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TECHNOLOGICAL ASSURANCE OF MECHANICAL PROCESSING OF COMPLEX SHAPED PARTS BASED ON MACHINING CENTERS WITH NUMERICAL CONTROL

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Abstract. To achieve high precision in the machining of complex-shaped parts, the correct combination of technologies with the machining center is necessary, especially if it has only 3 axes, to obtain the best results. The present study focuses on technological assurance of the mechanical processing of complex-shaped parts on Computer Numerical Control (CNC) machining centers. The study proposes a methodology for optimizing the machining process by implementing appropriate technological measures, such as tool selection, cutting parameters, and cost-effective process planning. The proposed methodology aims to enhance the quality and productivity of the machining process while minimizing the production time and cost. The results of the study demonstrate the effectiveness of the proposed methodology in improving the machining performance and achieving the desired product quality.

Key words: *CNC milling, technological assurance, complex surfaces, manufacturing efficiency, three-axis machines.*

Rezumat: Pentru a obține o mare precizie în prelucrarea pieselor de formă complexă este necesară combinarea corectă a tehnologiilor cu centrul de prelucrare, mai ales dacă are doar 3 axe, pentru a obține cele mai bune rezultate. Prezentul studiu se concentrează pe asigurarea tehnologică a procesului de prelucrare mecanică a pieselor de formă complexă pe centrele de prelucrare cu comandă numerică. Studiul propune o metodologie de optimizare a procesului de prelucrare prin implementarea măsurilor tehnologice adecvate, cum ar fi selecția sculelor, parametrii de tăiere și planificarea procesului eficient din punct de vedere al costurilor. Metodologia propusă urmărește să sporească calitatea și productivitatea procesului de prelucrare, minimizând în același timp timpul și costul de producție. Rezultatele studiului demonstrează eficacitatea metodologiei propuse în îmbunătățirea performanței de prelucrare și atingerea calității dorite a produsului.

Cuvinte cheie: *Frezare CNC, asigurare tehnologică, suprafețe complexe, eficiență în fabricație, mașini cu trei axe.*

1. Introduction

Today, Computer Numerical Control (CNC) machining centers have become essential in the modern mechanical processing industry. These machines are programmed to carry out complex operations with increased precision and efficiency, reducing the need for manual intervention and allowing for the production of superior quality products. To maximize performance and minimize errors in the mechanical processing process, it is important to ensure appropriate technology [1], choose and use durable tools [2,3], and ensure adequate High-Speed Machining (HSM) [4,5].

The profitability of the machining process is an important concern for any modern company. Additionally, the frequent change in quality conditions and the complexity of prismatic bodies make the machining process more difficult and costly. In the case of parts with complex shapes that require multiple technological operations, it is important to find solutions to ensure the required quality and precision. This may involve the use of more advanced machining technologies as well as the development of more efficient machining strategies. Furthermore, it is important to consider the costs and time required for each technological operation in order to achieve optimal profitability of the machining process.

The economic instability in recent years has made it difficult to acquire state-of-the-art equipment, especially for small companies. In this situation, 3-axis CNC machines remain a viable solution, offering many advantages in terms of serviceability and ease of use. However, if we focus on machining complex parts, 3-axis machines have disadvantages, such as ensuring precision, especially for the machining of complex parts, due to the limitation of movement.

There is an impressive volume of studies and research in the field, which have focused on various issues such as energy consumption [6], but a great emphasis has been placed on optimizing the actual execution stage, leading to the development of different methods and techniques of optimization [7,8]. In most cases, ensuring manufacturing processes is the priority criterion throughout the manufacturing chain, responding promptly from the product design stage, process planning, operation scheduling, tooling, and actual execution.

Therefore, the technological assurance of the machining process remains a problem that can still be studied and improved, especially in the context of our goal to maintain competitiveness and efficiency of the machining process on 3-axis machine tools in the future. Due to the movement limitations of 3-axis CNC machines, parts with complex surfaces require a different or rather particular approach due to areas that cannot be described by a simple equation or a standard geometric form. The combinations of curves, planes, sophisticated contours, and specific details represented by these surfaces create difficulties for the traditional method of realization and manufacturing. Therefore, there is an observed increase in the number of parts with complex shapes that become crucial in the aesthetic functionality and performance of mechanisms in various industries, creating new challenges for engineers.

