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PRELIMINARY ANALYSIS OF SURFACE TOPOGRAPHY IN TANGENTIAL TURNING

Abstract. *Among the productivity-increasing high feed turning procedures, the tangential turning is studied in this paper. Our main focus was a preliminary analysis of the machined surface topography by the DoE method. To achieve this goal 2 kinds of cutting speed, feed and depth of cut were chosen as factors which are influence the surface topography, resulting in 8 experimental setups. After the cutting experiments 2D profile measurements and shape error measurements were done. In this paper the Ra, Rz parameters of the roughness profile, Wa, Wz parameters of the waviness profile and the straightness error were analysed in more depth. We determined their alteration as a function of the studied parameters and designated our further research directions.*

Keywords: *design of experiments; roughness; straightness; tangential turning; waviness.*

1. INTRODUCTION

Different goals can be achieved by the researchers and development engineers by studying and adjusting the manufacturing processes and systems. An important aim in the automotive engineering is to alter the properties the workpieces in that way which results in the weight reduction and less fuel consumption [1]. Production engineers tend to emphasize the better surface quality and cost reduction [2]. The productivity can be increased by procedures, where high feeds can be adjusted while maintaining the good surface quality [3]

In machining of outer cylindrical surfaces, various procedures and variants could produce surfaces with high feed [4]. Among these we analyse the tangential turning in this paper [5], where the design of the cutting tool and the machining kinematic are both differ from the traditional longitudinal turning (Figure 1). The tool moves on a course which is tangential to the workpiece and the linear cutting edge is inclined to the feeding motion (usually 30-60°).

Tangential turning is capable to machine rotationally symmetric shaped surfaces with a proper edge profile, among the production of outer cylindrical surfaces. In the former case, calculations must be done based on the workpiece profile to describe the cutting edge. Though, a straight cutting edge is sufficient in the latter. However, this edge should be inclined to the feed motion to achieve better cutting conditions and lower loads. Tool life is significantly better than in traditional turning [7] due to the different geometry and kinematics. Tool wear occurs on the whole cutting edge, a concentration point can not be observed. Due to the many differences, machine tools have different requirements like higher rigidity [8].

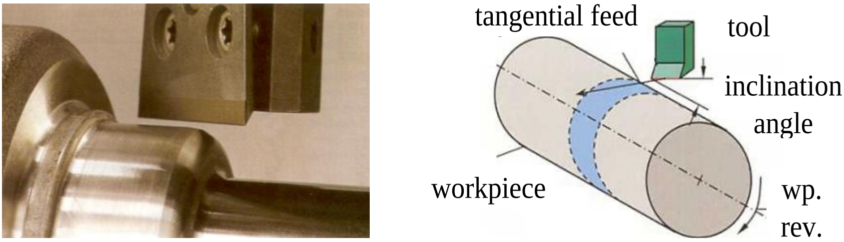

Figure 1 – Tangential turning and its kinematic scheme [6]

The main reason of this is the alteration of the ratios and values of the cutting force components due to the modification of the feed movement and the increased danger of vibration due to the increased chip width. Machining accuracy depends on many factors in this procedure as well [9], for example the value of the inclination angle, the tangential feed, or the depth of cut. Twist-free surfaces can be produced [6] because the cutting edge touches the coating cylinder of the workpiece machined surface throughout the machining process, so a very small groove depth can be achieved. Leichner et al. have promising results in the tool wear, oil leakage and cost reduction when sealing surfaces are machined by tangential turning in their study [10]. Developments are being carried out for the application of this procedure in the machining of hardened surfaces [11], the EMAG machine tool manufacturing company also has such a solution among others [12].

Analysis of the surface topography is important describe the tribological properties of the machined parts [13]. It is usually followed by the study of the surface layer [14,15] due to the life-time prediction, but the geometric properties of the machined parts have a higher impact on the working conditions. Therefore, we carried out a preliminary analysis of the surface topography in tangential turning of hardened surfaces in this paper. We analysed several parameters of the 2D roughness and waviness profiles and the straightness error.

2. EXPERIMENTAL CONDITIONS

The study consisted of two parts: cutting experiments and determining the equations describing the analysed process. The former was completed on a machine tool capable of producing the tangential feed motion, the letter was accomplished by Design of Experiments method.

