UNIVERSITY OF MISKOLC
FACULTY OF MECHANICAL ENGINEERING AND INFORMATICS

INHOMOGENEITY OF THE TOPOGRAPHY OF SURFACES MACHINED WITH TOOLS WITH GEOMETRICALLY DEFINED CUTTING EDGES

BOOKLET OF PHD THESES

Prepared by:
Antal Nagy
Mechanical Engineer, MSc

ISTVÁN SÁLYI DOCTORAL SCHOOL OF MECHANICAL ENGINEERING SCIENCES
TOPIC FIELD OF ENGINEERING MATERIAL SCIENCE, PRODUCTION SYSTEMS AND PROCESSES
TOPIC GROUP OF MANUFACTURING SYSTEMS AND PROCESSES

Head of Doctoral School:
Prof. Dr. Gabriella Vadászné Bognár
DSc, Full Professor

Head of Topic Group:
Dr. Zsolt Maros
Associate Professor

Scientific Supervisor:
Prof. Dr. János Kundrák
DSc, Professor Emeritus

Miskolc
2025

TABLE OF CONTENTS

NOTATIONS USED IN THE THESIS BOOKLET

a_e [mm] – width of cut (radial depth of cut)
a_p [mm] – depth of cut (axial depth of cut)
b_ε [mm] – tool nose width
CAD – Computer-Aided Design
D_{sz} [mm] – tool nominal diameter
f [mm/tooth] – feed per revolution
f_z [mm/tooth] – feed per tooth
iC [mm] – inscribed circle diameter of the insert
R_a [µm] – arithmetical mean roughness
R_k [µm] – reduced core roughness depth
R_p [µm] – maximum peak height
R_z [µm] – maximum height of the profile
r_ε [mm] – tool nose radius
S_a [µm] – arithmetical mean height of the scale limited surface
S_k [µm] – reduced core roughness depth of the scale limited surface
S_p [µm] – maximum peak height of the scale limited surface
S_z [µm] – maximum height of the scale limited surface
v_c [m/min] – cutting speed
α_o [°] – orthogonal clearance angle
γ_o [°] – orthogonal rake angle
κ_r [°] – principal cutting edge angle
κ_r' [°] – secondary cutting edge angle

1. Scientific background

The first chapter of my dissertation presents the topographical characteristics and inhomogeneity of surfaces machined with tools with geometrically defined cutting edges. Among the machining processes considered, particular emphasis is placed on face milling, for which the surface roughness characteristics are described in detail. Based on the literature review, the aims of the dissertation are identified.

1.1. Topography and inhomogeneity of surfaces machined with tools having defined edge geometry

In the manufacturing process, the components of mechanical engineering products are produced with the required accuracy and surface quality in order to meet the specified structural, functional, and other performance requirements during their intended service life [1]. The proper formation of the geometrical characteristics of their surfaces plays a key role in achieving these requirements [2]. Surface topography comprises features of various scales, including macro- and micro-geometrical elements such as form and waviness deviations, as well as surface roughness irregularities [3].

Accuracy and surface quality requirements can be fulfilled through machining processes, among which cutting is prominent, offering precise, efficient, and versatile solutions [4] [5]. In this process, a tool removes material from the workpiece, resulting in the formation of one or more newly machined surfaces. As a result, the cutting edge(s) impart a characteristic texture to the surface [6].

Machining processes using tools with geometrically defined cutting edges typically produce periodic surface topography – regular, directionally repeating tool marks – formed by the cutting edge(s) of the tool. Depending on the relative motions between the tool and the workpiece, various patterns are generated on the machined surfaces, which can be classified into six basic lay types [3]. This classification is based on the analysis of theoretical surface topography, determined by the geometry of the cutting edge in the tool reference plane, the kinematic relations between the tool and the workpiece, and the feed rate. In the case of surfaces having parallel or perpendicular lay (e.g. produced by turning, drilling, peripheral milling, or planing), as well as circular lay (e.g., face-turned), the surface texture and roughness values measured in a given direction remain consistent across different areas. However, on surfaces having crossed lay (machined with e.g., planing, shaping, or turning with two different cutting directions), multidirectional lay (e.g., face-milled or sawed with rotary tools), or radial lay (e.g., planed or shaped with circular feed), the theoretical height of topographical elements varies across the surface, and the roughness values measured in a given direction differ significantly.

The topography of a surface machined with a tool with geometrically defined cutting edge is considered inhomogeneous if the theoretical roughness values vary at successive measurement locations within a cutting mark formed during a single cutting period.

Among the machining processes considered, face milling is highlighted and the characteristics of its surface topography and inhomogeneity are presented in detail. The surface texture consists of cycloidal curves shifted in the feed direction. As a result, milling marks repeat regularly in this direction [7], and the plane defined by the tool axis and the feed rate vector is considered the symmetry plane (Figure 1, section A–A). On both sides of this plane, the radial width and height of the tool marks decrease, and the radial distance between adjacent grooves also decreases (Figure 1a). Due to the cycloidal tool marks, the surface texture is asymmetric relative to the symmetry plane. However, this asymmetry is typically negligible when the applied feed value is significantly smaller than the tool diameter ($D_{sz} >> f$). Therefore, the theoretical roughness values at measurement locations equidistant from the symmetry plane in opposite directions are nearly identical, differing only slightly [8].

