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EFFECT OF SHIFT IN SPEED TURNING ON MACHINED SURFACE QUALITY

Pavel Polák[1], Petr Dostál[2], Katarína Kollárová[1]

[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 Technology and Automobile Transport, Faculty of Agronomy, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic

Abstract

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This article describes the evaluation of machined material roughness in speed turning on a machining centre Doosan Puma 700 LY. The machined surface of semi-finished products from steel 14 260 was compared at selected cutting conditions. A half of compared samples from steel 14 260 was in the original, thermally untreated condition (mild steel), and the second half of samples was thermally treated (hardened steel, with a hardness of samples 50 HRC). The experiment focused on turning the selected samples in order to evaluate the roughness of machined surfaces. Cutting tool shift was variable during individual measurements. This experiment contributes to a quick orientation in the given issue and points out to optimisation of cutting conditions.

Keywords: cutting tool, cutting conditions, turning, roughness, machining centre, cutting blade, cutting speed

INTRODUCTION

Present efforts focus on optimisation of cutting conditions so that the best surface quality at the lowest production cost can be achieved. Lower production cost can be achieved by shortening the production time of machining, which can be performed by higher cutting speeds. Current advances in technology enabled manufacturing working machines that use increasing machining speeds (Neslušan, 2009, Brychta *et al.*, 2011) as well as developing and using various new cutting materials that are more resistant, harder and can be machined at higher speeds. Speed turning, as indicated by its title, is turning at higher speeds in comparison with conventional turning. One of the basic benefits of this method is in reduced cutting forces, the consequence of which is a higher surface quality of a workpiece. Its drawback is in the fact that it has not been used to a larger extent in mass production until now and has not been tested on all types of materials sufficiently (Čep and Petrů, 2011, Kumar and Narang, 2013, Vasilko, 2009). The term 'quality' is generally understood as a certain assessment of product condition according to pre-determined criteria and signs. When this term is connected with the machined surface, surface quality is defined as a geometric shape of surface, size of unevenness, and physical and chemical condition of material layers. Surface quality can be assessed according to various criteria, while surface roughness being one of the most important (Polák *et al.*, 2014, Havrila, 2011, Valter, 2012).

Roughness represents the size of unevenness from an ideally smooth surface, as a consequence of used cutting tool and cutting conditions (such as shift or cutting speed). Roughness can affect the functionality of components; therefore, it is important to reach the best values of roughness. Roughness is influenced by such factors as cutting conditions, cutting tools as well as the machined material. Cutting conditions include cutting speed, shift or depth of cut. Shift is defined as the size of cutting tool shift during one revolution of a workpiece. This experiment focuses on studying the effect of shift on surface quality evaluated according to roughness measurements (STN 41 4260, 1995).

MATERIAL AND METHODS

Definition of machined material

The machined material was Si – Cr steel, designated according to the standard STN 41 4260 as steel 14 260 (STN 41 4260). This steel is suitable for more stressed springs used especially for automobiles, railway carriages as well as for valve springs up to a temperature of 300 °C, or flat components requiring high wear resistance such as the covering of active parts of building or agricultural machines. They may not be welded. The chemical composition of this steel according to STN 41 4260 is shown in Tab. I.

Preparation of machined material

Steel 14 260 was in the form of a cold-drawn rod. There were used two types of this steel, i.e. mild and hardened steel with diameters of 100 mm and 63 mm and a length of 1,200 mm (Figs 1 and 2).

To ensure a perfect fixing of the workpiece into the machining centre and due to a high weight and length of workpiece, centring holes were prepared on both ends of the shift. The centring hole is prepared also for elimination of undesirable vibration leading to worsened surface roughness of the workpiece.

Definition of turning tool

Two types of holders (i.e. Sandwik and Walter) and two types of exchangeable cutting blades (Walter) have been used for measurements.

Cutting blade holders

The holder SANDVIK DRSNL 2525M 12 is used for fixing an exchangeable cutting blade of round shape (Gupta *et al.*, 2011), and the holder WALTER DDJNL 146D is used for fixing a blade of rhombus shape (Sandvik Coromant, 2012) (Fig. 3).

