JOURNAL OF PRODUCTION ENGINEERING VOL. 28, NO. 1
(2025) DOI: 10.24867/JPE-2025-01-026

Original research article

Journal of
Production Engineering

https://jpe.ftn.uns.ac.rs/index.php/jpe
ISSN: 1821-4932 (print), ISSN: 2956-2252 (online)

Form accuracy and cutting forces in turning of X5CrNi18-10 shafts: Investigating the influence of thrust force on roundness deviation under low-feed machining conditions

El Majdoub Wafae 0009-0004-5926-661X, ***Muhammad Hamza Daud*** 0009-0002-7932-2135, ***István Sztankovics**** 0000-0002-1147-7475

University of Miskolc, Institute of Manufacturing Science, H-3515 Mikskolc, Egyetemváros, Hungary

ABSTRACT

In nowadays manufacturing, it is important to respect the tolerances and meet the standards of accuracy. So, this paper tends to investigate the effects of cutting parameters on thrust force and shape deviations during the longitudinal turning of X5CrNi18-10 austenitic stainless steel under wet conditions. The research is done based on experimental setup used to measure cutting forces. There are many parameters representing the shape errors, but the roundness was the focus of this paper. Eight setups were examined by varying the cutting parameters, such as cutting speed, feed and depth of cut in two levels. Four elements of roundness parameters were selected to be analysed (RONt, DFTC, slope and Ecc). Based on experimental and theoretical methods, the graphs were generated with the aim of observing the influence of cutting conditions on the surface quality while using hard machined material and then drawing conclusions of the best cutting parameters selection to optimise the turning process. The study emphasises the importance of controlling the tool deflections and material resistance by optimising the settings. The results of this work give a practical approach to enhance precision and surface quality in turning operations.

ARTICLE INFO

Received: 26 March 2025
Revised: 30 May 2025
Accepted: 13 June 2025

KEYWORDS:
Cutting force;
Roundness;
Design of experiments;
Longitudinal turning;
Shape accuracy.

**Corresponding author's e-mail:*
istvan.sztankovics@uni-miskolc.hu

1. INTRODUCTION

Due to the continued growth of industries like aerospace, medical and automotive. The demand for high-precision parts is increasing. To meet strict tolerances and enhance production accuracy, the manufacturer is obliged to adopt advanced technologies [1, 2].

Turing is widely used in industries to shape cylinders in a desired form. Because of its ability to machine high-quality components in a short time, focusing on customer satisfaction [3]. So, to achieve the accuracy required and optimal results, it is essential to select the right parameters, especially cutting speed, depth of cut and feed, which influence the quality of the surface directly [3, 4].

The ongoing research is done for the purpose of improving machining processes. Besides studying the influence of cutting parameters on the machined part, there is another important factor which plays an essential role in optimising the process by affecting the tool, surface quality and design shape directly. This factor is cutting forces that can be defined as a direct interaction between the tool and the workpiece. Studying these forces can develop new machining strategies to meet the market demands [5]. The material's machinability information can be provided by cutting force measurements, allowing manufacturers to select optimal cutting parameters to avoid the chatter and enhance tool life [6, 7].

In turning operations, the focus is on obtaining parts with dimensional accuracy standards and high surface quality. Many factors influence surface quality, such as workpiece setup, machine tool errors and temperature [8]. Among the mentioned factors, the cutting forces are the most critical that cause deflections in the machine, tools and workpieces, leading to deviation and low-quality parts [9].

Published by the University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia.

The surface quality errors are classified into three mean groups: dimensional errors, geometric errors and surface roughness. These increase from cutting force deflections, thermal effects and machine tool geometry. As a result, it is important to study the relation between cutting conditions, tool wear, cutting force and shape deviation to ensure the surface quality. Many studies reveal that the product quality depends on analysing the workpiece under different cutting conditions and parameters [10,11].
Variations in tool condition and deflection refer to the changes in cutting forces, which makes it necessary to measure forces for precision and the safety of machines. For this reason, a lot of companies make instruments for noting the real-time cutting forces, which are used by advanced systems to observe deflections, tool wear, and vibrations [12].
One of the studies aims to investigate the effects of cutting parameters on shape error parameters. From the obtained results it can be observed that cutting forces and shape error parameters get significant effects while varying feed rate and depth of cut. However, cutting speed had less impact on force but did influence cylindricity at higher speeds. Thus, it is important to choose the correct parameters [13].
Another study focused on how geometric errors get affected by cutting forces in turning. Using Kienzle's equations, they estimated cutting forces and guessed deflections dependent on machine and workpiece data by building a software model. From that, it was noticed that the measured values were more acceptable; however, the simulated results also had reduced errors. The results change with getting closer to more accurate values, which shows the model's capability for upgrading machining precision [14].
Due to the high strength, corrosion resistance, and formability, X5CrNi18-10 is widely used. But these characters raise different problems as well, like burrs, tool wear and high cutting forces. By increasing feed and cutting speed, burrs increase, but lubrication decreases it [15]. One of the conducted studies observed that turning without lubrication results in tool wear because of heating at high speed. Which can be improved by coating tools and lowering the speed. Same investigation stated workpieces hardening as a bigger challenge in machining because of high cutting forces at low feed rates and higher friction and tool wear [16].
Because of low heat conductivity, cutting forces increase due to bad selection of parameters for steel during milling operations. Tools can be preserved by managing cutting speed, feed rate and depth of cut [17]. Similar results have been noticed in turning marine pump shafts made from the same steel [18]. A study was conducted to investigate the material behaviour under cold conditions. The results reveal that due to machining under cold conditions, the material changed from soft austenite into hard martensite by investigating internal deformation and explained the challenges in machining [19].
The aim of this study is to investigate the influence of cutting forces (thrust force) on roundness deviation while varying cutting speed, feed and depth of cut under wet conditions.

