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IMPROVING THE MACHINING PROCESS BY ANALYSING THE RELATIONSHIP BETWEEN CUTTING FORCE AND TEMPERATURE IN DRILLING OF ENGINEERING STEELS

Pavel Polák[1], Zuzana Poláková[2], Ján Žitňanský[1], Petr Dostál[3], Katarína Kollárová[4]

[1] Department of Quality and Engineering Technologies, Faculty of Engineering, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic
[2] Department of Statistics, Faculty of Economics and Management, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic
[3] Department of Technology and Automobile Transport, Faculty of AgriSciences, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic
[4] Department of Science and Research, Faculty of Engineering, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic

Abstract

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This paper describes the experiment of measuring the temperature and cutting force during the drilling of short holes without using cutting lubricants, at constant cutting speed, and at increasing shift. Measurement was performed on steel samples of grade 11 523. During drilling, temperature was monitored by a thermocouple, using the method of two foreign metals. Cutting force was measured by a strain-gauge sensor. The experiment provides a quick orientation in the given issue and points out to the optimisation of cutting conditions. Based on results, it can be stated that the range of temperatures and the size of cutting forces depends on technological conditions, cutting parameters, and mechanical and physical properties of tool and workpiece's material.

Keywords: metal working, hole boring, cutting conditions, tool shift

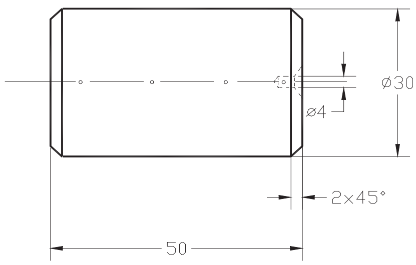
INTRODUCTION

The machining technology and production process optimisation significantly contribute to mechanical production. Machining is a working process where raw product obtains the required shape and size of machine component by removing material particles from the surface layer. Removing can be performed by various means, whereby the most widespread is cutting where chips are separated from base material. Working conditions include all the factors determining the given machining process (Zdravecká and Kráľ, 2004), i.e. tool's material and geometry, the quality of material, condition of cutting edge when replacing the tool, cutting conditions, time of machining by the given tip, and cutting environment. Holes can be created by casting, extruding, cutting or machining on lathes, turret lathes, and automatic machines. The highest size and shape accuracy and meeting the prescribed distance of their axes can be achieved by drilling, which is used for preparing both bottomed and bottomless holes in solid material, or for machining and enlarging holes created by other technology (Žitňanský *et al.*, 2014; Dostál *et al.*, 2011). After lathing, drilling is the second most frequently used operation. In addition to drilling into solid material, boring is used for only enlarging and refining already pre-drilled, pre-cast and other holes. The main cutting motion – rotation in drilling is performed by the tool – drill which concurrently moves into cut by manual or machine shift. In the experiment, attention is paid to the relationship of cutting forces and temperatures at changing shift of the working tool into machined material in the process of drilling.

MATERIALS AND METHODS

Sample

The experiment was performed on test samples from a cylindrical rod of diameter D = 35 mm. The material of the samples used was the steel of grade 11 523 (Fig. 1 and Tab. I), in three pieces. All the samples were machined to the following dimensions: D = 30 mm, length L = 50 mm, the size of centring hole d = 4 mm, and surface roughness R_a = 1.6 µm.



1: *Test sample*

Working Machine

The experimental part of work was performed on a simple stand drilling machine KAZANLIK BS 30 (Kazanlik, Russia) (Fig. 2).

Cutting Tool

In experimental machining, there were used spiral drills with a taper shank of diameter Ø = 20 mm (STN 221140 POLDI HSS 02) (Fig. 3). A new drill of the same parameters was used for each sample. The toll is recommended for drilling the components from plain and alloyed steel, cast steel of strength up to 900 N·mm^{-2}, grey malleable and spheroid graphite cast iron, sintered steel, aluminium alloy with short chip. The drill is manufactured from high-speed steel highly alloyed by wolfram with carbon content up to 1.45% C. Hardness reaches up to 64 HRC. This hardness is maintained up to temperatures of about 600 °C.

