# SERBIATRIB '25

## 19th International Conference on Tribology

14 – 16 May 2025, Kragujevac, Serbia

# PROCEEDINGS

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Serbian Tribology Society

University of Kragujevac
Faculty of Engineering

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**EDITOR: Slobodan Mitrović**

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# FUNCTIONAL ANALYSIS OF SURFACE ROUGHNESS

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**Abstract:** *Surface roughness is a key factor in defining the functionality and durability of mechanical components, particularly in the context of contact parts exposed to load, friction, and wear. This study analyzes the impact of different machining methods on the surface roughness of a shaft component in a handwheel made from stainless steel 1.4301 (X5CrNi18-10). The experimental research involved a comparison between conventional machining using a GALLIC 16 lathe and an Oerlikon milling machine with CNC machining on a MAZAK SQT 15MS machining center. Machining parameters were varied to assess their influence on the final surface roughness. Measurements were conducted using an INSIZE ISR C-002 profilometer, analyzing key roughness parameters (Ra, Rz, Rt, Rsk, and Rku). The results indicated that CNC machining achieved significantly lower roughness values (Ra = 0.672 µm) compared to conventional machining (Ra = 2.175 µm). Additionally, CNC-processed surfaces were more uniform and exhibited smaller deviations in topography, whereas conventional machining resulted in more pronounced irregularities and greater profile amplitude variations. It was concluded that CNC machining is more suitable for applications requiring high precision and smooth surfaces, while conventional machining may be advantageous in scenarios where improved adhesion and lubricant retention are critical factors. These findings contribute to the optimization of machining strategies in accordance with specific industrial application requirements.*

**Keywords:** *Surface Roughness, Conventional Machining, CNC Machining, Profilometry, Machining Optimization.*

## 1. INTRODUCTION

Surface roughness plays a crucial role in defining the functionality and durability of mechanical components, particularly in contact parts exposed to load, friction, and wear. Different machining methods generate surfaces with specific characteristics that can directly impact component performance under real operating conditions. To ensure control over the final surface finish and optimize production, it is essential to analyze the influence of various machining regimes on surface roughness and its suitability for operational requirements. A comparative analysis of surface roughness across different machining methods provides insights into the advantages and limitations of each technology, facilitating the selection of the optimal process based on specific technical and economic requirements [1]. Additive manufacturing, as a modern approach to producing complex geometries and structures, often requires additional finishing operations to achieve the desired surface quality. In this context, the post-processing of additively manufactured parts may involve both conventional and CNC methods, each offering specific advantages depending on the component's requirements. Given that both additive and traditional machining processes play a role in industrial manufacturing, a detailed analysis of surface roughness across different machining methods can contribute to optimizing finishing strategies and enhancing the functional properties of machined components [2].

Depending on product requirements, surface finishing can be achieved through various methods, with each technology offering specific advantages in terms of precision, speed, cost-effectiveness, and the functionality of machined surfaces. Traditional processes, such as shaping with modular tools, profiling with disc or finger cutters, and final finishing through grinding (Maag, Niles, Reishauer methods), are commonly used in the precision manufacturing of gears and other complex components. On the other hand, modern CNC processes, including power skiving, parametric programming, and integrated "done-in-one" approaches, provide a higher level of flexibility and accuracy, which is particularly beneficial for serial production and intricate geometries. However, despite the increasing reliance on automated processes, conventional machining still plays a significant role in the industry, especially for small-batch production, simpler geometric requirements, or specialized applications where CNC precision is not a decisive factor [3].

The design of industrial components in fields such as aeronautics and turbomachinery presents specific machining challenges, requiring a high level of precision and controlled surface finish quality. In these applications, the presence of deep grooves, thin-walled structures, and complex contours necessitates a carefully selected machining strategy to minimize thermal effects, reduce vibrations, and achieve optimal surface roughness. Factors such as cutting speed, depth of cut, and machining strategy directly influence the final surface quality. For instance, in the machining of aluminum alloys, the application of optimized tool paths can enhance heat dissipation and contribute to roughness reduction. Additionally, appropriate cooling and lubrication systems, including methods such as minimum quantity lubrication (MQL) and cryogenic cooling, play a crucial role in maintaining surface finish quality and extending tool life [4].