2. EXPERIMENTAL CONDITIONS AND METHODS

The study's objective is to look at how cutting factors affected the turning process's cutting force and shape error. To get the craved outcome and finish the study, this research used both the cutting experiment and theoretical evaluation. Three parameters were regulated during the experiment to be considered in the study: the depth of cut (a) varied in two levels (0.5 and 1 mm), the feed (f) varied in two levels (0.08, 0.3 mm/rev), and the cutting speed (v_c) varied in two levels (200, 300 m/min). Table 1 represents the chosen settings.

Table 1 – *Experimental setups and the transformed values.*

Setup	1	2	3	4	5	6	7	8
Selected values of the setup parameters								
$v_c \left[\frac{m}{min}\right]$	200	300	200	300	200	300	200	300
$f \left[\frac{mm}{rev}\right]$	0.08	0.08	0.24	0.24	0.08	0.08	0.24	0.24
$a\,[mm]$	0.5	0.5	0.5	0.5	1	1	1	1
Transformed values of the setup parameters								
$v_c'\,[-]$	-1	1	-1	1	-1	1	-1	1
$f'\,[-]$	-1	-1	1	1	-1	-1	1	1
$a'\,[-]$	-1	-1	-1	-1	1	1	1	1

For the machining workpiece, stainless steel X5CrNi18.10 with a hardness value of 310HV10 was selected. The name cites the chromium-nickel austenitic stainless steel, which is distinguished by the extraordinary resistance to corrosion that the chromium element offers. To test the cutting force in three directions, the workpieces, each with an outside diameter of 50 mm, were split into five equal parts of 30 mm by 5 mm grooves.
To get cutting force data, the equipment listed below was assembled. The experiment was conducted in a lubricated state using a 5% emulsion of "CIKS HKF 420" type coolant oil on a HAAS model ST-20Y-EU lathe. To achieve the substantial condition for machining, the DNMG150604-MF1 CP500 carbide/ceramic with a negative form insert was set up to the DDJNL2525M15 tool holder. This kind of tool can be used to cut a variety of materials rough and hefty.
A dynamometer was mounted on the machine's turret head, and the cutting tool was secured to it with an appropriate tool holder to get the measured data. To convert the electric signals into a proportionate output voltage that could be analysed. The cutting force that was produced was divided into three forces (F_c cutting force, F_p passive force, and F_f feed force) and recorded by attaching three charge amplifiers to a dynamometer. A Talyrond 365 precision measuring device was employed using parameters based on conventional protocols and measurements from prior investigations to obtain all the data, which required shape error measurements. A cylinder with a 22.0 mm axial length per run was measured by taking measurements across nine planes with a 2.75 mm gap between them.

The following parameters were analysed (where the shape errors are defined in the ISO 12180-1 standard):

- F_p – thrust force, part of the cutting force and radial to the workpiece [N]
- σ_{Fp} – standard deviation of the passive force, which is calculated during the constant phase [N]
- *RONt* – Roundness, the minimum radial separation of two cylinders, coaxial with the fitted reference axis [µm]
- *DFTC* – Departure from True Circularity, it is a measure of the radial departure within a user-defined angular window, the maximum radial departure is reported as the DFTC [µm]
- *Slope* – It is a measure of how rapidly the measured profile is changing [µm]
- E_{cc} – Eccentricity is the distance from the reference datum to the center of the fitted reference circle [µm].

Equation 1 illustrates how polynomial equations were developed to compute and depict the parameters under analysis. The variables (v_c, f, and a) and their interactions are included in this equation, and the constants (ki) measure each factor's contribution.

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

The parameters are represented by the function y (v_c, f, a) in this context. These equations quantify and illustrate the impact of cutting speed, feed rate, and depth of cut on the geometric characteristics of machined surfaces. They offer a systematic basis for analysing and optimizing machine processes to achieve targeted dimensional accuracy and surface quality.