Complex parts (Figure 1) have a wide range of applications in various industries and sectors, including the automotive, aviation, aerospace, medicine, and pharmacy industries. These parts are used as critical components such as engines, turbines, radiators, surgical instruments, separation devices, or prostheses, to provide superior performance and necessary solutions for users. As can be seen in modern industry, the use of complex-shaped parts is a key element.

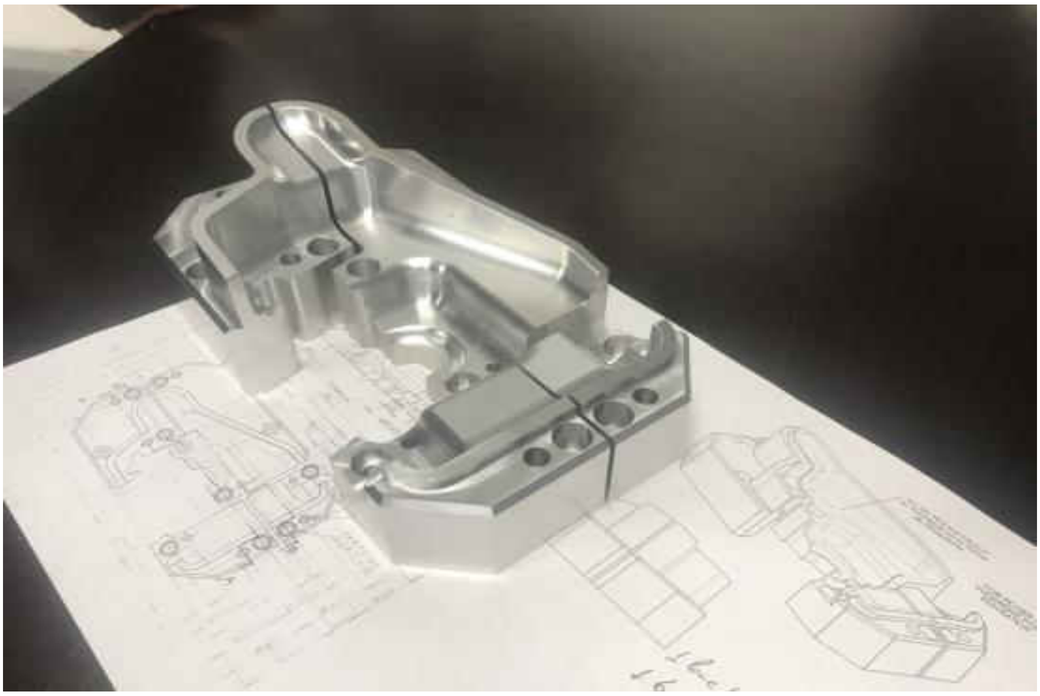

Figure 1. Assembly from different parts with complex shape [9].

In this context, ensuring the technological assurance of the machining process becomes crucial, and investment in advanced technological solutions such as appropriate software, strategies, or tools becomes the main element of success.

It is true that mechanical machining is an extremely important aspect in today's industry, and companies need to pay special attention to the machining processes to ensure efficient, precise, and high-quality production. In an increasingly competitive environment, the quality and efficiency of the machining process make the difference between success and failure. Therefore, it is important for companies to consider these aspects and invest in advanced technologies and adequate technological assurance to maintain their competitiveness.

Even though mechanical machining has made significant progress in recent decades, there are still challenges in achieving precise machining operations, strict tolerances, complex geometries, difficult-to-machine materials, or high productivity requirements, especially for owners of older machines such as 3-axis CNC machining centers, which face difficulties in performing certain operations. It is important to emphasize that technological assurance is not just an optional choice but an imperative necessity for companies in the machining industry.

As early as Wolfgang Kuehn. [10−13] pointed out that the digital factor, namely 3D simulation and visualization software, is the key to development, which can be introduced at various stages to improve product and process planning. Of course, since then, the software has evolved into an intelligent CAD/CAM system [14], responding to simple but automated CNC machine programming through the use of artificial intelligence and automatic learning. There is a myriad of products on the market that develop three-dimensional models and offer programming and toolpath visualization possibilities, or even the entire machine tool [9]. The most well-known ones are: SolidCam, NX, ArtCAM, Mastercam, Esprit, PowerMill, Fusion 360, each having specific features that make it difficult to choose the best software [15].