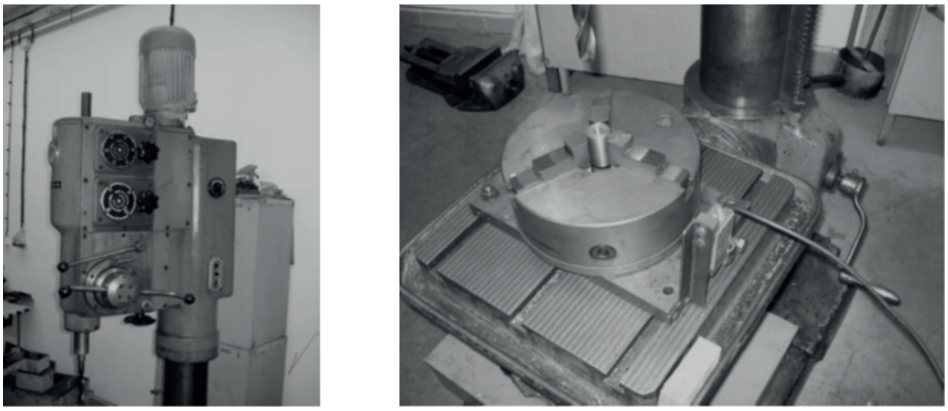
Experimental Method

The experimental part was performed at the Department of Quality and Engineering Technologies, in the laboratory of machining at the Faculty of Engineering of the Slovak University of Agriculture in Nitra (Fig. 4). Individual sensors of temperature and cutting force were calibrated to maximum possible values that the said sensors

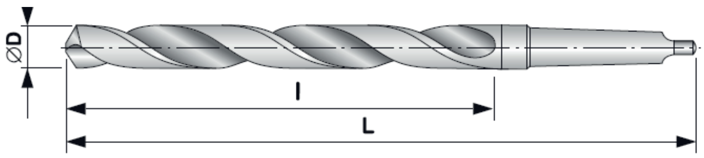
I: *Material sheet of steel 11 523*

MATERIAL SHEET OF STEEL 11 523						
Standard:	STN 41 1523					
Material identification:	11 523					
Material number:	411523					
Colour identification:	-					
Waste category:	002					
Specific weight (kg/dm^3):	7.850					
CHEMICAL COMPOSITION (wt%)						
	C	Mn	N	P	S	Si
Max.:	0.200	1.600	0.009	0.040	0.040	0.550
MECHANICAL PROPERTIES						
	R_e (MPa)		R_m (MPa)	σ*Dt* (MPa)		
				static	volatile	alternating
	320–360		520–640	140–210	90–135	65–95
THERMAL TREATMENT						
Method	Temperature (°C)					
Normalising	870–900					
Soft annealing	680–710					
Tempering	670–700					
Weldability						
Guaranteed						
USAGE						
Bridge and other welded structures, strips and bands for bent profiles and tubes, machine parts, welded spiral cases of water wheels, seamless and welded tubes, tubular welded structures of machines, automobiles, motorcycles (loaded statically and dynamically) and bicycles.						