Table 2 – *Force and shape error measurement results.*

Setup	1	2	3	4	5	6	7	8
F_p [N]	131.9	95.71	184.4	145.4	138.9	108.43	174.2	222.0
σ_{Fp} [N]	1.90	2.29	8.42	3.43	3.72	2.33	7.10	8.7
RONt [µm]	1.83	1.74	1.93	2.71	1.82	1.29	1.94	3.77
DFTC [µm]	0.97	0.53	0.78	1.10	0.67	0.70	0.85	1.84
Slope [µm]	0.023	0.019	0.027	0.029	0.025	0.018	0.023	0.034
Ecc [µm]	1.02	2.35	3.7	3.76	2.14	1.1	5.18	3.8

3. RESULTS

Several assessments were carried out throughout the assigned research project. To evaluate the variability of cutting parameters in relation with the mean of F_p and standard deviation (σ_{Fp}), the main effects of analysis were plotted. The Total roundness Error (*RONt*) and Departure from True Circularity, *Slope* and Eccentricity are the chosen shape errors parameters that were examined in compliance with the methods described in the previous sections. Table 2 provides a summary of all measured and computed values for these parameters. To start the discussion section, the calculation formulas for the output parameters under investigation, obtained from Equation 1, were also developed. Equation 2 also defines the principal thrust force in the region under study.

$$F_p(v_c, f, a) = \big((10.1a - 5.2)f - 0.7a - 0.001\big)v_c + (-2240a + 1482)f + 170.4a + 90.37 \quad (2)$$

The mathematical representation of the standard deviation of the thrust cutting force is shown in Equation 3.

$$\sigma_{Fp}(v_c, f, a) = ((1.1a - 0.86)f - 0.12a + 0.09)v_c + (-249.7a + 232.8)f + 30.74a - 22.88 \quad (3)$$

The total roundness error is determined by Equation 4.

$$RONt(v_c, f, a) = \big((0.15a - 0.006)f - 0.016a - 0.0013\big)v_c + (-30.68a + 1.71)f + 3.167a + 2.051 \quad (4)$$

The Departure from True Circularity r is calculated by the application of Equation 5.

$$DFTC(v_c, f, a) = \big((-0.02a + 0.057)f + 0.0108a - 0.0136\big)v_c + (8.58a - 14.95) * f - 3.134a + 4.270 \quad (5)$$

The slope is calculated by the application of Equation 6.

$$Slope(v_c, f, a) = ((0.0015a - 0.000354)f - 0.000166a + 8.4 * 10^{-6})v_c + (-0.3708a + 0.127)f + 0.0423a + 0.01583 \quad (6)$$

The Eccentricity is calculated by the application of Equation 7.

$$ECC(v_c, f, a) = \big((0.1163a - 0.1375)f - 0.0567a + 0.048\big)v_c + (-18.8a + 42.02)f + 13.22a - 10.85 \quad (7)$$

4. DISCUSSION

After the research methodologies, tools, measured results, and pertinent equations are presented, the next step concentrates on assessing the data that has been gathered. There are two phases to this analysis:

- Analysis of the Main Effects: The first step looks at how the cutting force and shape error characteristics, like cylindricity, are affected by the cutting parameters, which include feed rate, cutting speed, and depth of cut.
- Analysis of the Surface Diagram: Based on the equations mentioned, a surface plots were proceeded to evaluate and analyse the impact of cutting parameters on measured thrust force and roundness parameters.