In face milling, it may occur – due to the relative motion conditions and the perpendicular orientation of the tool axis and the machined surface – that the cutting edges engage the surface twice during a single revolution of the tool: first during the front-cutting motion [9], and again during the back-cutting motion within the continued feed movement. In such cases, the crossing cycloidal tool paths intersect, resulting in a surface texture composed of diamond-shaped protrusions. These features become progressively lower in height as the distance from the symmetry plane increases, although their width – measured in the feed direction – remains constant (Figure 1b) [10]. While the periodic nature of the topography with double milling marks is preserved in the feed direction, measurements taken at different locations (and in different directions) yield significantly varying profiles and measured areas (see profiles in sections X–X and Y–Y in Figure 2) [7]. Due to secondary material removal, lower roughness height values are observed in the topography [8]. The extent of this reduction depends on the specific characteristics of the intersection between the front- and back-cutting traces.

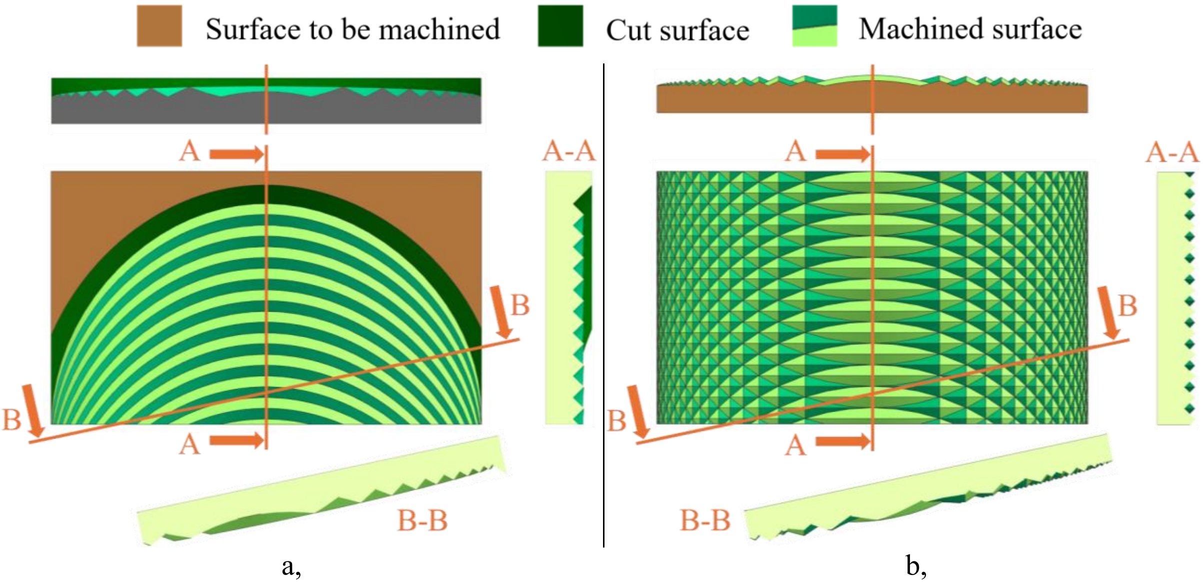


Figure 1 Theoretical face-milled topography with single (a) and double (b) cutting marks (A–A: symmetry plane)

Based on all of the above, it can be concluded that face-milled surface topography is complex, and its roughness may vary significantly depending on the specific locations examined [8] [9] [11]. The characteristics of such inhomogeneous topographies can only be comprehensively assessed through measurements performed at multiple, deliberately selected locations. However, both the Hungarian and international literature offers relatively few publications that provide a thorough analysis of face-milled surface topography. Chuchala et al. measured five areas on milled surfaces: one in the symmetry plane and two mirrored locations on either side. They compared roughness results across these surface elements, considering the direction of tool–workpiece relative motion – up-milled region, down-milled region and near the symmetry plane [12]. Varga and Kundrák took into account the kinematic conditions and the resulting differences in topographical regions formed by the cutting movement of the face milling tool edge. Their analysis involved measurements for a 5×5 grid of locations across the surface [13]. They found, in agreement with Zhenyu et al. [14], that the maximum roughness values occur in the symmetry plane and gradually decrease in parallel measurement planes further from it. Correspondingly, the peak height of the roughness profiles also decreased in those regions. Furthermore, higher roughness values were observed on the up-milled side/part of the surface. Felhő and Kundrák investigated both the theoretical and measured roughness of surfaces milled with increasing feeds, assessing in three parallel planes: the symmetry plane and two others at equal distances on either side [15]. They highlighted that roughness values differ across various regions of the topography, with the differences becoming more significant at higher feeds.