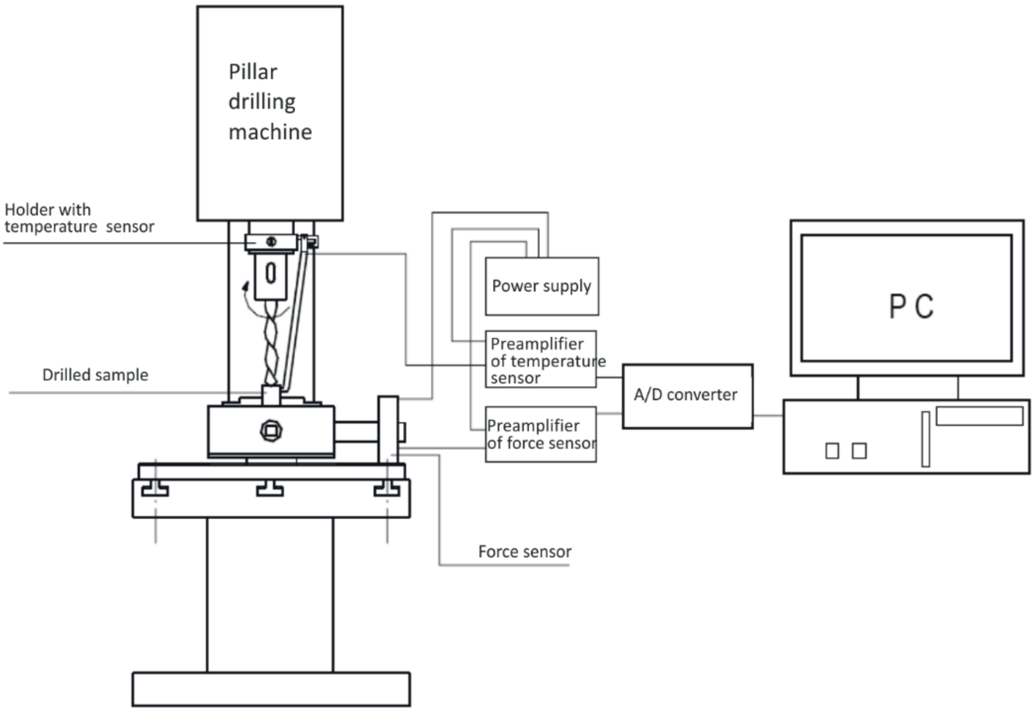
Source: Vávra *et al.*, 2009



2: *Simple stand drilling machine KAZANLIK BS 30*
Source: own photo



3: *Screw drill with taper shank*
Source: Stimzet, 2009



4: *Connection diagram of measuring system*

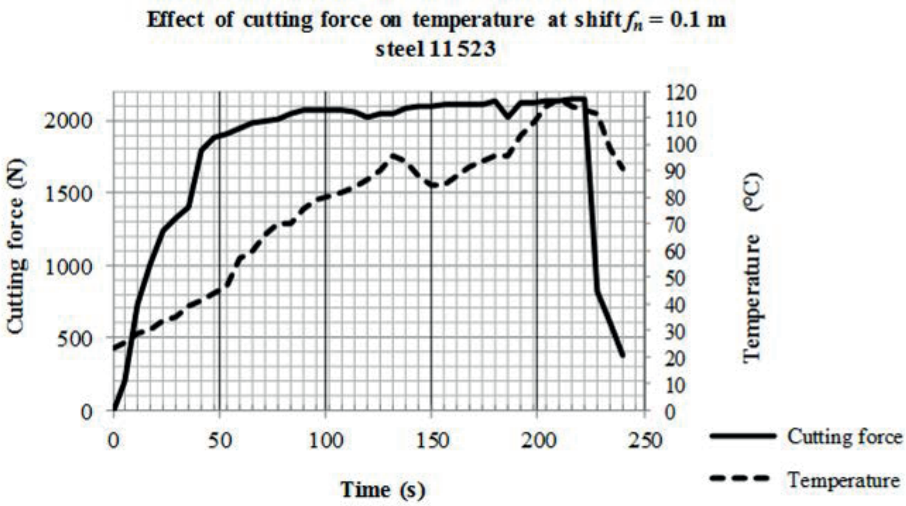
enable sensing. A clamping device was fixed to the simple drilling machine KAZANLIK BS 30 by using screws. The samples were gripped in the clamping device, which ensured a firm clamping of the workpiece and reliable sensing of measured quantities during drilling. Measured values were recorded in a PC using the Visi DAQ Task Designer software by Advantech. Each measurement was performed with three samples. In the first measurement, the speed for sample 1 was set to n = 85 rpm, and shift was f_n = 0.1 mm. In the second measurement, the speed for sample 2 was n = 85 rpm, and shift was f_n = 0.16 mm. In the third measurement, the speed for sample 3 was n = 85 rpm, and shift was f_n = 0.25 mm. In all experiments, cutting speed was kept constant, i.e. v_c = 5.24 m·min^{-1}. The temperature sensor was placed on the non-rotational withdrawable spindle of the drilling machine so that it was able to record the temperature on the perimeter of the sample, always at the level of cutting edge, along the whole trajectory of the drill.

Correlation and regression analysis was used for testing the relationship between cutting force and temperature at different shifts. Based on the value of correlation coefficient (R) and index of determination (R^2), there was selected the most suitable model, which was parabola ($y = b0 + b1x + b2x^2$) at all the three shifts (Poláková, 2011).