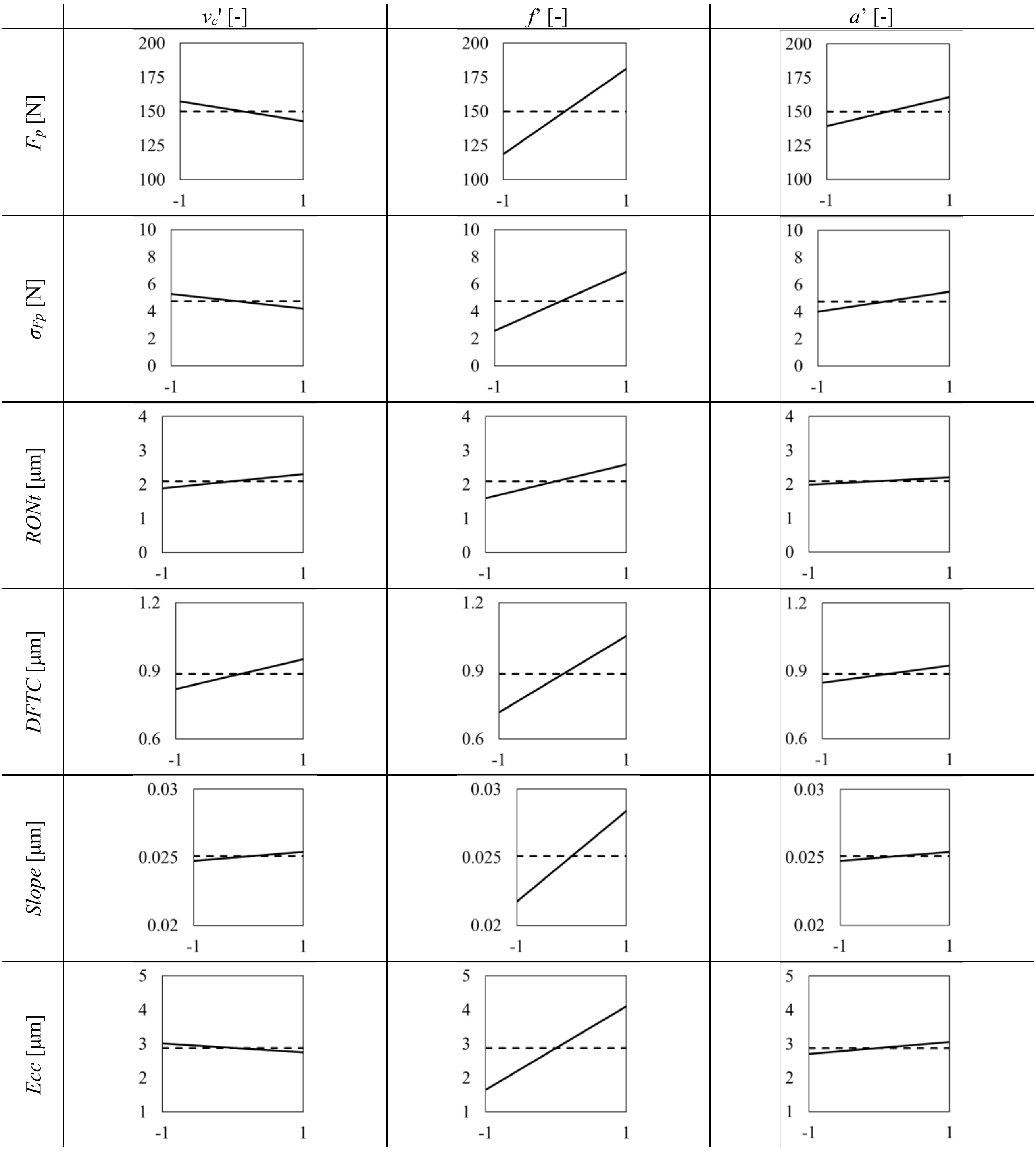


Fig. 1 *Main effect plots of the studied variables.*

4.1 Main effect analysis

The primary effect plots were created with the intention of evaluating the impact of the thrust force and roundness. The plots shown in Fig 1 were used to investigate each parameter independently. Calculating the mean of the average values and representing it as a dashed line is the initial step in the approach used to generate the graphs. Two means were then produced from the three cutting parameters, one in the upper limit (1) and one in the lower limit (-1) that were joined by a continuous or solid line. To optimize the cutting setting for greater precision, the direction and slope demonstrate how the cutting parameters influence the thrust force and roundness.

The first line represents the correlation between thrust force and cutting parameters; the analysis shows increasing the cutting speed decreases the thrust force. In parallel, F_p significantly rises with increasing the feed and depth of cut.

As a result, the feed has the strongest effects in producing higher thrust force. The second line illustrates the standard deviation of thrust force in function of cutting speed, feed and depth of cut. The graphs show that varying the cutting speed from 200 to 300 m/min decreases the force component. However, the standard deviation of thrust forces increased as the feed and depth of cut were raised.

The second part of the main effects analysis is focused on examining the roundness parameters under different cutting conditions. The impacts of cutting speed on the roundness characteristics can be seen in the first column of Fig. 1. While increasing the cutting speed can produce roundness errors, especially in *RONt* and *DFTC*, it can slightly improve the *Ecc.*

Because of the increased material resistance and tool vibrations, the plots show in the second column that the feed can raise the total roundness deviation (*RONt*), *DFTC*, slope and eccentricity *(Ecc).* This can explain that boosting the feed might decrease the precision of the turned part.

At the end, the impact of the depth of cut is examined, and the findings are demonstrated in the graphs in the final column of Fig. 1. The depth of cut has a minimal impact on the roundness parameters. As the depth of cut varied from 0.1 to 0.3 mm, the roundness errors rose.

4.2 Detailed analysis of the technological parameters

To analyze the effects of cutting parameters on the thrust force components and shape error parameters, two surface graphs were generated for each parameter studied to compare the effects of the depth of cut, which varied in two levels (0.5/1.0 mm). Each surface plot with a constant depth of cut represents the effect of the other parameters by varying cutting speed in two levels (200/300 m/min) and feed in two levels as well (0.08/0.24 mm/rev).

Fig. 2 represents the influence of feed rate and cutting speed on the thrust force main (F_p) during a turning operation. In both depths of cut, as the feed increases from 0.08 mm/rev to 0.24 mm/rev, the thrust force increases, which can be explained by requiring more force to remove the material. In parallel, the thrust force reduces at higher speed (300 m/min) due to the heat generation which softens the material and decreases the resistance. However, at a higher depth of cut (1.0 mm), the effects are more noticeable, and the thrust force values are higher. As a result, the feed has the strongest effects on producing resistance.

