature measurements were processed using the special software PicoLog Recorder. As a result, the numbers in a txt format files were obtained which were further processed into the graphs by Microsoft Excel 2010 software. Evaluation of the temperature measurement which was measured without a contact on the circular saw blade in four distances from the axis of the shaft - 60 mm, 70 mm, 80 mm and 90 mm, was performed for each circular saw blade. In the graph (Fig. 5), a hot saw blade on the beginning of the cutting is shown. From the graph, it is possible to see a dynamic temperature change at the start of a gradual stabilization of the temperature in the range from 25°C to 28°C.

In the following graphs (Figs. 6, 8, 10), the waveforms trend lines while cutting are shown separately for each circular saw blade in listed distances from its centre.

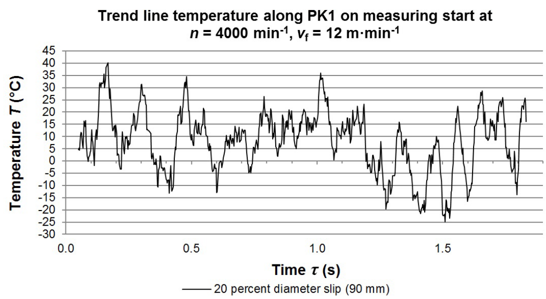

Fig. 5: Conduct trend line at the start of the cutting PK1.

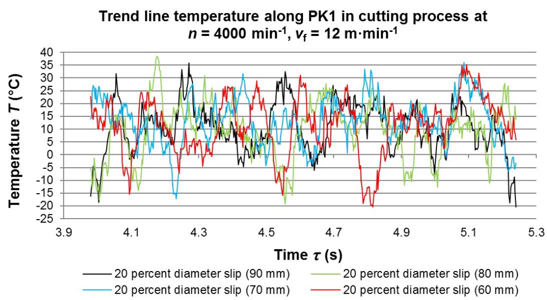

Fig. 6: Waveforms trend lines while cutting PK1.

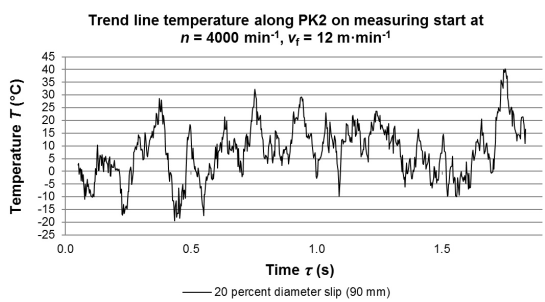

Fig. 7: The course of the trend line at the beginning of the cutting PK2.

In the graph (Fig. 7), it is possible to see the hotness of the circular saw blade at the beginning of the cutting process. From the graph, it is possible to see a dynamic temperature change at the start of a gradual stabilization of the temperature in the range 22°C to 25°C.

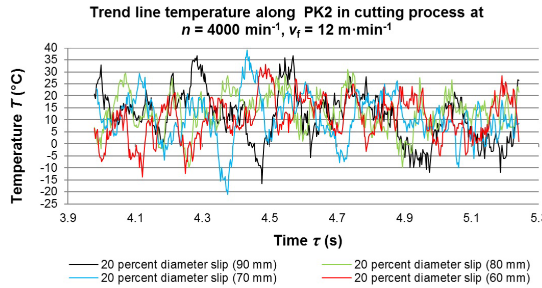

Fig. 8: Waveforms trend lines while cutting PK2.

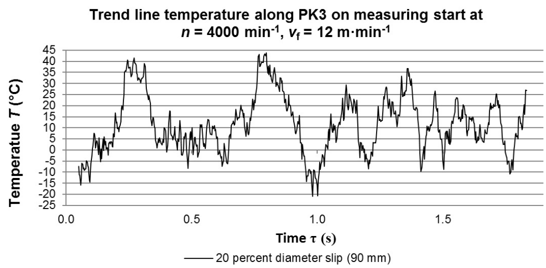

Fig. 9: The progress of the trend line at the beginning of the cutting PK3.

In the graph (Fig. 9), we see the hotness of the circular saw blade at the beginning of the cutting. From the graph, there obviously are big changes of the dynamic temperature at the start of a gradual stabilization of the temperature in the range of 25 °C to 30 °C.