The cutting experiments were carried out on an EMAG VSC 400 DS hard machining centre. The machined workpieces were 42CrMo4 grade alloyed steels which were hardened to 60 HRc. The machined diameter was 70 mm. The tangential turning tool was made by HORN Cutting Tools Ltd. and had an

inclination angle of 45° (holder code: H117.2530.4132). A S117.0032.00 coded MG12 type uncoated carbide insert was fixed into the holder.
Our aim was to study the effects of the alteration of the cutting speed (v_c), the feed per workpiece revolutions (f) and the depth of cut on the tangential turning process. Therefore (taking into consideration the principles of the Full Factorial DoE method) 2 kinds of each variable were chosen for the experiments, resulting in 8 experimental setups. In this preliminary study we aimed to analyse the process on lower and higher cutting speeds, therefore 100 m/min and 200 m/min values were adjusted. The feed was chosen to 0.3 mm/rev and 0.6 mm/rev and the depth of cut was adjusted to 0.1 mm and 0.2 mm from a similar consideration. The resulted setups can be seen in Table 1.

Table 1 – Experimental setups

Setup	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
v_c [m/min]	100	200	100	200	100	200	100	200
f [mm/rev]	0.3	0.3	0.6	0.6	0.3	0.3	0.6	0.6
a [mm]	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2

The necessary measurements were carried out after the experiments. In this paper we intended to analyse the roughness and waviness profiles and the straightness error, because these values describe well the accuracy of a generatrix of the cylindrical surface.
The analysed parameters were (ISO 4287:1997 and ISO 4287:1997):

- R_a – Arithmetical mean height of the roughness profile [µm]
- R_z – Maximum height of the roughness profile [µm]
- W_a – Arithmetical mean height of the waviness profile [µm]
- W_z – Maximum height of the waviness profile [µm]
- *STRt* – straightness error [µm]

The surface roughness was measured with an AltiSurf 520 three-dimensional topography measuring instrument using a confocal chromatic probe. The shape error was measured with a Talyrond 365 accuracy measuring equipment. The variables of the measurement were chosen according to ISO 4288:1996 standard.

The gathered results were evaluated by the Design of Experiments method. By using this we were able to give equations, which are capable to calculate and present the parameters on the studied parameter intervals. These equations were determined in a polynomial form as can be seen in Equation 1, where the k_i are the constant of the different factors.

$$y(v_c, f, a) = k_0 + k_1 v_c + k_2 f + k_3 a + k_{12} v_c f + k_{13} v_c a + k_{23} f a + k_{123} v_c f a \quad (1)$$

3. EXPERIMENTAL RESULTS

The measurements were carried out on the workpieces after the cutting experiments as described in Section 2. The roughness and waviness parameters were measured in 3 profiles on each surface, while the straightness error was measured on 2 opposite generatrix of the machined cylindrical workpiece. The average values of the measured values were calculated. The result of the measurements and the calculations can be seen in Table 2.

Table 2 – Measured results and calculated averages

			1	2	3	4	5	6	7	8
R_z [μm]		1	14.13	3.61	7.63	3.37	9.56	2.60	15.09	3.70
		2	12.41	3.80	9.02	3.20	7.97	2.48	15.75	3.59
		3	15.75	3.86	7.37	3.54	8.16	2.39	17.68	3.89
		Avg.	14.10	3.75	8.01	3.37	8.56	2.49	16.17	3.73
R_a [μm]		1	2.38	0.43	1.22	0.45	1.61	0.30	2.64	0.41
		2	2.14	0.40	1.17	0.43	1.42	0.29	2.83	0.42
		3	2.31	0.43	1.10	0.44	1.43	0.29	2.40	0.42
		Avg.	2.28	0.42	1.17	0.44	1.48	0.29	2.62	0.42
W_z [μm]		1	2.75	0.35	0.15	0.26	1.48	0.57	3.03	0.27
		2	2.23	0.32	0.73	0.34	1.17	0.65	1.84	0.21
		3	1.73	0.41	0.41	0.41	0.94	0.52	2.49	0.27
		Avg.	2.23	0.36	0.43	0.34	1.20	0.58	2.45	0.25
W_a [μm]		1	0.98	0.26	0.13	0.09	0.60	0.42	0.93	0.10
		2	0.91	0.25	0.24	0.14	0.44	0.45	0.56	0.06
		3	0.68	0.27	0.15	0.16	0.40	0.43	0.84	0.08
		Avg.	0.85	0.26	0.18	0.13	0.48	0.43	0.78	0.08
STRt [μm]		1	0.27	0.56	0.58	0.43	0.64	0.61	1.71	0.66
		2	0.54	0.52	0.36	0.61	0.54	0.71	1.83	0.56
		Avg.	0.41	0.54	0.47	0.52	0.59	0.66	1.77	0.61