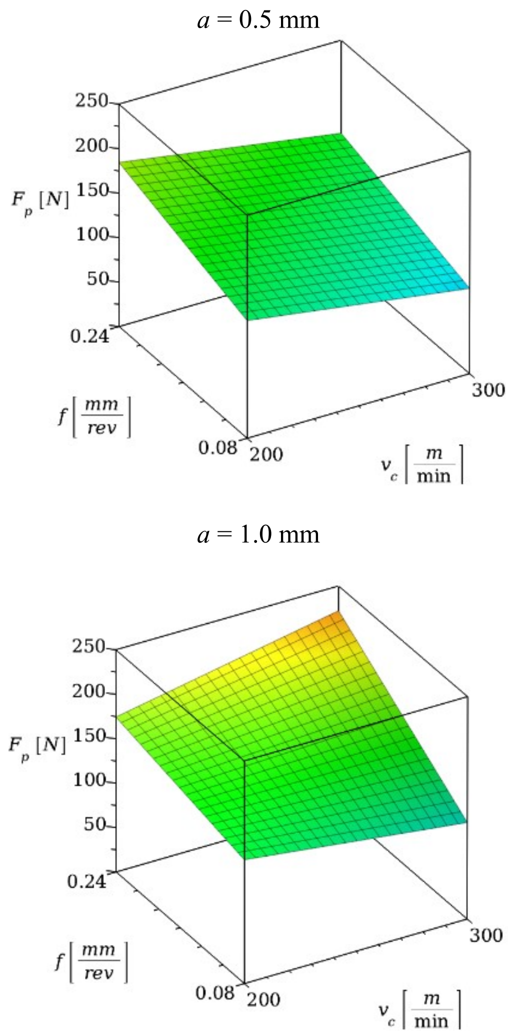


Fig. 2 *The thrust force in function of the studied variables.*

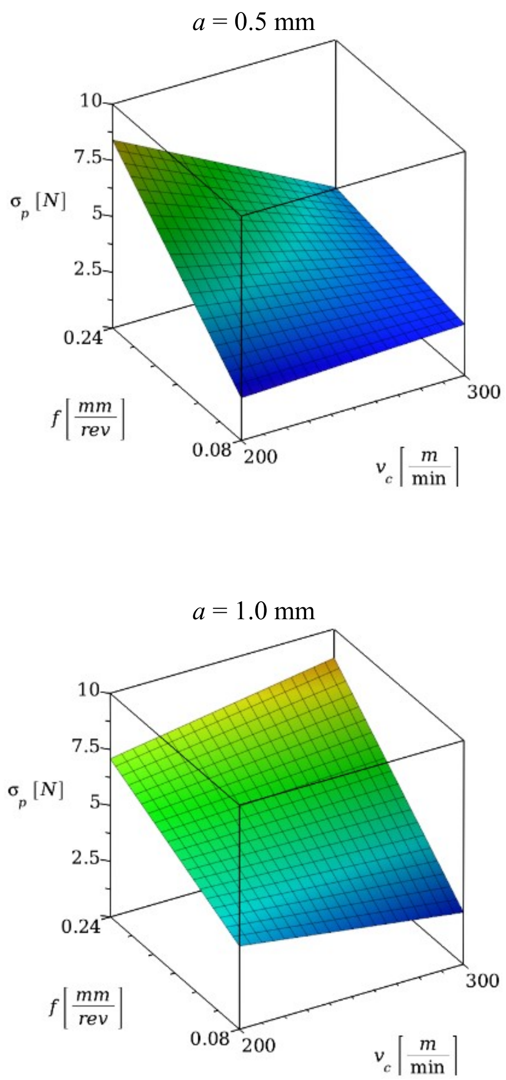
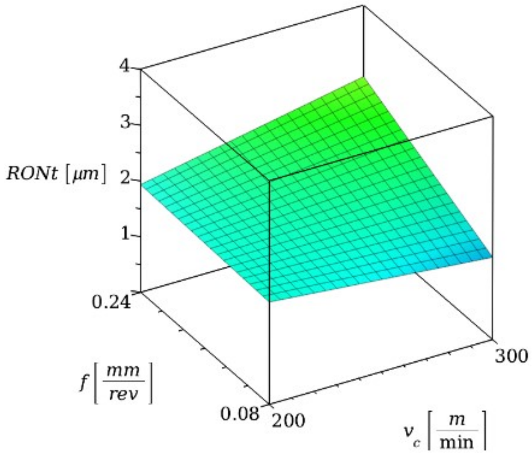


Fig. 3 *The standard deviation of the thrust force in function of the studied variables.*

The change in standard deviation as a function of feed, cutting speed, and depth of cut is shown in Fig. 3. Both plots show a direct relation between the standard deviation of the thrust force σp, feed rate f and cutting speed v_c. In the first plot, σp goes down from about 8.39 N to nearly 2 N as v_c increases from 200 to 300 m/min at the highest feed (0.24 mm/rev), showing strong responsiveness to variation of speed. In parallel, at a higher depth of cut (1.0mm), σ_p decreases slightly at a small feed (0.08mm) and increases at the highest feed (0.24mm) while varying the speed between 200 m/min and 300 m/min, which shows less dependence on v_c. However, the results show the best selection of the cutting parameters can optimize the forces produced.