Exchangeable cutting blades

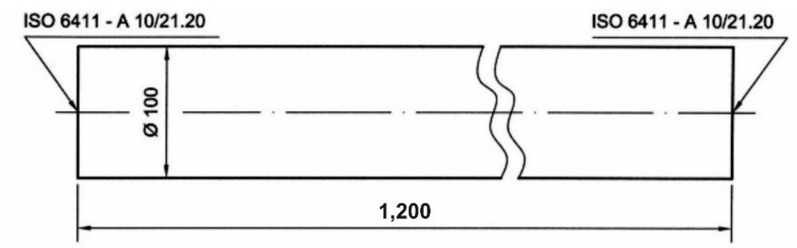
Two types of cutting blades have been used in the experiment.

WALTER S – RNGN 120400 – is a cutting blade of round shape (Fig. 4), which was used for roughing in our experiments. It is made of ceramic material on the basis of aluminium and silicon suitable for machining hardened steels in difficult conditions. Its designation is WCB according to the Walter (2012).

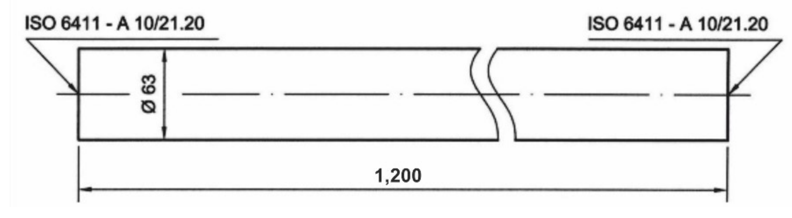
WALTER – DNGA 150608 – is a cutting blade used for finishing operations – smoothing. It is made of cubic boron nitride. Its designation is WCB 50 and is used for finishing operations of hardened steels at high speeds.

I: *Chemical composition of steel 14 260 (Source: STN 41 4260, 1995)*

Chemical composition of steel 14 260 [wt%]							
C	Mn	Si	Cr	Ni	Cu	P	S
0.50–0.60	0.50–0.80	1.30–1.60	0.50–0.70	max. 0.50	max. 0.30	max. 0.035	max. 0.035

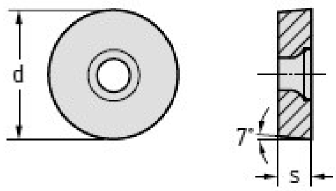


1: *Workpiece with centring hole (workpiece diameter 100 mm)*
(Source: own work)

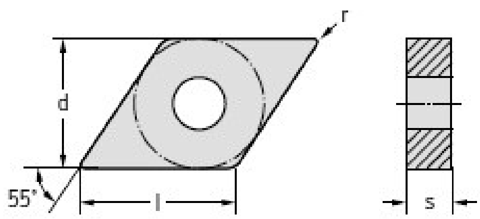


2: *Workpiece with centring hole (workpiece diameter 63 mm)*
(Source: own work)

3: *Holders WALTER DDJNL 146D and SANDVIK DRSNL 2525M 12*
(Source: Sandvik Coromant, 2012)



4: *Cutting blade WALTER S – RNGN 120400*
Source: Walter, 2012)



5: *Cutting blade WALTER – DNGA 150608*
(Source: Walter, 2012)

Definition of machining centre

Machining was performed on the machining centre Doosan Puma 700 LY (Fig. 6). This machining centre is designed for hard machining with interrupted cut, high accuracy and for obtaining a quality surface. High turret head speed and high shifts minimise incidental machining times. Conventional manufacturing method and rigid structure combined with progressive technologies adds to this turning centre a high technological value.

6: *Machining centre Doosan Puma 700 LY*
(Source: Doosan Infracore America Machine Tools)

7: *Roughness meter Diavite DH – 8*
(Source: DIAVITE AG)

Definition of roughness meter

Roughness was measured using a roughness meter Diavite DH – 8 (Fig. 7). It is used for measuring various types of surfaces such as bumps and holes, fragile, soft, flexible, sharp, hard or abrasive surfaces.