As different materials require tailored machining approaches, the proper combination of machining strategy and surface roughness measurement method is a key step in optimizing the manufacturing process. Understanding the interaction between tool selection, machining parameters, and finishing techniques enables more precise control over surface characteristics and better adaptation to specific industrial applications. For this reason, it is crucial not only to determine which machining process yields a higher-quality surface finish but also to assess under which conditions a particular technology proves to be more advantageous in terms of cost-effectiveness and production efficiency.

The selection of the optimal machining technology depends on multiple factors, including tolerance requirements, production costs, and the expected functionality of the component. In some cases, conventional machining may offer a more cost-effective solution without significant compromises in quality, while CNC technologies provide more precise control over surface finish and greater repeatability in serial production. Given these differences, the analysis of surface roughness across various machining methods is important not only from the perspective of surface quality but also in finding a balance between technical requirements and production economics [2,5].

To ensure accurate and reliable evaluation of surface finish, modern roughness measurement methods increasingly incorporate advanced optical and non-contact techniques. Methods such as laser 3D profilometry and optical interferometry enable precise surface structure scanning without physical contact with the sample, providing a detailed insight into the micro- and meso-structure of the surface. These approaches are particularly valuable in fields where preserving the surface from mechanical damage is crucial, such as precision mechanics, high-quality industrial manufacturing, and cultural heritage analysis [5,6].

However, tactile measurement methods, which rely on physical contact with the surface, remain widely used due to their high accuracy and reliability. They are particularly important in industrial applications where standardized roughness parameters, such as Ra and Rz, are essential for quality control and machining process optimization. For this reason, contact-based methods continue to be indispensable in surface finish analysis, providing precise and repeatable results in accordance with technical requirements [7-9].

This study analyzes the surface roughness of a shaft component in a handwheel made from stainless steel 1.4301 (X5CrNi18-10), comparing the results obtained through conventional machining and CNC machining. Given that surface roughness plays a crucial role in the functionality of mechanical components, particularly in shaft elements such as the handwheel, its control is essential for ensuring proper adhesion, reducing friction in contact with other components, and enhancing wear resistance during operation [7,10]. The aim of this study is not only to determine the differences in surface finish between conventional and CNC machining methods but also to assess the cases in which a particular approach is more technologically and economically advantageous.

## 2. MATERIALS AND METHODS

The research was conducted on a shaft component of a handwheel, made from stainless steel 1.4301 (X5CrNi18-10), with a diameter of Ø65 mm and a length of 65 mm (Fig. 1). The machining was performed using two different methods: conventional machining and CNC machining, to compare the effects of these technological processes on the final surface roughness.

**Figure 1.** Shaft component of the handwheel

The machining of the shaft component of the handwheel was carried out in multiple stages on conventional machines, including transverse and longitudinal chip removal, hole drilling, groove milling, and thread cutting.

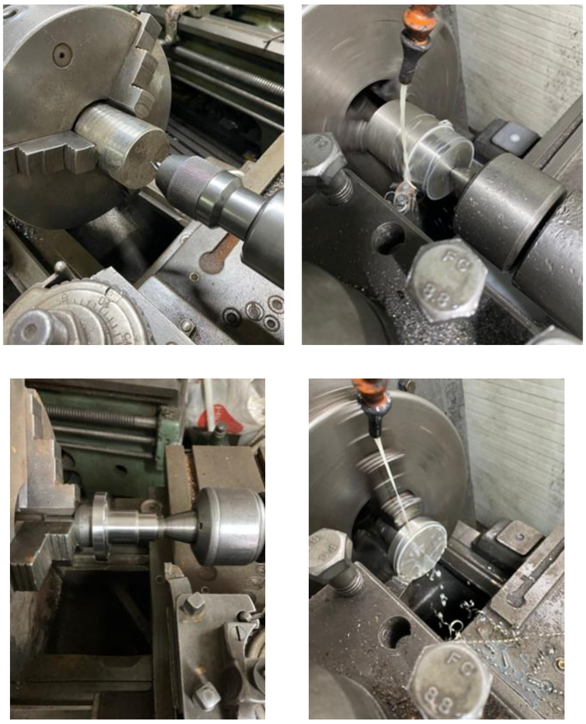


**Figure 2.** Specific machining operations on the GALLIC 16 lathe

The process began with rough machining on a GALLIC 16 lathe (working length: 1000 mm, machining diameter: 400 mm, spindle speed: 40–2000 rpm) (Fig. 2). Subsequently, precise milling and drilling operations were performed on a universal Oerlikon milling machine (working length: 800 mm, spindle speed: 63–2800 rpm) to achieve the final dimensions and define the component geometry.