The plots in Fig. 4 illustrate how the total roundness *RONt* [µm] varies while changing feed rate f [mm/rev] and cutting speed v_c [m/min]. At a depth of cut of 0.5 mm, the roundness error increases from 2µm to almost 3µm while the cutting speed goes from 200 m/min to 300 m/min at a feed of 0.24 mm/rev. However, this change in the roundness is more pronounced in the second plot of 1 mm. The *RONt* increased by 2µm at a higher feed. As a result of bad selection of parameters, the quality of the machined part is affected.

a = 0.5 mm



a = 1.0 mm

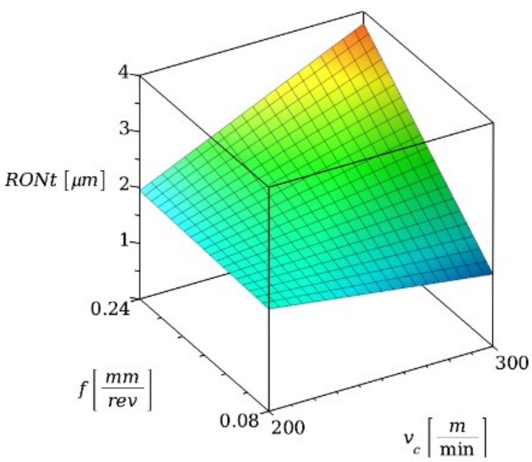
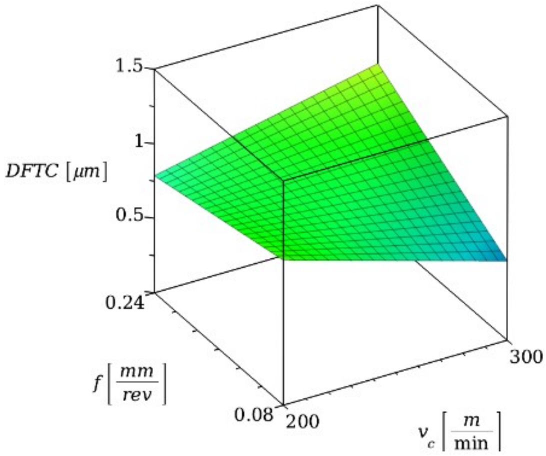


Fig. 4 *The RONt error in function of the studied variables.*

Fig. 5 represents the departure from true circularity in function of the depth of cut, feed and cutting speed. Both plots show the same changes in the studied parameter, but it is more noticeable at 1.0 mm depth of cut, which highlights the role of increasing the depth of cut in producing inaccurate parts. In the second plot, the *DFTC* goes from 0.75 µm to 1.5 µm at 0.24 mm/rev feed while increasing cutting speed. However, at a 0.5 mm depth of cut and 0.08 mm/rev feed, the *DFTC* seems to decrease slightly while varying the cutting speed from 200 m/min to 300 m/min. The analysis gives insight into how the optimal selection of cutting parameters can minimize the shape errors.

a = 0.5 mm



a = 1.0 mm

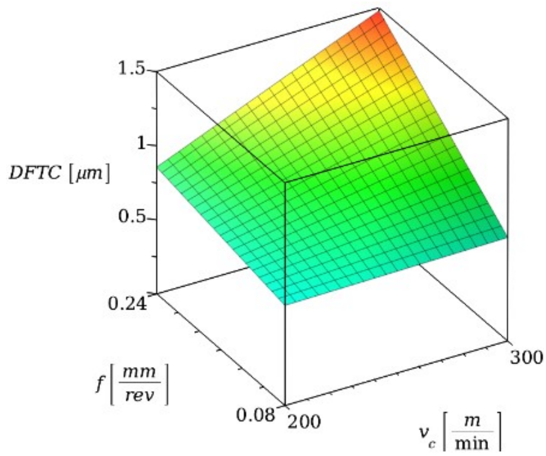
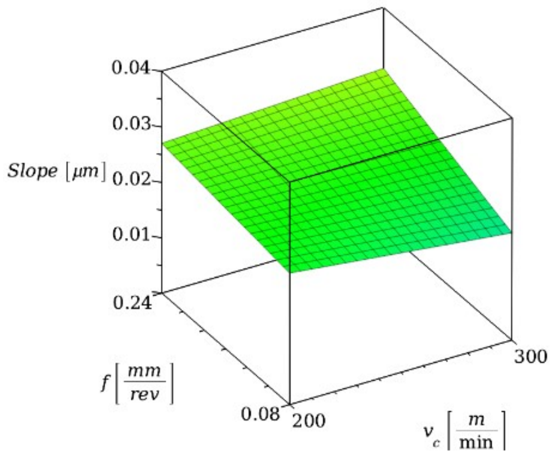