The evaluation of the results continued by the determination of the equations of the different parameters. Equation 2 presents the calculation of the Arithmetical mean height of the roughness profile; Equation 3 shows the function of the Maximum height of the roughness profile. The equation of the Arithmetical mean height and the Maximum height of the waviness profile can be seen in Equations 4 and 5. Finally, the resulted function of the straightness error is shown in Equation 6.

$$R_a(v_c, f, a) = 12.22 - 0.0579v_c - 22.10f - 58.45a + 0.109v_cf + 0.2805v_ca + 146.3fa - 0.7136v_cfa \quad (2)$$

$$R_z(v_c, f, a) = 71.83 - 0.3240v_c - 125.3f - 355.9a + 0593v_cf + 1.635v_ca + 859.4fa - 4.027v_cfa \quad (3)$$

$$W_a(v_c, f, a) = 5.78 - 0.0289v_c - 11.37f - 31.07a + 0.058v_cf + 0.1751v_ca + 72.78fa - 0.4011v_cfa \quad (4)$$

$$W_z(v_c, f, a) = 16.42 - 0.0828v_c - 33.38f - 87.22a + 0.171v_cf + 0.4624v_ca + 214.2fa - 1.122v_cfa \quad (5)$$

$$STRt(v_c, f, a) = -0.130 - 0.0027v_c - 0.5f - 2.5a + 0.0023v_cf + 0.005v_ca + 7.4 \cdot 10^{-15}fa - 0.0056v_cfa \quad (6)$$

4. DISCUSSION

The experimental results presented in Section 3 are shown in surface diagrams in Figures 2, 4 and 5. Based on these we drew the following conclusions. The cutting speed has a significant impact in the studied range on the Arithmetical mean height of the roughness profile (Figure 2). This proves our initial opinion, that higher cutting speed is needed to achieve smoother surfaces with tangential turning, which phenomenon caused by the chip removal mechanism. Two times higher cutting speed resulted in 2-4-fold lower R_a. The alteration of the feed rate showed less significant change in the surface roughness. This caused by the change in the generation method of the tool marks. At 0.6 mm/rev feed the geometry of the tool can be observed on the profile, while at 0.3 mm/rev the roughness is generated through different phenomenon (chip formation, vibration, etc.). The surface roughness is least affected by the difference in the depth of cut.

The measured profiles of Setups 4, 6, 7 and 8 are presented in Figure 3, where we show the alteration, when one of the studied parameters is halved. The described observation from Figure 2 can also be seen in Figure 3. We can see, that halving the depth of cut does not show any change in the roughness profile. While halving the cutting speed and feed rate in the studied range results in different profiles, which means that a different surface generation method must come to the fore.