The final machining on the lathe included thread cutting, which required precise surface profiling to ensure the proper accuracy of the joint.

For machining, cutting tools made of hard metal (HM) and high-speed steel (HSS) were used, with machining parameters varying depending on the operation. The spindle speed ranged from 120 to 600 rpm, while feed rates were in the range of 0.1 to 0.6 mm/rev, depending on the process requirements. The depth of cut varied between 0.3 mm and 4 mm, depending on the operation and the type of tool used.

The machining of the shaft component of the handwheel on the CNC machining center MAZAK SQT 15MS (working length: 600 mm, spindle speed: 35–5000 rpm) was performed in a single clamping, ensuring high accuracy and process repeatability. All operations—including longitudinal and transverse chip removal, drilling, groove milling, and thread cutting—were executed automatically, eliminating the need for repositioning the workpiece between different machines. This significantly reduced potential deviations caused by multiple clamping operations.

Hard metal (HM) cutting tools were used for machining, with optimally adjusted operating parameters. The spindle speed ranged from 800 to 2500 rpm, while feed rates varied between 0.05 and 0.3 mm/rev, depending on the operation. The depth of cut ranged from 0.2 mm to 5 mm, with the finishing process performed with minimal deviations from the specified dimensions.
The surface roughness analysis was conducted using the INSIZE ISR C-002 profilometer (Fig. 3), which enables precise determination of roughness parameters through a contact measurement method.

This analysis provided key data on the quality of the surface finish for each of the applied machining processes, enabling detailed comparative assessments and the evaluation of the impact of machining methods on the final surface structure.

**Figure 3.** Surface roughness testing on the profilometer

## 3. RESULTS

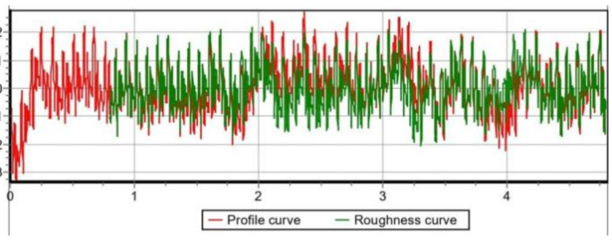
Surface roughness measurements were conducted in the final machined zone of the shaft component of the handwheel. The obtained roughness parameter values for both machining methods are presented in Table 1.

**Table 1.** Roughness parameters

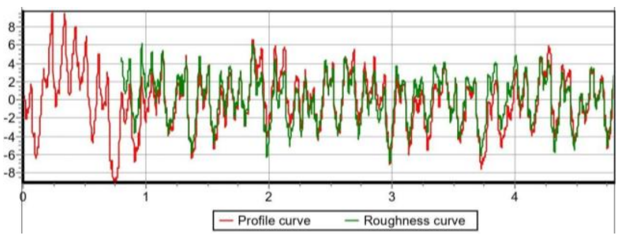
| Parameter | MAZAK SQT 15MS | Gallic 16, Oerlikon |
|---|---|---|
| Ra, µm | 0.672 | 2,175 |
| Rz, µm | 3,477 | 8,259 |
| Rt, µm | 8,883 | 12,990 |
| Rsk,/ | 0,934 | 0,077 |
| Rku,/ | 3,70 | 2,853 |

The measurements revealed significant differences in roughness parameters between the two machining methods. The surface roughness parameter Ra, which represents the arithmetic mean deviation of the profile from the mean line, was 0.672 µm for CNC machining, compared to 2.175 µm for conventional machining, indicating nearly three times smoother surfaces with the CNC method. Similarly, the Rz and Rt values, which define the maximum variations in profile height, were significantly lower for CNC machining, further confirming a more uniform surface finish.

Figures 4a and 4b show the profile curves of samples machined on the CNC machining center and the conventional machine.




a)




b)

**Figure 4.** Profile Curves: a) Machining on the CNC Machining Center, and b) Conventional Machining

The analysis of these graphs indicates that surface topography deviations are more pronounced in conventional machining, with greater irregularity amplitudes and more distinct peaks and valleys. In CNC machining, the surface structure is more uniform, with smaller variations in the profile, which aligns with the numerical values of the roughness parameters.