Calculation of cutting speed

In turning, cutting speed (v_c) is the circumferential speed of workpiece defined at the intersection of cutting edge and machined surface. It depends especially on machined material properties, cutting properties of tool material, chip cross-section and on selected cutting tool life. Cutting speed of workpiece at the point of turning is determined according to the following relation:

$$v_c = \frac{\pi \times D \times n}{1{,}000} \left(m \cdot min^{-1} \right) \quad (1)$$

where:
D – diameter of machined surface (mm),
n – number of speed revolutions (min-1).

Calculation of machining time

Machining time depends on workpiece length, shift and rotational frequency of workpiece, and is calculated according to the following relation:

$$\tau_s = \frac{l}{f \times n} \text{ (min)} \quad (2)$$

If the frequency of workpiece rotation *n* is substituted by:

$$n = \frac{1{,}000 \times v_c}{\pi \times D} \text{ (min)} \quad (3)$$

the resulting relation will be:

$$\tau_s = \frac{l \times \pi \times D}{1{,}000 \times v_c \times f} \text{ (min)} \quad (4)$$

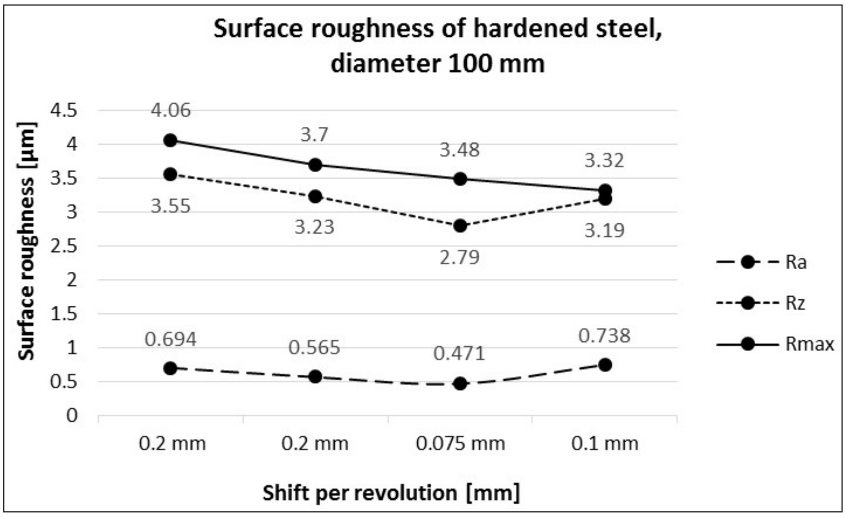
where:
l – workpiece length (mm),
f – shift per revolution (mm),
n – number of spindle revolutions (min^{-1}).

II: *Cutting conditions of individual measurements*

	Hardened steel		Mild steel	
Steel diameter (mm)	100	63	100	63
Roughing				
Spindle revolutions per minute	700	700	700 637 600	700 631
Cutting tool shift (mm)	0.2	0.2	0.2	0.2
Smoothing				
Spindle revolutions per minute	700	700	700 685 6637	700 631
Cutting tool shift (mm)	0.075 0.1	0.075 0.1	0.075 0.1 0.25	0.075 0.1 0.15 0.25

III: *Cutting conditions of individual measurements for the hardened steel of diameter 100 mm*

Hardened steel (diameter 100 mm)											
Cutting conditions								Results			
Ser. no.	Depth of cut a_p (mm)	Cutting speed (m.min$^{-1)}$)	Spindle revolutions (min^{-1})	Shift per revolution (mm)	Embedding length (mm)	Cutting blade type	Machining time (s)	Surface roughness (μm) R_a	R_z	R_{max}	Operation
1	2.5	220	700	0.2	113	1	48.6	0.694	3.55	4.06	roughing
2	2.5	220	700	0.2	106.5	1	45.8	0.565	3.23	3.7	roughing
3	0.15	220	700	0.075	106.5	2	122.1	0.471	2.79	3.48	smoothing
4	0.15	220	700	0.1	106.5	2	91.6	0.738	3.19	3.32	smoothing



8: *Surface roughness for the hardened steel of diameter 100 mm*

RESULTS

Cutting tool shift was gradually changing, whereby measurement was performed in cutting conditions specified in Tab. II.