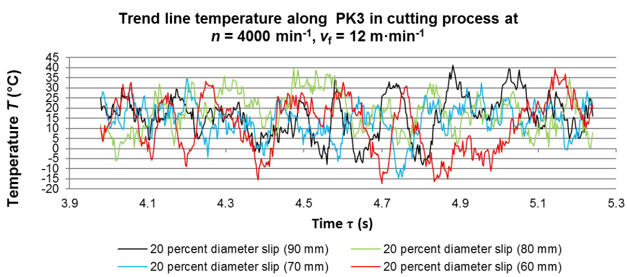

Fig. 10: Waveforms trend of the lines while cutting PK3.

From the trend lines course of the temperature PK1 results that at the greatest distance from the centre of the circular saw blade, i.e. 90 mm, the temperature is about 28°C. From the trend lines course of the temperature PK2, the temperature is about 25°C, and when measuring the PK3, the temperature is about 30°C. On the basis of the previous, the highest temperature was on the circular saw blade PK3. This circular saw blade has been treated with injections. At the distance of 80 mm from the centre of the circular saw blade, the results of the PK1 are about 25°C, the results of the PK2 are about 24°C and at the PK3, the highest temperature up to 28°C was achieved. At the distance of 70 mm from the centre of the circular saw blade, we have measured the temperature about 23°C at the PK1, about 22°C at the PK2 and about 25°C at the PK3. Here we can see that the results again repeat and the highest temperature reached PK3 circular saw blade. By the last distance of 60 mm from the flange, we have the following results: melting PK1 about 21 °C, PK2 had the temperature about 21°C and PK3 about 23°C.

DISCUSSION

Based on the experimental measuring (Konov 1982) shows that the temperature at the distance of 0.5 mm from the cutting edge reaches the maximum value T = 500°C, in the sector of the tooth root T = (52 ÷ 110)°C and at the region of the clamping collars T = (22 ÷ 46)°C. The temperatures depend on the cutting conditions. The cutting conditions in the experimental measuring were: v_c = (37.9 ÷ 66.7) m•s^{-1}; f_z = (0.2 ÷ 1) mm; h = (70 ÷ 15) mm and w = (10 ÷ 70) %. (Danielson and Schajer 1993), in their work, indicate the temperature in the area under the root circle at four different radiuses. Cutting material was used with dimensions: thickness h = 75 and 100 mm, width b = 250 mm, length l = 2.5 and 3.1 m. The highest temperature measured in the cutting was near of the tooth root and reached T = 26.7°C. (Ratnasingam et al. 2010) report the results of experimental temperature measurements on the tooth, with 6 thermocouples were sequentially located 1 mm from the cutting edge. The highest measured temperature is 1 mm from the cutting edge: for particleboard T = 196°C, for the solid wood T = 127°C. The temperature T = 669°C was determined in the cutting process on the surface of the cutting edge (Martinez and Hankele 2015). Authors (Khviyuzov et al. 2015) evaluated coefficient of thermal emissivity for the mentioned temperature ranged T = (30 ÷ 100) °C varied (0.2 ÷ 0.34) when measured by infrared thermometers.

Our experimentally measured temperatures of the circular saw blade body were in the range T = (22 ÷ 30)°C. The coefficient of the thermal emissivity was 0.25 as given by the infrared thermometer. The temperatures and coefficients of thermal emissivity were in very good equality. From the experimental measurements can be concluded: PK3 had the highest temperature for each of the four distances (90 mm, 80 mm, 70 mm and 60 mm) from the centre of the saw blade (Fig. 10). PK3 had a special surface treatment, it had the spray paint RAL 9006 with a thickness of 100 microns. From the results we can deduce that the injection affected the temperature of the saw blade (in the expected heat transfer coefficient – α) which cooled slowly. This finding corresponds well with the differential Eq. 2.

Major changes of the temperature during the cutting may be caused mainly by wood defects such as knots etc. The temperature at four different radiuses of the saw blades confirms the theoretical assumption of concentric temperature distribution with a temperature gradient from the edge to the radius of the clamping flanges of the saw blade. In the graphs (Figs. 5, 7, 9), great dynamic changes of the temperature in a very short period of time (in the order of ms) are shown. Temperature stabilization occurs within 1second of time.

CONCLUSIONS

The experimental measuring confirmed the influence of saw body modification on the concentrical distribution of temperature in the radial direction of the circular saw blade. The smaller temperature gradient was evident on the circular saw blade with a surface coated in a thin layer of RAL9006 material. The theory of vibration of rotating circular saw blade informs, that temperature gradient in radial direction of circular saw blade has the influence on critical rotational speed and its stability. The coating of surface of circular saw blade with using of thin layer is possible way how to change its attributes. We suggest this obtained experience to confirm and develop with following research.

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