These differences significantly impact the functionality of machined components—smoother surfaces are more suitable for reducing friction and wear, while rougher surfaces can enhance adhesion and lubricant retention in certain applications. The following section of the paper examines in greater detail the influence of these differences on the operational characteristics of components and the selection of the optimal machining process.

## 4. DISCUSSION

Surface roughness measurements revealed significant differences between the two machining methods, with the surface machined on the MAZAK SQT 15MS machining center exhibiting lower roughness values compared to the surface machined on conventional machines (Gallic 16 and Oerlikon) [11].

The most important parameter, the arithmetic average roughness Ra, was 0.672 µm for CNC machining, whereas it measured 2.175 µm for conventional machining, representing a difference of more than three times. This discrepancy indicates a significantly more uniform and smoother surface finish in the CNC process, which can be attributed to more precise control over machining parameters, more stable clamping, and reduced vibration effects [1,4,11]. In conventional machining, manual process control and multiple workpiece clamping contribute to increased variability in surface quality, reflected in higher Ra values [11,12].

Similarly, the Rz parameter, which represents the average height difference between the peaks and valleys of the profile, was 3.477 µm for CNC machining, whereas it was significantly higher at 8.259 µm for conventional machining. These results indicate that surface irregularities are more pronounced in conventional machining, which can affect surface behaviour in application—particularly in terms of friction and lubricant retention [12,13].

The maximum surface height variation, Rt, showed even greater differences—measuring 8.883 µm for CNC machining compared to 12.990 µm for conventional machining. These findings confirm that CNC machining produced a more uniform and consistent surface finish, while conventional machining resulted in more prominent peaks and depressions. This variation can be attributed to tool changes, differing machining regimes, and vibrations during the process [12,13].

The Rsk parameter (skewness coefficient) revealed different surface characteristics for the two machining methods. The surface machined on the CNC machining center had an Rsk value of 0.934, indicating a predominance of peaks, whereas the conventional machining surface had an Rsk value of 0.077, suggesting a more evenly distributed surface structure. This result implies that the CNC-machined surface may be more suitable for joints requiring good adhesion, as the presence of pronounced peaks enhances contact between components. On the other hand, the conventional surface may be more effective in retaining lubricant, which can be beneficial in applications where proper lubrication is necessary to reduce wear in dynamic joints [12,13].

Similarly, the Rku parameter, which indicates the prominence of peaks and valleys, was 3.70 for CNC machining, whereas it measured 2.853 for conventional machining. A higher Rku value in CNC machining suggests more pronounced peaks and valleys, whereas the conventional machining surface was somewhat more uniform but exhibited generally greater deviations in relief. This distinction is crucial for engineering applications where a specific surface texture is required, depending on the functional demands of the component [12,13].

The obtained results confirm that CNC machining enables high precision, uniformity, and repeatability of surface structure, making it suitable for applications where low friction coefficients and minimal roughness are crucial (e.g., sliding joints and bearings, sealing interfaces, precision mechanical components, etc.) [13,14].

On the other hand, the higher roughness observed in conventional machining can be advantageous in certain industrial applications, such as parts requiring improved adhesion, components that need better lubricant retention, or parts intended for further processing [13,14].

Although CNC machining provides higher precision in achieving a fine surface finish and ensures a more uniform surface structure, conventional machining has its own advantages. It is particularly beneficial in scenarios where better lubricant retention or enhanced surface contact is required for improved adhesion or friction characteristics. Therefore, the choice of machining method is not solely dependent on achieving the lowest roughness but also on the functional requirements of the component and its operating environment.

## 5. CONCLUSION

The research results indicate that the choice of machining method depends on the functional requirements of the component. CNC machining is superior when low roughness and high precision are required, which is crucial in the automotive, medical, and precision industries. On the other hand, conventional machining remains important in applications where higher roughness and better lubricant retention are advantageous, such as in heavy industry and the energy sector.

Further research can contribute to the optimization of machining parameters and the adaptation of surface finishing to specific technical requirements. These findings can be valuable for industrial practice, enabling engineers to select the optimal machining strategy for each specific part.

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