Measured values

Machining times were calculated according to Eq. 3, cutting speeds were determined according to Eq. 1. The measured values for turning the hardened steel of diameter 100 m are shown in Tab. III. Cutting blade types indicated in Tab. III are as follows:

1. VBD Walter – RNGN 120400
2. VBD Walter – DNGA 150608

Fig. 8 contains the roughness behaviour of hardened steel (diameter 100 mm) at determined cutting conditions. Roughness is specified in three various characteristics, R_a – mean arithmetic deviation of profile [μm], R_z – arithmetic mean of highest profile heights [μm] and R_{max} – maximum value of highest profile heights, whereby R_a – mean arithmetic deviation of profile will be decisive. In practical conditions, suitable roughness values expressed in this characteristic range around the value of 1.6 μm.

This is not valid for turning the mild steel with the diameter of 100 mm because blades were partially worn and cutting conditions that were not changing (except for shift) were unsuitable for mild steel, whereas being suitable for hardened steel.

Roughness values are shown in Fig. 9.

During turning (Tab. IV, values in lines 5, 6, 7), the cutting part of exchangeable cutting blade was repeatedly destructed, which led to the damage of workpiece surface, as can be seen in Fig. 10. Therefore, roughness measurements were not performed.

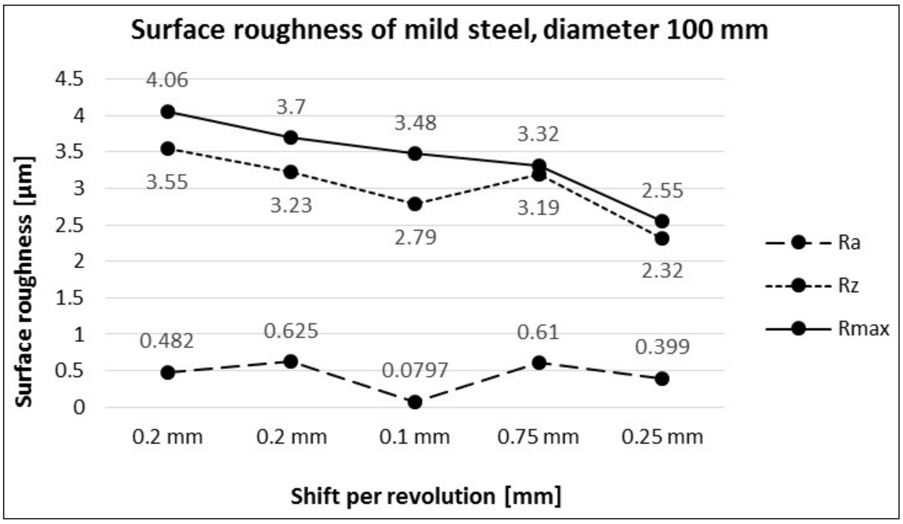
Subsequently, a new cutting blade was used on this surface for smoothing, the resulting roughness being 0.399 μm at shift 0.25 mm (Fig. 11). In this case, the largest roughness value was 0.625 μm at shift 0.2 mm.

Tab. V depicts the results of measurements for turned hardened steel (diameter 63 mm), and Fig. 12 illustrates the roughness behaviour for the same steel. Due to the lower workpiece diameter, also cutting speed was lower than for the larger workpiece diameter, i.e. 138 m·min^{-1}. At lower cutting speed, roughness values decreased with increasing speed.