2. Materials and Methods

A case study was conducted for the development of this article, describing an existing machining process on a complex component produced on a 3-axis machine. For the experimental part, a 3D model was developed, used in ultrasonic welding installations for plastic material. Figure 2 represents the machined model, consisting of a set of 3 components labeled as 1, 2, and 3, each having a number of complex zones labeled as A, B, and C.

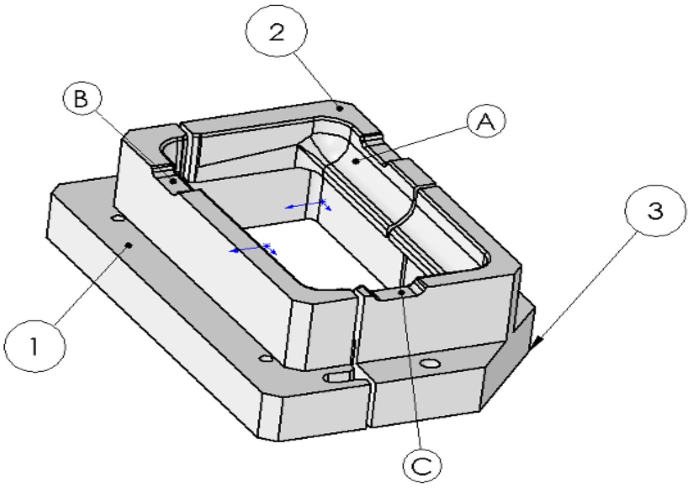

Figure 2. Analysis of the experimental model. The three components of the assembly are numbered by the number 1, 2 and 3, and by the letters A, B and C their complex areas are represented.

This model was created in Solidworks 2021 software.The process technology was developed for the 3-axis machining center AWEA AF 1000, utilizing a total of 14 tools for the execution of the work. The program for the technological process was created in Solidcam 2016 and processing time for each component is presented in Table 1.

Table 1

Track number	Number of Tools	Number of Installations	Total time, min
1	11	3	120
2	11	3	164
3	11	4	173

Processing time for each component

To improve this manufacturing process, it is necessary to first conduct an analysis following the steps mentioned above. After examining the program, it was identified that the most costly stages are the roughing and finishing of the complex surfaces, Figure 3.

This operation is carried out using an 8 mm ball nose tool with parameters described in table 2, using the HSS (High-Speed Steel) machining technique. The Paralel Cuts Constant Z technique is a constant machining technique that allows for obtaining a uniform and precise finish in a shorter time and with reduced effort.

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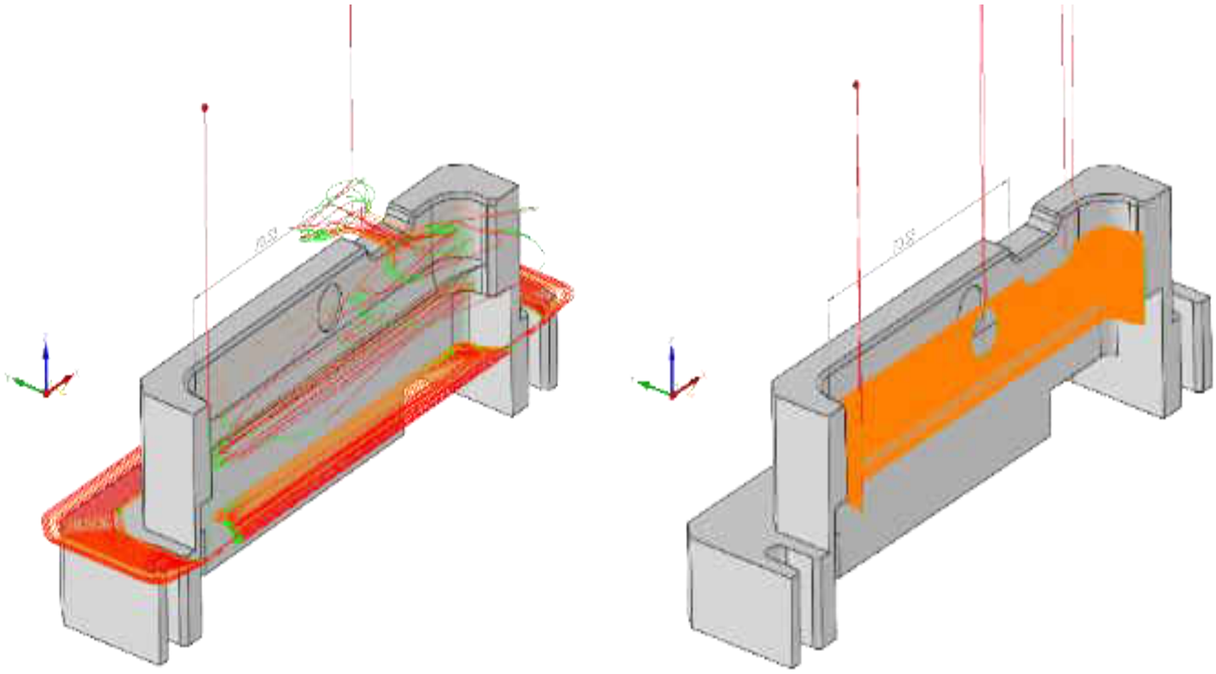