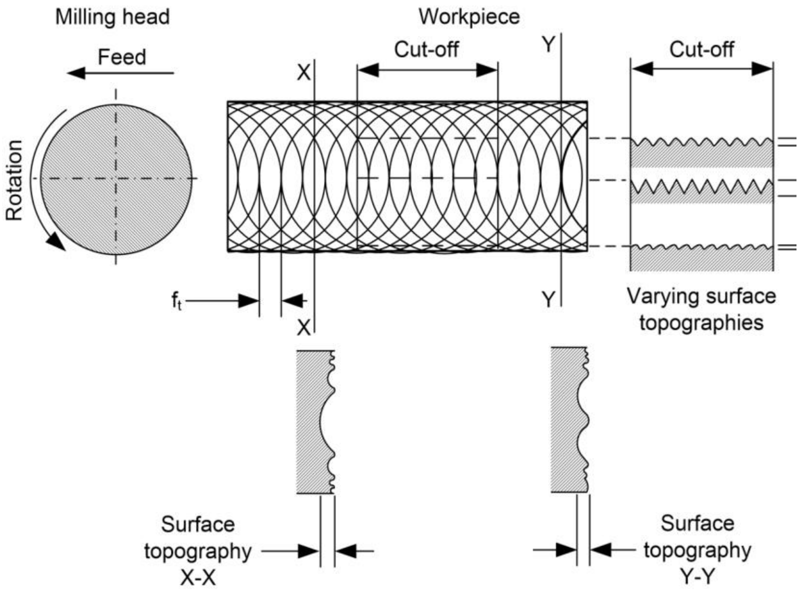


Figure 2 Profiles recorded at different locations and directions on a face-milled surface with double milling marks [7]

In summary, it can be stated that the regularity of roughness variation has not been comprehensively determined, yet it can significantly influence the functional properties of mated surfaces. Therefore, the aim of this dissertation is to investigate the inhomogeneity of machined surfaces and to reveal their characteristic features.

1.2. Aims of the Dissertation

The aim of my research is the theoretical and experimental investigation of the topography and roughness variation of surfaces machined with geometrically defined cutting edge tools, with a focus on revealing the magnitude, characteristics, and correlations of their inhomogeneity. The research has been carried out in the following steps:

- A theoretical overview of the topographies of surfaces produced with geometrically defined cutting edge tools, including analysis of their texture.
- Classification of machined surface topographies based on the type of lay, and identification of machining methods that generate inhomogeneous topographies. Selection of the process expected to produce significant roughness variation on the finished surface.
- Presentation and theoretical characterization of the inhomogeneity of surface topographies produced by the selected process, face milling. Demonstration of the effects of investigated parameters.
- Determination of topographical parameter(s) best expressing the inhomogeneity based on the greatest variation and relative distribution characteristics of values.
- Investigation of the effects of tool and workpiece motions on surface texture and roughness variation. Theoretical and experimental comparative analysis of the inhomogeneity of face-milled topographies with single and double milling marks, considering kinematic conditions and tool edge geometry; revealing their magnitude

and nature. Assessment of the influence of measurement direction on the values of the investigated topographical parameters.

- Examination of the influence of milling tool and workpiece geometry on the degree and nature of inhomogeneity on face-milled topographies, establishing correlations. Comparative analysis of topographies produced with different tool edge geometries, determining and ranking their inhomogeneity.
- Analysis of the roughness inhomogeneity of the studied surfaces in response to changes in feed per tooth and cutting speed.
- Evaluation of the effects of measurement setup on the magnitude of inhomogeneity, including the number and distribution of measurement locations on the surface. Based on the results, establishment of a roughness measurement strategy for face milling that accounts for the process-specific characteristics.

Figure 3 shows the research steps of the investigation into topographical inhomogeneity. The expected outcome is the determination of the characteristics of inhomogeneity on surfaces produced by the examined machining process, as well as the correlations between the selected cutting parameters, tool and workpiece geometry, and roughness variations. This will allow the design and manufacturing of components that better meet the functional requirements of the machined surfaces.