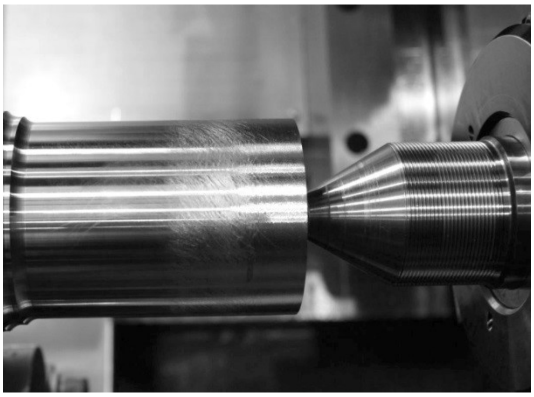
The lowest surface roughness of 0.394 μm (Fig. 12) was reached at shift 0.2 mm, being in this step the largest shift, and the highest surface roughness was 0.817 μm at shift 0.1 mm. By comparing the values from Fig. 10 and 12 it can be stated that lower surface roughness values at decreasing

IV: *Cutting conditions of individual measurements for the mild steel of diameter 100 mm*

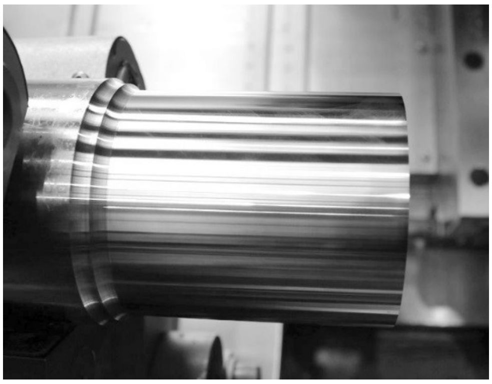
Mild steel (diameter 100 mm)											
Cutting conditions							Results				Operation
Ser. no.	Depth of cut a_p (mm)	Cutting speed (m·min⁻¹)	Spindle revolutions (min⁻¹)	Shift per revolution (mm)	Embedding length (mm)	Cutting blade type	Machining time (s)	Surface roughness (µm)			
								R_a	R_z	R_{max}	
1	2.5	220	700	0.2	116.5	1	49.9	0.482	3.55	4.06	roughing
2	2.5	220	700	0.2	116.5	1	49.9	0.625	3.23	3.7	roughing
3	0.25	220	700	0.1	116.5	2	99.9	0.0797	2.79	3.48	smoothing
4	0.15	220	700	0.75	116.5	2	133.1	0.61	3.19	3.32	smoothing
5	2.5	188	600	0.2	110	1	55	*	*	*	roughing
6	2.5	200	637	0.2	110	1	52.3	*	*	*	roughing
7	2.5	200	637	0.25	100	1	37.7	*	*	*	roughing
8	0.3	215	685	0.25	100	2	35	0.399	2.32	2.55	smoothing



9: *Surface roughness of mild steel (diameter 100 mm)*



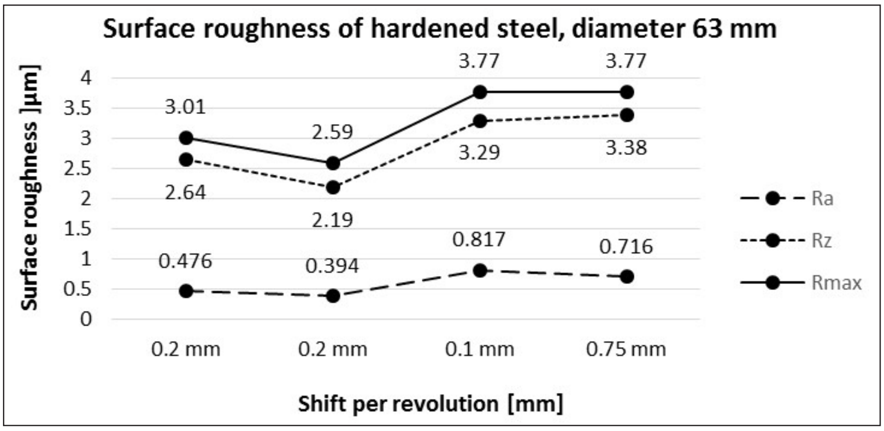
10: *Damaged surface of workpiece for the surface of mild steel (diameter 100 mm)*



11: *Surface roughness 0.399 μm for the mild steel of diameter 100 mm*

V: *Cutting conditions of individual measurements for the hardened steel of diameter 63 mm*