a) b)

Figure 3. The area with the longest processing time.
a) roughing operation; b) finishing operation.

Table 2

Tool parameters

Specification	Information
Diameter	4 mm
Shank	4 mm
Cutter length	15 mm
Rotation speed	6500 rpm
Cutting Depth	1/3 D
Cutting Width	1/2 D
Single Edge Feed	0.15 mm

Within the presented research framework, the discussion of surface roughness is focused on the universally recognized Rz.

Figure 4. Measurement of surface roughness using Form Talysurf 50 (Taylor Hobson Co Ltd).

3. Solving the fixing problem

The examination of the second and third models showed that, in addition to the long processing times in the finishing and roughing operations, there is a problem with the fixation of the components, resulting in small linear errors and the occurrence of vibrations.

Following the analysis, it has been decided to use a 10 mm tool for the finishing operation. This decision was made due to the advantages offered by using a larger tool, such as easier access along the machined surface and a reduction in the total processing time.

In order to ensure better fixation of the part during the operation, a technological support has been developed. It is an essential component in the processing process, as it ensures stability and accuracy in positioning the part.

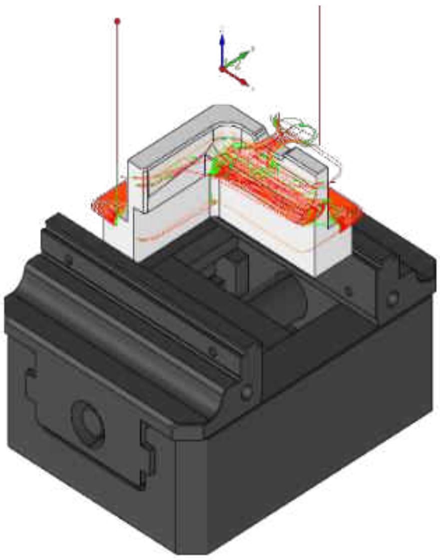
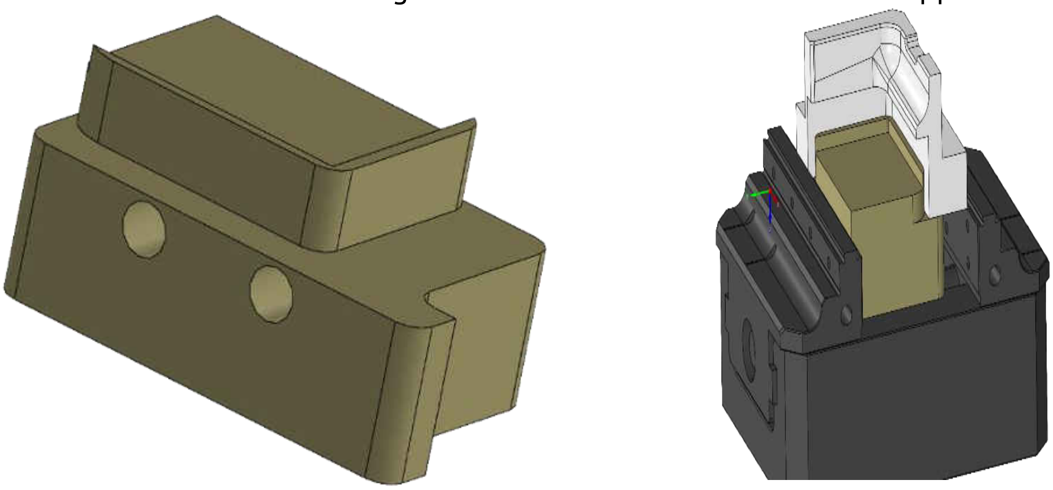


Figure 5. Fixing problems.