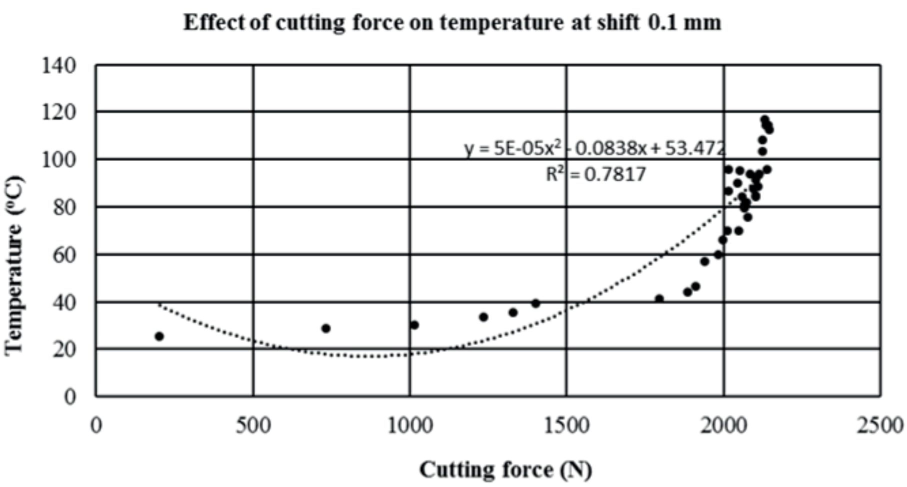
RESULTS

The strain-gauge sensor of force – Utilcell-M120 (Utilcell, Tecnicas de Electronica y Automatismos, S.A., Spain) was used for recording cutting forces in the drilling process. It is a sensor with a deformation measuring element from beryllium–copper alloy. Temperature was monitored by a thermoelectric couple, which leads through a protective tube and ends with the temperature sensor's head. The measurement of temperatures by thermocouples is based on using the thermoelectric effect. When the joint of two conductors from different metals, e.g. copper (+) constantan (-), is heated up, thermoelectromotive force proportional to the temperature of the joint is generated on the free ends of conductors. To obtain the necessary information, temperature was always recorded at the level of cutting edges, along the whole trajectory of the drill. The sensor was fixed to the non-rotational withdrawable spindle of the drilling machine using a socket. Recorded contact was always at the level of cutting edges of the drill.

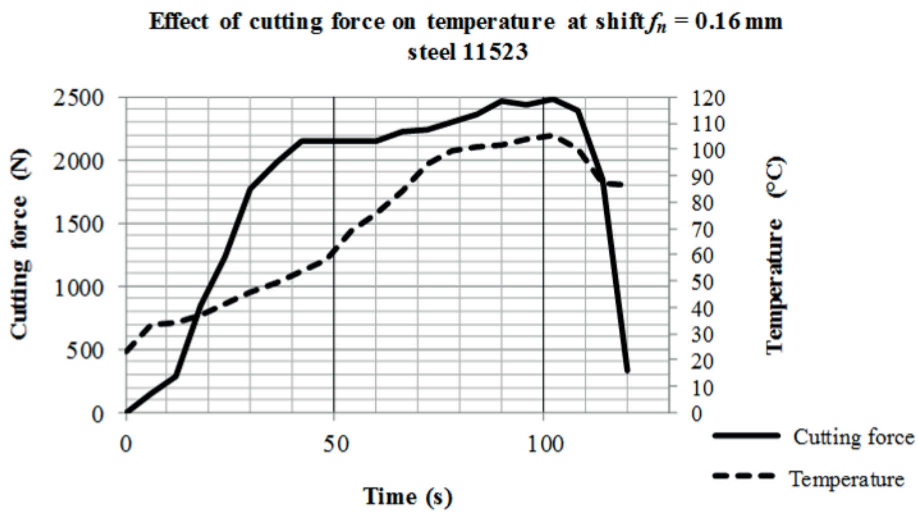
The graphs of cutting forces and temperatures in time series were constructed from measured values and were analysed.