Hardened steel (diameter 63 mm)											
Cutting condition							Results				
Ser. no.	Depth of cut a_p (mm)	Cutting speed (m·min⁻¹)	Spindle revolutions (min⁻¹)	Shift per revolution (mm)	Embedding length (mm)	Cutting blade type	Machining time (s)	Surface roughness (μm)			Operation
								R_a	R_z	R_{max}	
1	2.5	138	700	0.2	116.5	1	49.9	0.476	2.64	3.01	roughing
2	2.5	138	700	0.2	116.5	1	49.9	0.394	2.19	2.59	roughing
3	0.25	138	700	0.1	100	2	85.7	0.817	3.29	3.77	smoothing
4	0.25	138	700	0.075	100	2	114.3	0.716	3.38	3.77	smoothing



12: *Surface roughness for the hardened steel of diameter 63 mm*

shift are reached with increasing cutting speed, and the contrary applies to lower speed in our measurements.

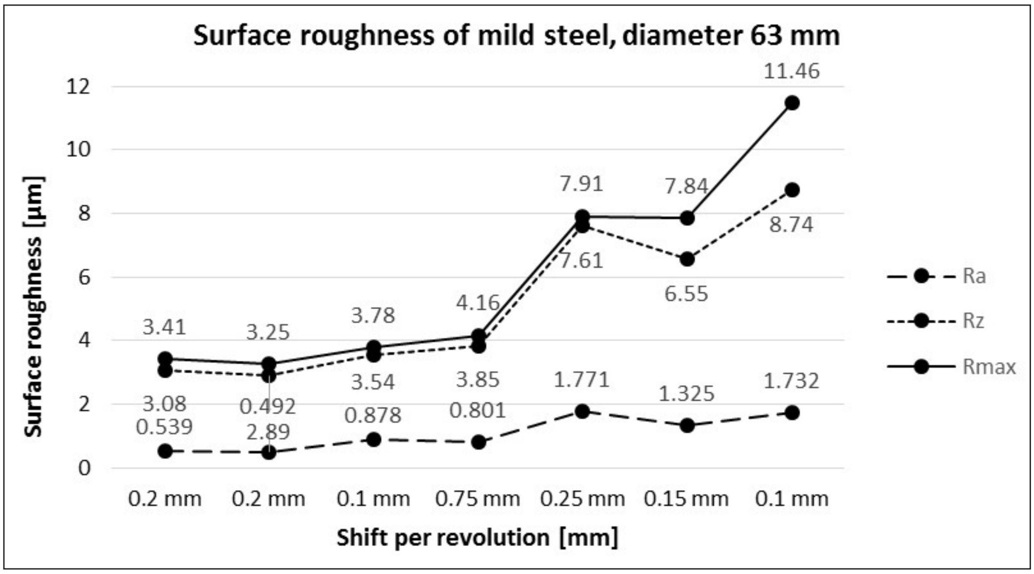
Tab. VI shows the results of measurements for turning the mild steel of diameter 63 mm, and Fig. 13 shows the surface roughness behaviour for the same steel. The roughness values from Fig. 13 proved neither an ascending nor a descending trend depending on shift. The variability of values was caused by the wear of cutting blades and unsuitable cutting conditions for mild steel, which was demonstrated also in turning the mild steel at higher speed. Also in this measurement the exchangeable cutting blade was damaged, the surface was devalued and roughness values could not be measured (Fig. 14).

In these cutting conditions, the highest surface roughness was 1.771 μm at shift 0.25 mm. Even though this value was highest in our measurements, it is still suitable in practice in terms of quality.