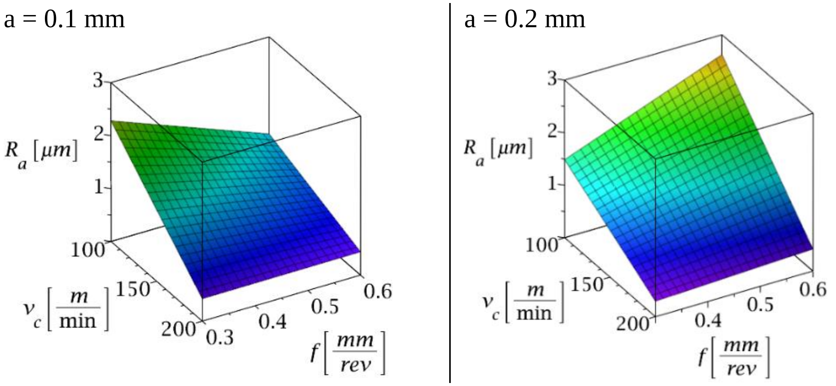

Figure 2 – Visualization of Equation 2 with depth of cut of 0.1 mm and 0.2 mm

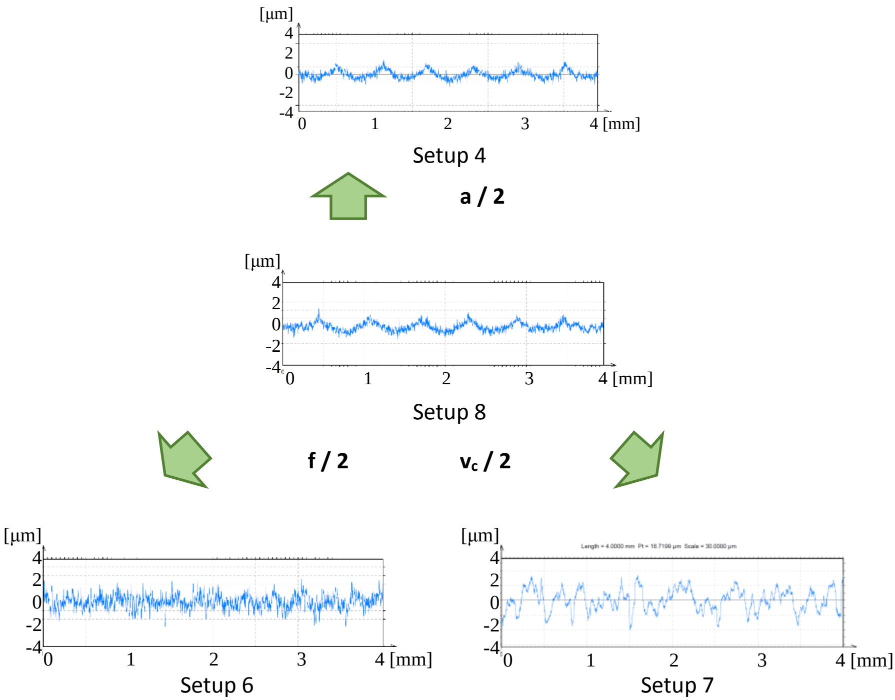

Figure 3 – Alteration from the roughness profile of Setup 8 when halving the studied technological parameters (a, f, v_c)

Figure 4 shows the alteration of the surface waviness. This parameter can indicate a vibration in the machining system, which can easily occur in tangential turning. It can be concluded from the picture that higher feed and cutting speed results in lower waviness. Increasing the feed is good for the cutting, because it stretches the cross-sectional area of the chip by increasing the chip width, which results in higher cutting forces stabilizing the process. Furthermore, it has a beneficial effect on the average chip thickness, which is crucial to be higher than a given value (minimal undeformed chip thickness). Higher cutting speed results in better material removal mechanism, which is discussed earlier. This also lowers the occurring vibrations. Higher depth of cut mostly results in lower waviness. This is caused by the stabilization effect of the increased cutting forces and the direct increasing effect on the chip thickness.

The alteration of the straightness error can be seen in Figure 5. The first conclusion, which can be drawn from the graphs, is the effect of the depth of cut. A two-fold increase of this variable results in a 20% increase of STRt. Furthermore, lower cutting speed and higher feed resulted mostly with lower straightness error.