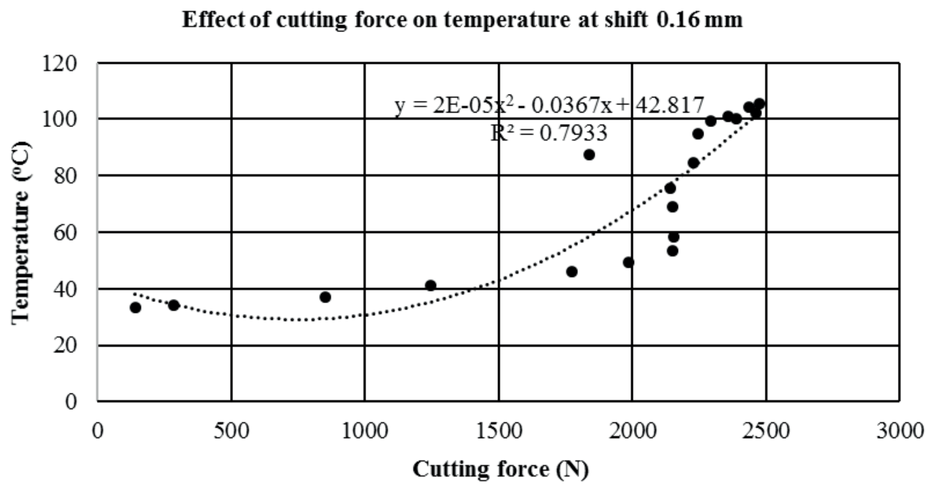
5: *Course of cutting forces and temperatures depending on time at spindle shift f_n = 0.1 mm*



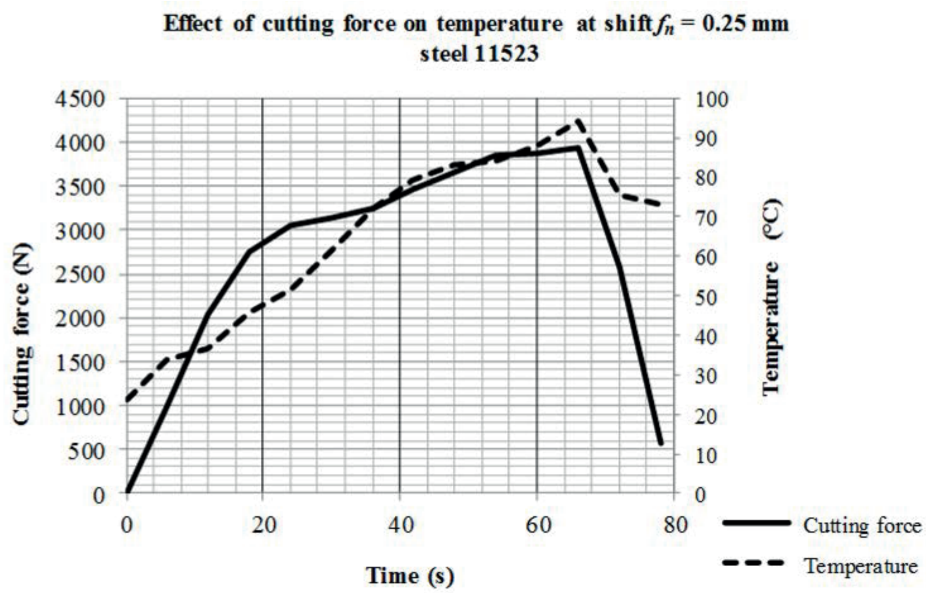
6: *Effect of cutting force on temperature at shift 0.1 mm*