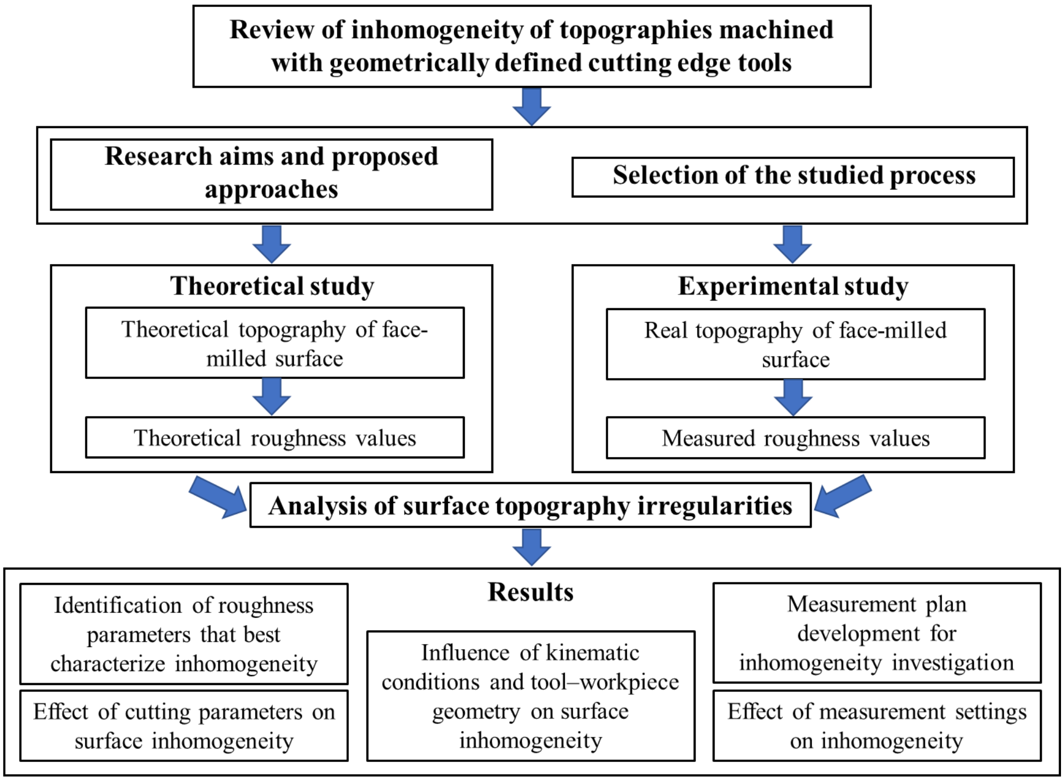


Figure 3 Steps of the research work

1.3. Research Tasks

To investigate the topographical inhomogeneity of face-milled surfaces, experiments were carried out using the machine and device park at the Institute of Manufacturing Science, University of Miskolc. Initially, preliminary experiments were carried outto select the roughness parameters to be analyzed for the study of topographical inhomogeneity. Subsequently, surfaces were machined using the chosen cutting parameters, followed by 2D and 3D roughness measurements. The following sections present the experimental conditions, the equipment used for roughness measurement, and the measurement procedure.

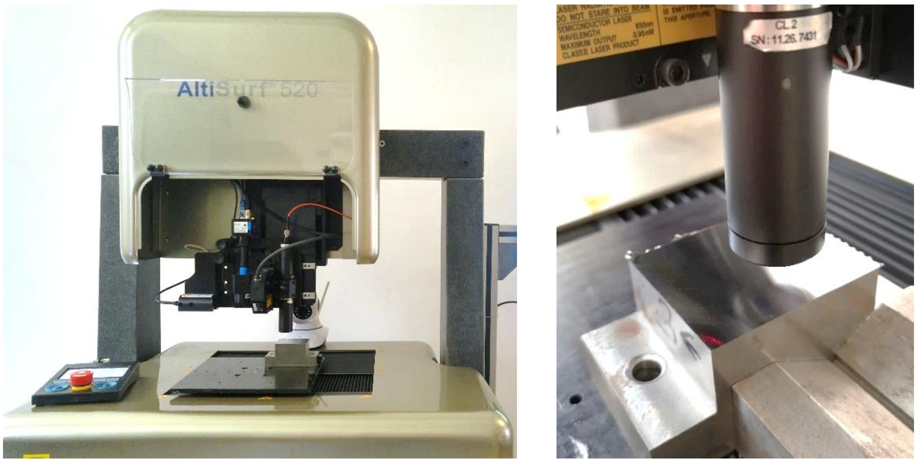
1.3.1. Experimental conditions

The machining was carried out on a PerfectJet MCV-M8 vertical CNC milling machine. Plane surfaces were milled on normalized C45 grade unalloyed steel (1.0503) workpieces with widths of 58 mm and 100 mm and a length of 50 mm. Face milling was performed without coolant or lubrication. In the experiments, tools with four different insert geometries and various nominal diameters were used. Each milling head was equipped with a single insert, ensuring that tool edge runout did not influence the formation of the surface topographies. The surfaces were machined using new, sharp tool edges during the experiments. The set cutting data (cutting speed, feed per tooth, axial and radial depth of cut) were adjusted based on designated baseline values. When analyzing the effect of the examined parameter, both lower and higher values differing by the same magnitude from the baseline were applied. The investigated ranges of the cutting parameters were: v_c = 200 – 400 m/min, f_z = 0.2 – 0.6 mm/tooth, a_p = 0.4 mm, a_e = 31.5 – 100 mm.

During machining, the symmetry plane of the milled surfaces as well as one edge on each side were aligned perpendicular to the tool axis. Additionally, the feed length of the workpiece determined the formed tool marks. Approaching the tool and feeding it until the tool axis coincided with the symmetry point of the machined surface produced single, front-cutting tool marks, while the subsequent feed motion – where the edge also scratched the surface during back-cutting – generated double milling marks.

1.3.2. Surface roughness measurement conditions

Surface roughness measurements on the machined surfaces were performed using an AltiSurf 520 three-dimensional surface topography measurement device (Fig. 4a). A CL2 confocal chromatic sensor equipped with an MG140 magnifier was used (Fig. 4b). The measurements were evaluated with the AltiMap Premium software, version 6.2.



a b

Figure 4 The topography measurement device (a), a workpiece with the roughness measurement sensor (b)

During the measurements and evaluations, the ISO 4287 [16], ISO 4288 [17] and ISO 25178 [18] standards were considered and strictly followed. For deviation analysis, measurement locations were taken on the surfaces in the symmetry plane as well as on parallel measurement planes at equal distances from it, or in directions at specified angles to the symmetry plane. For the 2D roughness measurements and evaluations, an evaluation length of 4 mm was set for feed per tooth (f_z) between 0.2 and 0.4 mm/rev, and 12.5 mm was set for f_z = 0.6 mm/rev, with corresponding cut-off lengths of 0.8 mm and 2.5 mm, respectively. For the 3D topography analysis, surface areas of 4 mm × 4 mm were evaluated at the designated measurement locations, applying a cut-off length of 0.8 mm.