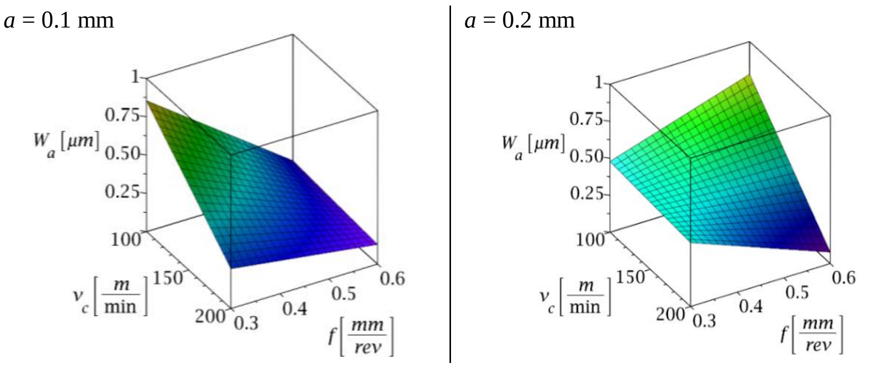

Figure 4 –Visualization of Equation 4 with depth of cut of 0.1 mm and 0.2 mm

The following conclusions can be drawn from the study:

- Higher feed and cutting speed in the analysed range resulted in better surface roughness while it lowered the machining time.
- The depth of cut affects mostly the shape accuracy.
- Other shape error parameters (e. g. cylindricity error) should be studied.
- Further experiments are needed on higher cutting speeds and feeds.

a = 0.1 mm a = 0.2 mm

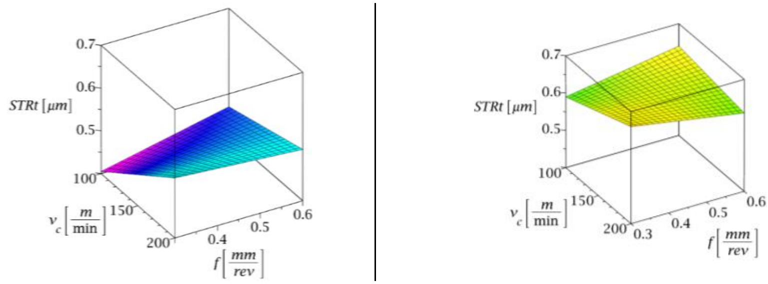

Figure 5 – Visualization of Equation 5 with depth of cut of 0.1 mm and 0.2 mm

SUMMARY

The analysis of the machined surface roughness and shape accuracy is important in finishing procedures. We studied the surface straightness and roughness of tangentially turned outer cylindrical hardened surfaces at different cutting speeds, feeds and depth of cuts. Equations for the calculation of given roughness, waviness and straightness parameters were determined using the Design of Experiments method. In our analysis we determined in detail the alteration of R_a, W_a and *STRt* parameters. The advantage of the application of high feed and cutting speed is shown as well as the increasing effect on the shape error of the depth of cut. In the end of our preliminary study, we determined our further goals in the analysis of tangential turning

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References: **1.** *Kovács, Gy.*: Optimization of structural elements of transport vehicles in order to reduce weight and fuel consumption. STRUCTURAL ENGINEERING AND MECHANICS 71:3 pp. 283-290., 8p. 2019. **2.** *Grewal S.:* Manufacturing process design and costing an integrated approach (1st ed. 2011). Springer London: Imprint: Springer. **3.** *Kundrák, J., Markopoulos, A. P., Makkai, T, Deszpoth, I., Nagy, A.:* Analysis of the Effect of Feed on Chip Size Ratio and Cutting Forces in Face Milling for Various Cutting Speeds. Manufacturing Technology 18/3 pp. 431-438. 2018. **4.** *Kundrák, J., Gyáni, K., Deszpoth, I.:* Precision Hard Turning of External Cylindrical Surfaces by Rotation Procedure. Cutting & Tool in Technological Systems, vol. 77, pp. 108-117, 2011. **5.** *Schreiber, L., Trott, K.:* Verfahren zur drallfreien spanenden Bearbeitung von rotationssymmetrischen Flächen. Patent DE19963897A1, 1999. **6.** *Schneider, J., Schreiber, L.*: Mit dem Tangentialdrehen zu drallfreien Oberflächen. Werkstatt und Betrieb, vol. 6, pp. 40-45, 2002. **7.** *Felho, C., Varga, G.*: Theoretical Roughness Modeling of Hard