Fig. 5 *The DFTC in function of the studied variables.*

Fig. 6 shows the third parameter of the roundness in function of cutting parameters. The slope in the first plot remains almost constant throughout the cutting speed changes from 200 to 300 m/min and feed from 0.08 to 0.24 mm/rev. The slope tends to increase from 0.023 to 0.037 µm at higher feed and higher cutting speed in the second slope (depth of cut = 1.0 mm). This comparison suggests a bigger impact between feed and cutting speed and depth of cut in impacting surface textures, as the second scenario shows a greater sensitivity of slope to cutting speed.

a = 0.5 mm



a = 1.0 mm

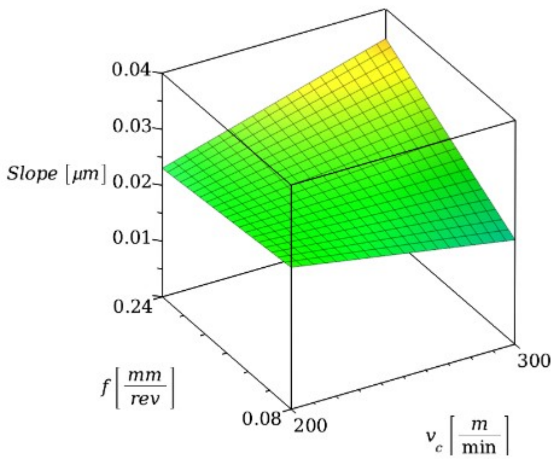


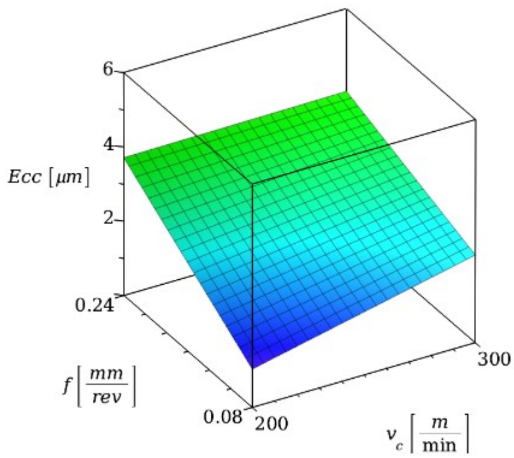
Fig. 6 *The Slope error in function of the studied variables.*

The last parameter of roundness analysis is presented in Fig. 7. Eccentricity has different variations while changing the depth of cut. The first plot shows *Ecc* slightly increases as vc increases, especially at lower feeds of 0.08 mm/rev. On the other hand, *Ecc* rises more speedily as f rises, showing a noticeable dependence on feed. In the second plot of 1mm depth of cut, the influence of feed is kept as in the first plot. However, the eccentricity tends to decrease while increasing the cutting speed in both feeds. These examinations gave a conclusion that using a high cutting speed can decrease eccentricity in certain circumstances. The first plot indicates the feed as a dominant factor affecting eccentricity; however, in the second plot, the cutting speed was highlighted as a controlling factor, depending on the depth of cut values.

5. CONCLUSIONS

The aim of this investigation is to examine thrust force and roundness parameters under different cutting parameters such as depth of cut, feed and cutting speed during the turning of X5CrNi18-10 stainless steel. Then the mean and standard deviation of the thrust force were calculated, as well as the roundness measured, and four components were selected to be studied (RONt, DFTC, Slope and Ecc). To conduct the study and analyse the influence of cutting parameters, the main effect analysis and surface plots were generated based on experimental and theoretical methods. The findings reveal that feed and depth of cut have a significant impact in increasing thrust force and shape deviations, particularly roundness error and eccentricity, while cutting speed has a minimal effect. Due to increasing material resistance and tool deflections, greater errors were observed at higher feed and depth of cut. The results highlight the importance of cutting parameter selection and how it can reduce the thrust force and enhance the machined part quality, providing guidance for improving the turning process and meeting accuracy standards even with hard machined materials.

a = 0.5 mm



a = 1.0 mm

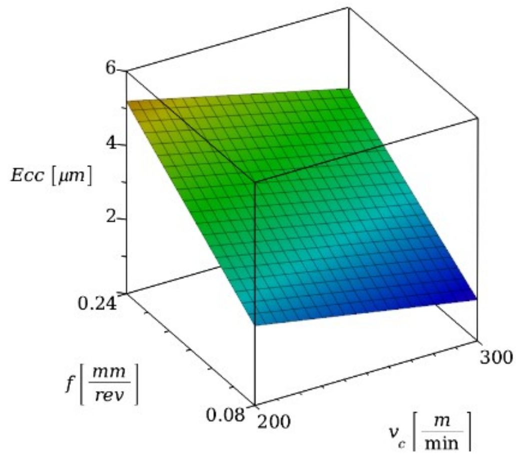


Fig. 7 *The Ecc error in function of the studied variables.*

ACKNOWLEDGEMENTS

This research was supported by project No. 2020-1.2.3-EUREKA-2022-00025 which was realized with financial help of the National Research Development and Innovation Fund of the Ministry of Culture and Innovation of Hungary.