The technological support (Figure 5) is composed of the mirrored surfaces of the finished part, allowing for a solid and precise fixation of the part during the finishing operation. This support is designed to maintain the part in a stable position and provide easy access to the tool. Two technological holes were made to attach the support to the machine.



a) b)

Figure 6. Technological support.

a) technological support; b) the assembly.

These holes are essential for proper mounting and fixation of the technological support onto the machine. By using these holes, the support is fixed in a secure and stable position, capable of withstanding the general forces and vibrations during the finishing operation.

4. Results and Discussion

The values obtained from the data analysis for the two finishing options, the initial one and the optimized one, are presented in Table 3 for comparation.

Table 3

The times obtained between the initial method and the optimized one

	Finishing, min	Fixation, min
The initial example	0:14:27	0:02:45
The optimized example	0:11:28	0:03:15

The data presented shows that in terms of finishing time, the optimized option resulted in a reduction of approximately 3 minutes compared to the initial option. However, the time required for fixing the part on the support slightly increased for the optimized option. In terms of the quality of the obtained surfaces, the optimized option managed to produce more uniform surfaces without visible defects compared to the initial option. Figures 7 and 8 display the acquired results, with a slight variation in the Rz parameter, which is 1.26 in the first figure and 1.24 in the second. These results suggest that optimizing the finishing process led to an improvement in the quality of the processed surfaces, even though the fixing time slightly increased.

It is important to mention that these data are estimations and may vary depending on the machine and support specifications, as well as the quality and dimensions of the part. Therefore, we can recommend testing and adjusting the finishing process for each individual part to ensure maximum quality of the processed surfaces and optimization of processing time.

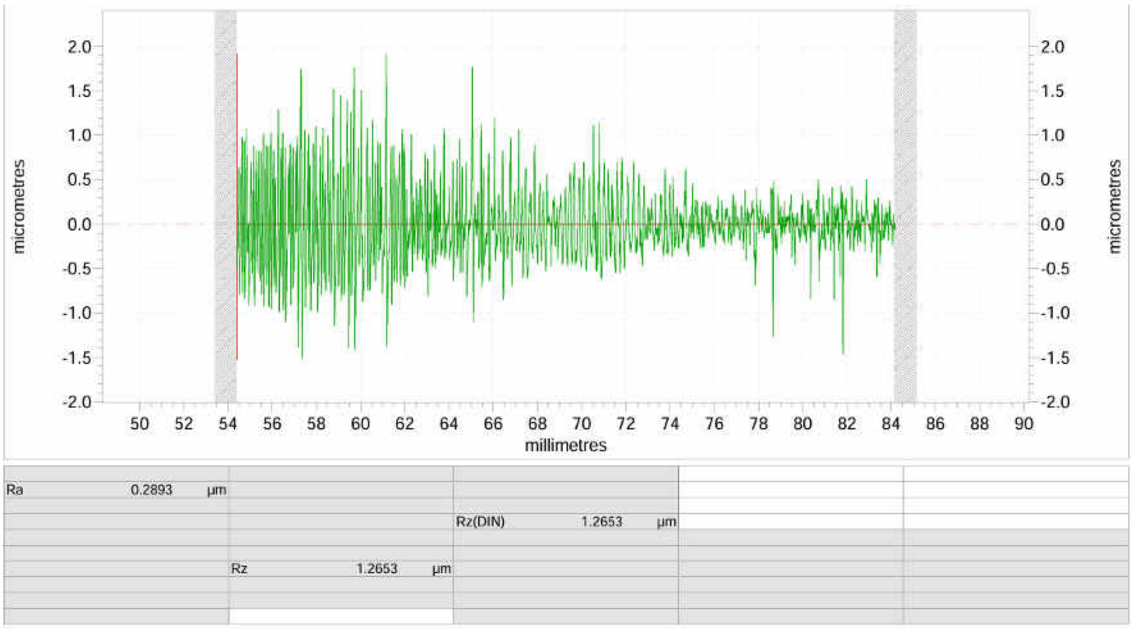


Figure 7. The micro-irregularities profile for the initial processing variant.