Turned Surfaces Considering Tool Wear. Machines. 10(3):188. 2022. **8.** *Fine, L.*: Off centre turning, International Journal of Machine Tool Design and Research. vol. 10, no. 1, pp. 15-24, 1970. **9.** *Nee, A. Y. C., Venkatesh, V. C.:* Form Accuracy of Tangentially Skived Workpieces. CIRP Annals-Manufacturing Tech., vol. 34, no. 1, pp. 121-124, 1985. **10.** *Leichner, T., Franke, V., Sauer, B., Aurich, J. C.:* Investigation of the tribological behavior of radial shaft rings and soft turned shafts under the influence of abrasive particles. Production Engineering, vol. 5, no. 5, p. 531–538, 2011. **11.** *Schubert, A., Zhang, R., Steinert, P.:* Manufacturing of Twist-Free Surfaces by Hard Turning. Procedia CIRP, vol. 7, pp. 294-298, 2013. **12**. *EMAG*: Scroll-Free Turning from EMAG: Fast, Precise, Reliable. EMAG GmbH & Co. KG, [Online]. Available: https://www.emag.com/technologies/scroll-free-turning.html. [Accessed 16. 02. 2021.]. **13.** *Molnar, V.*: Tribological Properties and 3D Topographic Parameters of Hard Turned and Ground Surfaces. Materials.; 15(7):2505, 2022. **14.** *Kundrak, J., Mamalis, AG., Gyani, K., Bana, V.:* Surface layer microhardness changes with high-speed turning of hardened steels. International Journal Of Advanced Manufacturing Technology 53 : 1-4 pp. 105-112. , 8 p. 2011. **15.** *Varga, G., Ferencsik, V.:* Analysis of Surface Microhardness on Diamond Burnished Cylindrical Components. Rezanie I Instrumenty V Tekhnologicheskih Sistemah 90 : 1 pp. 146-152. , 7 p. 2019.

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ПОПЕРЕДНІЙ АНАЛІЗ ТОПОГРАФІЇ ПОВЕРХНІ ПРИ ТАНГЕНЦІЙНОМУ ТОЧІННІ

Анотація. *Різні цілі можуть бути досягнуті дослідниками та інженерами-розробниками шляхом вивчення та коригування виробничих процесів та систем. При обробці зовнішніх циліндричних поверхонь різними методами та варіантами можна отримати поверхні з використанням великих подач. Серед них у цій статті аналізується тангенціальне точіння, де конструкція ріжучого інструменту та кінематика обробки відрізняються від традиційного поздовжнього точіння. Інструмент рухається по дотичній до заготівки, а лінійна ріжуча кромка нахилена до руху подачі (зазвичай 30-60 °). Тангенціальне точіння дозволяє обробляти обертально-симетричні фасонні поверхні з правильним профілем крайки, у тому числі під час виготовлення зовнішніх циліндричних поверхонь. Стійкість інструменту значно вища, ніж при традиційній токарній обробці завдяки іншій геометрії та кінематиці. Зношування інструменту відбувається по всій ріжучій крайці. Дослідження складалося з двох частин: експериментів з різання та визначення рівнянь, що описують аналізований процес. Робота виконувалася на верстаті, здатному виробляти тангенціальний рух подачі, з використанням методів планування експериментів. Після експериментів було проведено необхідні виміри. У цій роботі автори мали намір проаналізувати профілі шорсткості і хвилястості, і навіть помилку прямолінійності, оскільки ці величини добре описують точність циліндричної поверхні. Дослідження показали, що зменшення вдвічі глибини різання не показує жодних змін у профілі шорсткості. Зменшення вдвічі швидкості різання та подачі у досліджуваному діапазоні призводить до різних профілів, а це означає, що на перший план має вийти інший метод формування поверхні. Зміна швидкості подачі показала менш значну зміну шорсткості поверхні. Це спричинено зміною методу генерації слідів інструменту. Вища подача та швидкість різання призводять до меншої хвилястості. За результатами дослідження автори зробили такі висновки: більш висока швидкість подачі та швидкість різання в аналізованому діапазоні призвели до поліпшення шорсткості поверхні та скорочення часу обробки. Глибина різання переважно впливає на точність форми. Слід вивчити інші параметри помилки форми (наприклад, похибка циліндричності). Необхідні подальші експерименти з вищими швидкостями різання та подачею.*

Ключові слова: *планування експериментів; шорсткість поверхні; прямолінійність; тангенційне точіння; хвилястість.*