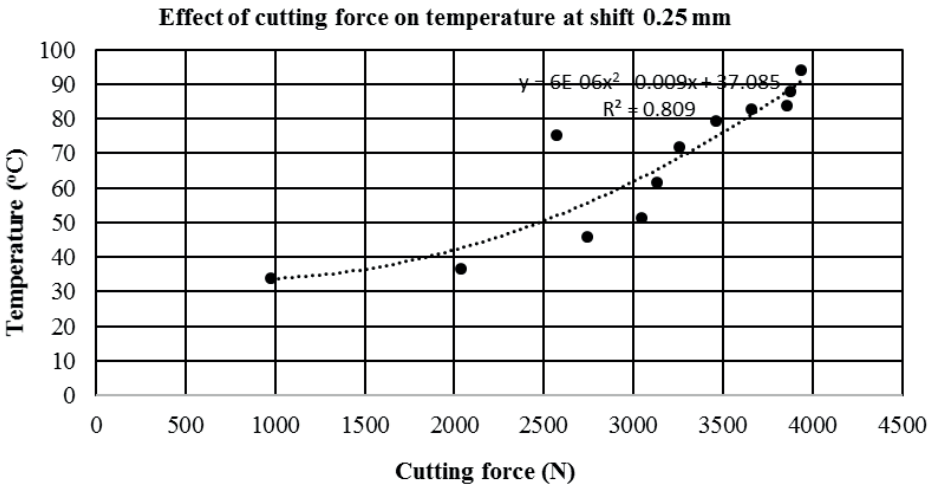
7: *Course of cutting forces and temperatures depending on time at spindle shift f_n = 0.16 mm*



8: *Effect of cutting force on temperature at shift 0.16 mm*



9: *Course of cutting forces and temperatures depending on time at spindle shift f_n = 0.25 mm*



10: *Effect of cutting force on temperature at shift 0.25 mm*

Fig. 5 illustrates the course of relationships between cutting forces and temperatures at spindle shift $f_n = 0.1$ mm.

It is evident that cutting force begins increasing at the moment when the drill got completely into engagement with the whole cutting edge and decreasing at the moment when the drill went out of engagement.

We have used the correlation and regression analysis to determine the effect of cutting force on temperature at different shifts. Fig. 6 illustrates the relationship at the spindle shift $f_n = 0.1$ mm.

At the shift 0.1 mm, there was used the second degree polynomial function in the form $y = 53.472 - 0.0838.x + 5.10^{-5}.x^2$ (Fig. 6). There is a strong statistical relationship between analysed attributes (R = 0.884). The temperature variation is explained to 78.17% by the selected regression model.

Fig. 7 illustrates the course of relationships between cutting forces and temperatures at the spindle shift $f_n = 0.16$ mm.

The second degree polynomial model was similarly used at the shift 0.16 mm (Fig. 8). This model explained 79.3% of the temperature variation. The equation is expressed as $y = 42.817 - 0.0367.x + 2.10^{-5}.x^2$.

Fig. 9 illustrates the course of relationships between cutting forces and temperatures at the spindle shift $f_n = 0.25$ mm.

The effect of cutting force on temperature at the shift 0.25 mm (Fig. 10) was also analysed. The parabolic function was used again to explain the relationship; it is expressed as $y = 37.085 - 0.009.x + 6.10^{-6}.x^2$. The temperature variation is explained to 80.9% (R^2) by the selected regression model.

CONCLUSION

From measured values it is evident that cutting force begins increasing at the moment when the drill got into engagement with the whole cutting edge and decreasing at the moment when the drill went out of engagement. The time to drill the sample declines by changing the speed of spindle shift. The courses of cutting forces and temperatures depending on time are illustrated in Fig. 5, at $f_n = 0.1$ mm. The maximum value of cutting force was 2,144.73 N, and the value of maximum temperature of the workpiece reached 116.99 °C. At the shift $f_n = 0.16$ mm, we have measured the maximum cutting force 2,476.38 N. At the shift $f_n = 0.25$ mm, cutting force was at the value 3,934.66 N. This measured value of cutting force reached the maximum value from all measurements. Based on measured results, by increasing the spindle shift the machining time declines and generated heat is removed mostly by chip out of the workpiece. Only heat generated by friction on the tool's back is getting into the workpiece. The amount of heat transferred into the workpiece is relatively small in relation to the total amount of removed heat generated during machining; therefore, in all measurements, the lowest value of mean temperature of the workpiece was reached with the shift $f_n = 0.25$ mm. High temperature causes rapid wear of the main cutting edge on the drill, thus causing annealing of the edge and sticking of formed chip upon the drill. As a consequence of that, the drill may be damaged or hacked, cracks may be formed, or it may even be broken.