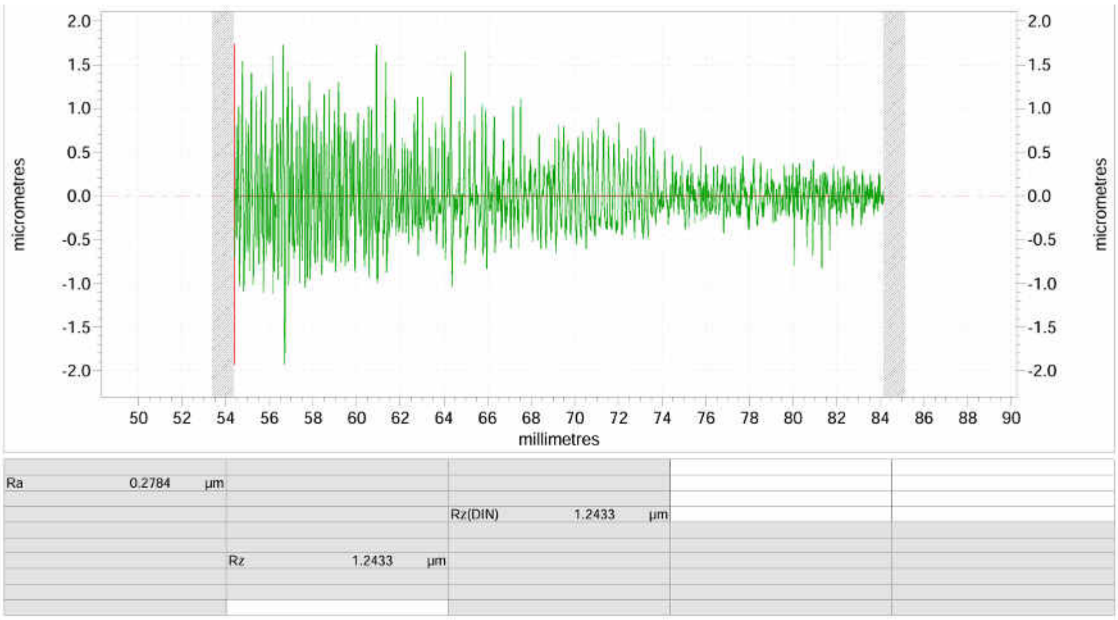


Figure 8. The micro-irregularities profile for the optimized processing variant.

The necessity of using special fixing supports for complex parts is not limited to this work alone, as exemplified in Wojnarowska's study [16]. For instance, in his research, he also proposed a support system for processing medical objects with complex geometry, such as cranial bone prostheses. He introduced a vacuum clamping system that proved the method's utility in producing complex components on a 3-axis milling machine, achieving good results in terms of surface roughness and precision. Additionally, a clamping support was put forth by Adli [17] to secure the pieces in place and consistently enhance the grip on thin parts during processing. In 2022, Ferchow [18] proposed integrated screw fixing supports, enabling the attainment of surface roughness results with a maximum Ra value of 1.42 µm.

Ensuring precision and surface quality on 3-axis machines remains an ongoing area of research. To address these parameters, Eckert [19] presented a new clamping system based on a pneumatic chuck with three gripping jaws controlled by force to manage workpiece deformation. This was combined with a visual model recognition system to ensure high repeatability in positioning, achieving results with a repeatability of ±0.1 µm.

Consequently, it can be confidently stated that clamping systems are imperative for securing parts on 3-axis CNC machines, thereby enhancing surface precision and quality. Furthermore, these systems provide rigid and precise fixation, eliminating unwanted vibrations and movements during processing, thereby contributing to high-quality outcomes and increased productivity.

5. Conclusions

In conclusion, the analysis of the data obtained from the modifications made to the processing and fixing process of the parts showed that using a dedicated technical support during processing and optimizing the finishing process can lead to a reduction in processing time and an improvement in the quality of the obtained surfaces confirmed in the roughness analyses.

However, it is important to consider the costs and efforts involved in designing and manufacturing a dedicated technical support for each individual part in order to optimize the processing process and ensure maximum quality of the processed surfaces.

Furthermore, the optimization of the finishing process needs to be done on an individual basis for each part, taking into consideration the machine and support specifications, as well as the quality and dimensions of the part.

Therefore, these improvements can result in a significant enhancement of the processing processes and the production of higher quality parts.

Conflicts of Interest: The author declares no conflict of interest.

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