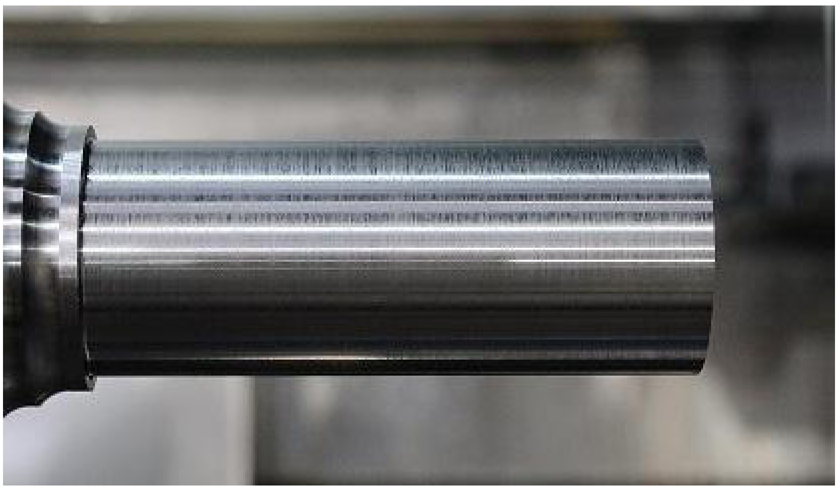
Based on all measured values, speed machining is suitable for machining hardened steels, where a descending trend in surface roughness with respect to decreasing shift has been proved. On the contrary, given cutting conditions were not suitable for machining the mild steel. It was proved that the heat originated during machining was removed by chip when turning hardened steels at higher speed.

VI: *Cutting conditions of individual measurements for the mild steel of diameter 63 mm*

Mild steel (diameter 63 mm)											
Cutting conditions							Results				
								Surface roughness (μm)			
Ser. no.	Depth of cut a_p (mm)	Cutting speed (m·min⁻¹)	Spindle revolutions (min⁻¹)	Shift per revolution (mm)	Embedding length (mm)	Cutting blade type	Machining time (s)	R_a	R_z	R_{max}	Operation
1	2.5	138	700	0.2	116.5	1	48.4	0.539	3.08	3.41	roughing
2	2.5	138	700	0.2	116.5	1	49.9	0.492	2.89	3.25	roughing
3	0.25	138	700	0.1	100	2	85.7	0.878	3.54	3.78	smoothing
4	0.25	138	700	0.075	100	2	114.3	0.801	3.85	4.16	smoothing
5	2.5	125	700	0.2	116.5	1	49.9	*	*	*	roughing
6	2.5	138	700	0.2	116.5	1	49.9	*	*	*	roughing
7	0.25	138	700	0.25	100	2	34.3	1.771	7.61	7.91	smoothing
8	0.25	138	700	0.15	100	2	57.1	1.325	6.55	7.84	smoothing
9	2.5	138	700	0.075	116.5	1	133.1	*	*	*	roughing
10	0.25	138	700	0.1	100	2	85.7	1.732	8.74	11.46	smoothing



13: *Surface roughness for the mild steel of diameter 63 mm*



14: *Damaged surface of the workpiece from the mild steel of diameter 63 mm*

CONCLUSION

The experiment focused on studying the effect of shift on the quality of machined surface in speed turning. Speed turning uses higher cutting speed than conventional turning. Surface roughness was considered the main criterion in assessing the surface quality. Two types of material were turned under pre-determined cutting conditions (shift, cutting speed, workpiece diameter, depth of cut), with measuring surface roughness. The results of measurements demonstrated the effect of shift on the quality of machined surface, this effect being not always equal. The main differences were in measuring the roughness of machined surface in thermally treated (hardened) and thermally untreated (mild) steel. When turning the hardened steel, surface quality is becoming better at higher speed with decreasing shift. It was contrary at lower speed, surface quality was better at higher shifts. In mild steel, roughness results were not as clear as in hardened steel. The effect of shift on surface roughness was proved but neither a decreasing nor increasing trend in surface roughness was demonstrated at variable speed of shift. Only the unsuitability of selected cutting conditions for mild steel was proved. There are many other combinations of cutting conditions at which the effect of shift and other parameters on surface quality can be studied, which however is beyond the scope of this paper.

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Contact information

Pavel Polák: Pavel.Polak@uniag.sk
Petr Dostál: petr.dostal@mendelu.cz
Katarína Kollárová: katarina.kollarova@uniag.sk