1.3.3. Method and procedure of theoretical investigations

For the theoretical investigation, I based my work on the research of Felhő. He considered the theoretical roughness as a basis, using a CAD model he developed [19], which is determined solely by the tool edge geometry and the kinematic conditions [20]. With this, he analytically established the theoretical values of roughness parameters for milled topographies [19]. At the same time, he developed the possibility for estimating and designing desired roughness values [9]. In collaboration with Kundrák, he pointed out that different roughness values occur on the surface in various directions and locations due to the kinematic conditions [15]. They described the differences and correlations between the theoretical 2D and 3D parameters and the actual measured roughness values in machining with geometrically defined cutting edge tools [9].

I examined the theoretical topographies of surfaces machined with the baseline cutting parameters. I created CAD models of these surfaces, taking into account the projection of the tool edge on the reference plane, the kinematic conditions of the tool and the workpiece – i.e. the cycloidal path of the tool edge – and the magnitude of the feed. The roughness of the topographical models was evaluated using the driver/software developed by Felhő [20], with the values of the designated roughness parameters. I determined several theoretical characteristics of the examined topographies: the nature of roughness variation, as well as the values of the analyzed roughness parameters and their spatial variations.

2. New scientific results, possibilities of application

Face milling is often used in industry as a finishing process for high-productivity machining of plane surfaces. Nevertheless, the variation of the surface topography is in most cases not considered, which can affect its functional properties. In my research, I addressed the questions related to surface inhomogeneity that have not yet been sufficiently determined, as outlined in the aims. The key conclusions drawn from these are summarized in the following theses.

2.1. Theses

T1. The concept of inhomogeneity is defined. Based on the relative motion and positioning between the tool and the workpiece, material removal processes using tools with geometrically defined cutting edges that result in inhomogeneous surface topography are identified. Regarding this, a measurement plan for analyzing the inhomogeneity of face-milled surface topographies is developed. [N12, N14, N17]

(Applied tool: an OFEX 05T3AE octagonal cutting insert in a Tungaloy T2845 PM 063.05Z5W tool, D_{sz} = 63 mm, κ_r = 45°, γ_o = 25°, α_o = 7°, r_ε = 0.4 mm. New edges for each surface. Set cutting data: f_z = 0.4 mm/tooth, v_c = 300 m/min, a_p = 0.4 mm, a_e = 63 mm. Studied roughness parameters: R_a, R_z, R_p, R_k, S_a, S_z, S_p, S_k.)

T2. On surfaces face-milled with single cutting marks, the roughness differences between symmetrical measurement locations relative to the symmetry plane remain minor (within 20%). On up-milled surfaces the range of measured values reaches up to 61%, which is nearly identical to that found on down-milled surfaces, and is even higher (a maximum of 78%) on surfaces machined with a symmetrical setup. Among the measurement planes oriented in the direction of feed, the differences in the symmetry plane are smaller (up to 20.5%) than in any other parallel measurement plane, where the range of values can reach up to 41% for amplitude parameters R_a, R_z, R_p and S_a, S_z, S_p, while for functional parameters R_k and S_k, they can be as high as 53%. [N18, N19]

(Applied tools: an SEKN 1203 AFTN square cutting insert in a Canela 074890063 tool, D_{sz} = 63 mm, κ_r = 45°, γ_o = 0°; α_o = 20°; b_ε = 0.85 × 45°; a RCKX 1606-MO-TR round cutting insert in an ATORN 10612120 tool, D_{sz} = 80 mm, iC = 16 mm, γ_o = 23°, α_o = 7°. New edges for each surface. Workpiece material: normalized C45 steel, 180 HB. Set cutting data: f_z = 0.2 mm/tooth, 0.4 mm/tooth, v_c = 300 m/min, a_p = 0.4 mm, a_e = 31.5 mm, 58 mm. Studied roughness parameters: R_a, R_z, R_p, R_k, S_a, S_z, S_p, S_k.)

T3. On surfaces face-milled with double milling marks, the values of roughness parameters decreased by 15–40% due to secondary material removal; however, the differences between them increased. The variation range of both amplitude parameters (R_a, R_z, R_p and S_a, S_z, S_p) and functional parameters (R_k and S_k) is significant in measurement planes oriented in the feed direction (up to 75% and 99%, respectively), as well as between values measured in different planes (up to 104% and 119%, respectively). [N11, N20, N25, N28]

(Applied tools:an SEKN 1203 AFTN square cutting insert in a Canela 074890063 tool, D_{sz} = 63 mm, κ_r = 45°, γ_o = 0°; α_o = 20°; b_ε = 0.85 × 45°; an RCKX 1606-MO-TR round cutting insert in an ATORN 10612120 tool, D_{sz} = 80 mm, iC = 16 mm, γ_o = 23°, α_o = 7°. New edges for each surface. Workpiece material: normalized C45 steel, 180 HB. Set cutting data: f_z = 0.2 mm/tooth, 0.4 mm/tooth, v_c = 200 m/min, 300 m/min, a_p = 0.4 mm, a_e = 58 mm. Studied roughness parameters: R_a, R_z, R_p, R_k, S_a, S_z, S_p, S_k.)