REFERENCES

[1] Harvey, N. - Robotics & Automation News. (2019, August 16), 5 industries that can't do without custom machining, from *roboticsandautomationnews.com/2019/08/16/5-industries-that-cant-do-without-custom-machining/25082/*, accessed on 2018-02-07.

[2] Abas, M., Salah, B., Khalid, Q. S., Hussain, I., Babar, A. R., Nawaz, R., Khan, R., & Saleem, W. (2020). Experimental investigation and statistical evaluation of optimized cutting process parameters and cutting conditions to minimize cutting forces and shape deviations in AL6026-T9. *Materials*, 13(19), 4327, DOI: 10.3390/ma13194327

[3] Santos, M. C., Machado, A. R., Sales, W. F., Barrozo, M. a. S., & Ezugwu, E. O. (2016). Machining of aluminum alloys: a review. *The International Journal of Advanced Manufacturing Technology*, 86(9–12), 3067–3080, DOI: 10.1007/s00170-016-8431-9

[4] Soren, T. R., Kumar, R., Panigrahi, I., Sahoo, A. K., Panda, A., & Das, R. K. (2019). Machinability behavior of Aluminium Alloys: A Brief Study. *Materials Today Proceedings*, 18, 5069–5075, DOI: 10.1016/j.matpr.2019.07.502

[5] Engineering, I. a. F. P., LaperrièRe, L., & Reinhart, G. (2014). *CIRP Encyclopedia of Production Engineering*. In Springer eBooks, DOI: 10.1007/978-3-642-20617-7

[6] Strafford, K., & Audy, J. (1997). Indirect monitoring of machinability in carbon steels by measurement of cutting forces. *Journal of Materials Processing Technology*, 67(1–3), 150–156, DOI: 10.1016/s0924-0136(96)02835-x

[7] Venkatesan, K., Manivannan, K., Devendiran, S., Mathew, A. T., Ghazaly, N. M., Aadhavan, N., & Benny, S. N. (2019). Study of Forces, Surface finish and chip Morphology on Machining of Inconel 825. *Procedia Manufacturing*, 30, 611–618, DOI: 10.1016/j.promfg.2019.02.086

[8] Benardos, P., Mosialos, S., & Vosniakos, G. (2006). Prediction of workpiece elastic deflections under cutting forces in turning. *Robotics and Computer-Integrated Manufacturing*, 22(5–6), 505–514, DOI: 10.1016/j.rcim.2005.12.009

[9] Hesselbach, J. (2011). *Adaptronik für Werkzeugmaschinen: Forschung in Deutschland*. Shaker Verlag. ISBN 978-3-8322-9809-8

[10] Lee, M., & Lee, C. (2011). Development of analysis model for geometric error in turning processes. *Journal of Central South University*, 18(3), 711–717, DOI: 10.1007/s11771-011-0752-0

[11] Chuangwen, X., Jianming, D., Yuzhen, C., Huaiyuan, L., Zhicheng, S., & Jing, X. (2018). The relationships between cutting parameters, tool wear, cutting force and vibration. *Advances in Mechanical Engineering*, 10(1), DOI: 10.1177/1687814017750434

[12] Tlusty, J., & Andrews, G. (1983). A critical review of sensors for unmanned machining. *CIRP Annals*, 32(2), 563–572, DOI: 10.1016/s0007-8506(07)60184-x

[13] Sztankovics, I., & Wafae, E. M. (2024). Preliminary study on the cutting force and shape error in turning of X5CrNi18-10 shafts with small feed. *Journal of Production Engineerin*g, 27(2), 21–28, DOI: 10.24867/jpe-2024-02-021

[14] Denkena, B., Dahlmann, D., Peters, R., & Witt, M. (2017). Model Based Compensation of Geometrical Deviations Due to Process Forces. *Journal of Machine Engineering*, 17(1), 5-16.

[15] Biermann, D., & Steiner, M. (2012). Analysis of Micro BURR formation in austenitic Stainless Steel X5CRNI18-10. *Procedia CIRP*, 3, 97–102, DOI: 10.1016/j.procir.2012.07.018

[16] Jurko, J., Panda, A., Gajdoš, M., & Zaborowski, T. (2011). Verification of Cutting Zone Machinability during the Turning of a New Austenitic Stainless Steel. In *Communications in computer and information science* (pp. 338–345), DOI: 10.1007/978-3-642-22456-0_49

[17] Jurok, D., Brychta, J., & Petru, J. (2015). Experimental Measurements of the Cutting Forces at Milling of Stainless Steels. *Annals of the Faculty of Engineering Hunedoara*, 13(1) 137-140.

[18] Labuda, W. (2018). Finishing treatment of marine pump shafts made of X5CRNI18-10 steel. *Journal of KONES Powertrain and Transport*, 25(2), 215–222, DOI: 10.5604/01.3001.0012.2803

[19] Kurc, A., & Stokłosa, Z. (2010). The effect of ($\gamma \rightarrow \alpha'$) phase transformation on microstructure and properties of austenitic Cr-Ni steels. *Archives of Materials Science and Engineering*, 41, 85–94.