Hole machining is quite common in engineering technology. It follows from the requirements for specific holes used not only for arranging various types of shafts and axes but also for jointing parts and other purposes. The choice of drilling technology is based on the design requirements for the shape and dimensions, namely the nature of semi-finished products, with regard to the requirements for quality, reliability and economic efficiency (Matisková *et al.*, 2014; Pauliček *et al.*, 2014).

The use of cutting conditions corresponding to the work on standard machine tools affects negatively the economy of machining. The high price of numerically controlled machines requires an increase in cutting conditions. Optimal cutting conditions are affected by appropriately chosen machining technique. The choice of machining technology depends on numerous production factors. Machining centers must meet technological and customer requirements as well as those related to the safety and protection of health (Matisková *et al.*, 2004; Kotus, *et al.*, 2014).

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REFERENCES

DOSTÁL, P., ČERNÝ, M., LEV, J., VARNER, D. 2011. Proportional monitoring of the acoustic emission in crypto-conditions. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 59(5): 31–38.

KOTUS, M., PAULIČEK, T., JANKAJ, D., SPIŠÁKOVÁ, Ž., HOLOTA, T., INGALDI, M. 2014. Audit bezpečnosti obrábacieho centra vo výrobnej organizácii. In: *Kvalita, technológie, diagnostika v technických systémoch*. Nitra: SPU, 51–56.

MATISKOVÁ, D., KOTUS, M. 2014. Methodology for determining the cutting conditions in drilling of automated manufacturing. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 62(5): 1033–1040.

MATISKOVÁ, D., PAVLENKO, S. 2004. Stratégia výberu technológii rezania materiálov. In: *Management of manufacturing systems*. Prešov: FVT TU, 151–155.

PAULIČEK, T., ČIČO, P., ORŠULA, V., JANKAJOVÁ, E., HOLOTA, T., KOTUS, M. 2014. Hodnotenie poruchovosti obrábacieho centra metódou FMEA. In: *Kvalita, technológie, diagnostika v technických systémoch*. Nitra: SPU, 74–79.

POLÁK, P., ŽITŇANSKÝ, J., FERANCOVÁ, M. 2014. Effect of type of cutting tips on cutting forces in turning. *Acta Technologica Agriculturae*, 17(3): 57–60.

POLÁK, P., ŽITŇANSKÝ, J., POLÁKOVÁ, Z. 2014. Planning of experiments in the process of machining materials [in Slovak: Plánovanie experimentov v procese obrábania materiálov]. In: *Collection of scientific papers 'Kvalita, technológie, diagnostika v technických systémoch'*. Nitra: Slovak University of Agriculture in Nitra, 284–291.

POLÁKOVÁ, Z. 2011. *Statistical methods, instructions for practical lessons* [in Slovak: *Štatistické metódy, návody na cvičenia*]. 1st ed. Nitra: Slovenská poľnohospodárska univerzita v Nitre.

STIMZET. 2009. Catalogue 2009. Available at: http://www.autostyl.net/UploadFiles/katalogy/Prumyslove_obrabeni/Obrabeni_otvoru/Katalog-STIM-ZET-obrabeni-otvoru.pdf.

VÁVRA, P. et al. 2009. *Engineering tables for secondary industrial schools of mechanical engineering* [in Slovak: *Strojnícke tabuľky pre SPŠ strojnícke*]. 5th ed. Bratislava: ALFA-PRESS.

ZDRAVECKÁ, E., KRÁĽ, J. 2004. *Basics of engineering production* [in Slovak: *Základy strojárskej výroby*]. Košice: Elfa.

ŽITŇANSKÝ, J., POLÁK, P., BERNÁT, R., ZÁLEŽÁK, Z. 2014. Effect of cutting conditions on size accuracy, shape and roughness of machined parts [in Slovak: Vplyv rezných podmienok na rozmerovú presnosť, tvar a drsnosť obrábaných dielcov]. In: *Collection of scientific papers 'Kvalita, technológie, diagnostika v technických systémoch'*. Nitra: Slovak University of Agriculture in Nitra, 173–180.

Contact information

Pavel Polák: pavel.polak@uniag.sk
Zuzana Poláková: zuzana.polakova@uniag.sk
Ján Žitňanský: jan.zitnansky@uniag.sk
Petr Dostál: petr.dostal@mendelu.cz
Katarína Kollárová: acta.tf@gmail.com