T4. On surfaces generated by face milling with single tool marks, the variation in 2D roughness values measured in directions inclined to the feed direction is minor (below 12%) up to an angle of 30°. At higher angles, up to 90°, the variation becomes significant – reaching up to 108% for amplitude parameters (R_a, R_z, R_p and S_a, S_z, S_p), and up to 126% for functional parameters (R_k and S_k). Surface values representative of the entire area can be obtained by using multiple offset parallel measurement planes aligned at an angle to the feed direction. The change in measurement direction has no influence on the 3D surface roughness characteristics of the topography. [N15, N21, N22, N24]

(Applied tool: an OCKX 0606-AD-TR octagonal cutting insert in an ATORN 10612120 tool, D_{sz} = 80 mm, κ_r = 43°, γ_o = 25°, α_o = 7°, r_ε = 0.5 mm. New edges for each surface. Workpiece material: normalized C45 steel, 180 HB. Set cutting data: f_z = 0.4 mm/tooth, v_c = 300 m/min, a_p = 0.4 mm, a_e = 58 mm. Studied roughness parameters: R_a, R_z, R_p, R_k, S_a, S_z, S_p, S_k.)

T5. The geometrical characteristics of the tool and the workpiece influence topography inhomogeneity as follows:

- Increasing the diameter of the milling tool – for surfaces of the same size – reduced the variation/range in roughness values from a maximum of 70% to 19%. However, at a constant engagement angle, the variation remains below 20%.
- Increasing the width of cut – without changing any other cutting or measurement parameters – resulted in nearly identical level of inhomogeneity.
- Face-milled surfaces produced with tools having different edge geometries were ranked based on the degree of inhomogeneity. In increasing order: parallelogram-shaped (24–32%), octagonal (38–51%), square-shaped with facet (37–74%), and round insert tools (31–73%). [N10]

(Applied tools: an RCKX 1606-MO-TR round cutting insert in an ATORN 10612120 tool, D_{sz} = 80 mm, iC = 16 mm, γ_o = 23°, α_o = 7°; an OFEX 05T3AE octagonal cutting insert in a Tungaloy T2845 PM 050.05Z4, T2845 PM 063.05Z5W or T2845 PM 100.05Z8 tool, D_{sz} = 50 mm, 63 mm, 100 mm, κ_r = 45°, γ_o = 25°, α_o = 7°, r_ε = 0.4 mm; an R215.44-15T308M-WL parallelogram-shaped cutting insert in a Sandvik R252.44-080027-15M tool, κ_r = 90°, κ_r' = 3°, γ_o = 0°, α_o = 11°, r_ε = 0.8 mm; an SEKN 1203 AFTN square cutting insert in a Canela 074890063 tool, D_{sz} = 63 mm, κ_r = 45°, γ_o = 0°, α_o = 20°, b_ε = 0.85 × 45°. New edges for each surface. Workpiece material: normalized C45 steel, 180 HB. Set cutting data: f_z = 0.4 mm/tooth, v_c = 300 m/min, a_p = 0.4 mm, a_e = 50 mm, 58 mm, 63 mm, 100 mm, $\varphi_1 = \varphi_2$ = 30°, 60°, 90°. Studied roughness parameters: R_a, R_z, R_p, R_k.)

T6. Changing the values of feed and cutting speed within the investigated ranges has a significant impact on the inhomogeneity of the surface topography. Increasing the feed per tooth caused the inhomogeneity of the face-milled surface to rise from 51% to 108% for amplitude parameters R_a, R_z, R_p and S_a, S_z, S_p, and from 49% to 75% for functional parameters R_k and S_k. Increasing the cutting speed, on the other hand, reduced the degree of topography inhomogeneity from 77% to 51% for amplitude parameters, while for functional parameters the variation fluctuated up to 67%. [N6, N8, N9, N13]

(Applied tools: an SEKN 1203 AFTN square cutting insert in a Canela 074890063 tool, D_{sz} = 63 mm, κ_r = 45°, γ_o = 0°; α_o = 20°; b_ε = 0.85 × 45°; an RCKX 1606-MO-TR round cutting insert in a ATORN 10612120 tool, D_{sz} = 80 mm, iC = 16 mm, γ_o = 23°, α_o = 7°. New edges for each surface. Workpiece material: normalized C45 steel, 180 HB. Set cutting data: f_z = 0.2 mm/tooth, 0.4 mm/tooth, 0.6 mm/tooth, v_c = 200 m/min, 300 m/min, 400 m/min, a_p = 0.4 mm, a_e = 58 mm. Studied roughness parameters: R_a, R_z, R_p, R_k.)

2.2. Possibilities of applications and further development

By applying the investigation method presented in the dissertation, the surface topographical characteristics can be described in greater detail than previous research results, and their inhomogeneity can be specified more precisely based on the analyzed roughness parameters. Consequently, components can be designed and manufactured to better meet the functional requirements of the machined surfaces. This is especially significant given the continuously increasing number of precision components produced.

The results of the dissertation can be further developed in several directions. For example, the topographical characteristics of the face-milled surfaces – such as the variation in the height and radial width of the tool marks, as well as the distinctive features of the tool mark intersections – can be explored in more detail, and a database can be created to support the planning of machining. Additionally, I intend to investigate the effects of machining parameters not covered in this dissertation, such as the use of cutting fluids, spindle tilting, and stepover, on surface inhomogeneity.

In the next phase of the research, I plan to investigate the closer relationship between surface inhomogeneity and functional parameters, including tribological tests. Furthermore, I intend to characterize topographies created with more complex tool geometries (e.g., end milling, ball-end milling) and to extend the analysis method to other machining processes using tools with geometrically defined cutting edge.

Publications related to the dissertation topic

[N1] J. Kundrak, T. Makkai, I. Deszpoth, A. Nagy, "Investigation of cutting force in face milling," *Cutting & Tools in Technological System,* vol. 87, pp. 118-125, 2017.

[N2] J. Kundrak, Gy. Varga, A. Nagy, T. Makkai, "Examination of 2D and 3D surface roughness parameters of face milled aluminium surfaces," *Cutting & Tools in Technological System*, vol. 88, pp. 94-100, 2018.

[N3] J. Kundrak, A.P. Markopoulos, T. Makkai, I. Deszpoth, A. Nagy, "Analysis of the effect of feed on chip size ratio and cutting forces in face milling for various cutting speeds," *Manufacturing Technology*, vol. 18, no. 3, pp. 431-438, 2018. (Scopus, Q2)

[N4] J. Kundrak, A.P. Markopoulos, T. Makkai, A. Nagy, "Theoretical and experimental analysis of the effect of chip size ratio on cutting forces in face milling of steel," *International Journal of Mechanical Engineering,* vol. 3, pp. 29-35, 2018.

[N5] J. Kundrak, A.P. Markopoulos, T. Makkai, A. Nagy, "Correlation between chip ratio and specific forces with increasing feed per tooth and cutting speed in face milling of steel," *WSEAS Transactions of Environment and Development*, vol. 14, pp. 338-346, 2018. (Scopus, Q4)

[N6] A. Nagy, J. Kundrak, "Effect of cutting speed on surface roughness: face milling of steel with a parallelogram insert," in *MultiScience - XXXIII. microCAD International Multidisciplinary Scientific Conference*, Miskolc-Egyetemváros, Magyarország, Miskolci Egyetem, 2019, p. D1-4.

[N7] J. Kundrak, A.P. Markopoulos, T. Makkai, N.E. Karkalos, A. Nagy, "Multi-objective optimization study in face milling of steel," in *ISPR 2018, Proceedings of the International Symposium for Production Research 2018,* Springer, 2019, pp. 3-15.

[N8] A. Nagy, J. Kundrak, "Investigation of surface roughness characteristics of face milling," *Cutting & Tools in Technological System,* vol. 90, pp. 63-72, 2019.

[N9] J. Kundrak, A. Nagy, A.P. Markopoulos, N.E. Karkalos, "Investigation of surface roughness on face milled parts with round insert in planes parallel to the feed at various cutting speeds," *Cutting & Tools in Technological System,* vol. 91, pp. 87-96, 2019.

[N10] C. Felhő, A. Nagy, J. Kundrak, "Effect of shape of cutting edge on face milled surface topography," in *Proceedings of the International Symposium for Production Research 2019*, Springer International Publishing, 2020, pp. 525-534.

[N11] A. Nagy, J. Kundrak, "Changes in the values of the roughness parameters on the face milled steel surface," *Cutting & Tools in Technological System,* vol. 92, pp. 85-95, 2020.

[N12] A. Nagy, "Influence of measurement settings on areal roughness with confocal chromatic sensor on face-milled surface", *Cutting & Tools in Technological System,* vol. 93, pp. 65-75, 2020.

[N13] J. Kundrak, A. Nagy, A.P. Markopoulos, N.E. Karkalos, D. Skondras-Giousios, "Experimental study on surface roughness of face milled parts with round insert at various feed rates," *Cutting & Tools in Technological System,* vol. 92, pp. 96-106, 2020.

[N14] A. Nagy, "Investigation of the effect of areal roughness measurement length on face milled surface topographies," *Cutting & Tools in Technological System,* vol. 94, pp. 60-69, 2021.

[N15] A. Nagy, J. Kundrak, "Analysis of the change in roughness on a face-milled surface measured every 45° direction to the feed," *Cutting & Tools in Technological System,* vol. 95, pp. 29-36, 2021.

[N16] A. Nagy, "Homlokmarással előállított síkfelületek érdességi és inhomogenitási vizsgálata" (Roughness and inhomogeneity analysis of plane surfaces machined by face milling), *Multidiszciplináris tudományok*, vol. 11, no. 2, pp. 207-212, 2021.

[N17] A. Nagy, J. Kundrak, "Mérési beállítások hatása a topográfia mért értékeire homlokmart felületen" (Effect of measurement settings on roughness values of face-milled topography), *Multidiszciplináris Tudományok,* vol. 12, no. 5, pp. 54-65, 2022.

[N18] J. Kundrak, C. Felhő, A. Nagy, "Analysis and prediction of roughness of face milled surfaces using CAD model," *Manufacturing Technology,* vol. 22, no. 5, pp. 558-572, 2022. (Scopus, Q3)

[N19] A. Nagy, J. Kundrak, "Analysis of inhomogeneity of surfaces milled with symmetrical, down- and up-milling settings," in *Development in Machining Technology – Scientific Reports vol. 10,* Cracow University of Technology, 2022, pp. 51-62.

[N20] A. Nagy, J. Kundrak, "Roughness investigation of single and double cutting marks on face milled surface, *Cutting & Tools in Technological System,* vol. 99, pp. 58-70, 2023.

[N21] A. Nagy, J. Kundrak, "Investigation of change in roughness in parallel sections in a direction different from feed vector on a face milled surface. in *Development in Machining Technology – Scientific Reports vol. 11,* Cracow University of Technology, 2023, pp. 67-79.

[N22] A. Nagy, J. Kundrak, "Investigation of face milled surface topography on C45 workpiece assuming movement at 30° and 60° to feed direction," *Cutting & Tools in Technological System,* vol. 98, pp. 116-127, 2023.

[N23] A. Nagy, "Egyszeres és kettős marónyommal előállított homlokmart topográfia ferdeségi és lapultsági elemzése" (Study of skewness and kurtosis on face-milled surfaces having single or double cutting marks), in *"Fiatalok a Tudományért" tudománynapi rendezvény: Válogatott publikációk,* Miskolc-Egyetemváros, 2023, pp. 95-100.

[N24] A. Nagy, J. Kundrak, "Roughness of face-milled surface topography in directions relative to the feed movement," *Manufacturing Technology*, vol. 24, no. 2, pp. 241-254, 2024. (Scopus, Q2)

[N25] A. Nagy, "Analysis of amplitude roughness on a plane surface face-milled with an octagonal insert," in *"Fiatalok a Tudományért 2024" tudománynapi rendezvény: Válogatott publikációk*, Miskolc-Egyetemváros, 2024, pp. 9-16.

[N26] A. Nagy, "Roughness profile element width and gradient analysis on a plane surface face-milled with an octagonal insert," in *"Fiatalok a Tudományért 2024" tudománynapi rendezvény: Válogatott publikációk*, Miskolc-Egyetemváros, 2024, pp. 23-30.

[N27] A. Nagy, "Roughness investigation of a plane surface face-milled with an octagonal insert: skewness and kurtosis," in *"Fiatalok a Tudományért 2024" tudománynapi rendezvény: Válogatott publikációk*, Miskolc-Egyetemváros, 2024, pp. 39-44.

[N28] A. Nagy, "Functional roughness parameter characterization of a plane surface face-milled with an octagonal insert," in *"Fiatalok a Tudományért 2024" tudománynapi rendezvény: Válogatott publikációk*, Miskolc-Egyetemváros, 2024, pp. 51-56.

References

[1] H. Youssef, H. El-Hofy, M. Ahmed, Manufacturing Technology: Materials, Processes, and Equipment, Boca Raton, Oxon: CRC Press, 2024.

[2] B. Griffiths, Manufacturing surface technology: surface integrity & functional performance, London: Penton Press, 2001.

[3] *ISO 21920: Geometrical product specifications (GPS) – Surface texture: Profile,* 2021.

[4] "Most Common Metal Fabrication Techniques And Tools," [Online]. Available: https://www.schuettemetals.com/blog/6-most-common-metal-fabrication. [Date of access: 1 July 2024].

[5] "Metal fabrication processes: understanding the different types," [Online]. Available: https://www.metafab.com/metal-fabrication-processes-understanding-the-different-types/. [Date of access: 1 július 2024].

[6] J. Davim, Surface Integrity in Machining, London: Springer-Verlag, 2010.

[7] G. T. Smith, Cutting Tool Technology, London: Springer-Verlag, 2008.

[8] A. Meijer, J. Bergmann, E. Krebs, D. Biermann, P. Wiederkehr, "Analytical and simulation-based prediction of surface roughness for micromilling hardened HSS," *Journal of Manufacturing and Materials Processing,* vol. 3, no. 3, p. 70, 2019.

[9] J. Kundrak, C. Felho, "3D roughness parameters of surfaces face milled by special tools," *Manufacturing Technology,* vol. 16, no. 3, pp. 532-538, 2016.

[10] M. Hadad, M. Ramezani, "Modeling and analysis of a novel approach in machining and structuring of flat surfaces using face milling process," *International Journal of Machine Tools & Manufacture,* vol. 105, pp. 32-44, 2016.

[11] M. Arizmendi, A. Jiménez, "Modelling and analysis of surface topography generated in face milling operations," *International Journal of Mechanical Sciences,* vol. 163, p. 105061, 2019.

[12] D. Chuchala, M. Dobrzynski, D. Pimenov, K. Orlowski, G. Krolczyk, K. Giasin, "Surface roughness evaluation in thin EN AW-6086-T6 alloy plates after face milling process with different strategies," *Materials,* vol. 14, no. 11, p. 3036, 2021.

[13] G. Varga, J. Kundrák, "Effects of Technological Parameters on Surface Characteristics in Face Milling," *Solid State Phenomena,* vol. 261, pp. 285-292, 2017.

[14] S. Zhenyu, L. Luning, L. Zhanqiang, "Influence of dynamic effects on surface roughness for face milling process," *The International Journal of Advanced Manufacturing Technology,* vol. 80, no. 9, pp. 1823-1831, 2015.

[15] J. Kundrak, C. Felho, "Topography of the machined surface in high performance face milling," *Procedia CIRP,* vol. 77, pp. 340-343, 2018.

[16] *ISO 4287: Geometrical Product Specifications (GPS) – Surface texture: Profile method – Terms, definitions and surface texture parameters,* 1997.

[17] *ISO 4288: Geometrical Product Specifications (GPS) – Surface texture: Profile method – Rules and procedures for the assessment of surface texture,* 1996.

[18] *ISO 25178: Geometrical product specifications (GPS) – Surface texture: Areal,* 2021.

[19] C. Felho, J. Kundrak, "Effect of the Changing of the feed on surface topography at face milling," *International Journal of Mechanical Engineering,* vol. 1, pp. 114-121, 2016.

[20] C. Felhő, "Investigation of surface roughness in machining by single and multi-point tools," Shaker Verlag, Aachen, 2014.