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CAD-BASED MACHINING SIMULATION CONSIDERING TOOL MICROGEOMETRY

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Abstract: Surface roughness is a critical parameter that measures the overall surface quality of a machined component. Most surface roughness measurement techniques are usually time-consuming to set up and measure, and require specialized equipment. This study proposes an alternative method for measuring the expected surface roughness on a machined component by utilizing the programming interface of a commercially available Computer-Aided Design (CAD) system. In contrast to the standard CAD models that the manufacturers provide, which usually lack critical geometrical aspects, the proposed algorithm takes into consideration the full geometry of the cutting tool, which influences the surface profile to a great extent. The CAD system utilized is a generic software, namely SolidWorks™. Specifically, the Application Programming Interface (API) and its methods were used to develop the algorithm that can simulate the kinematics of the machining process. The selected process is the external turning. Additionally, the surface profile, topography, as well as standard measurements were generated. All data were acquired with respect to typical machining parameters such as the depth of cut, feed rate, and cutting speed. Finally, to verify the accuracy of the algorithm, a set of nine cutting tests was carried out, under a widely used range of conditions, suggested by the tool manufacturer. Concluding, the experimental and the simulated measurements were compared in terms of the *Ra*, *Rz,* and *Rt* surface roughness values. The increased correlation percentages, exceeding 90% in most cases, proved the validity of the developed algorithm.
Key words: CAD-based simulation; API; surface roughness; surface topography; machining simulation; microgeometry; tool nose.

1. INTRODUCTION

Computer-Aided Design (CAD) has become an indispensable tool in modern engineering, facilitating the creation, modification, and optimization of designs with high precision. The integration of programming capabilities within CAD environment, referred to as CAD-based programming, has further enhanced the design and manufacturing processes by enabling automation, customization, and improved efficiency. This approach allows for the development of scripts and macros that can automate repetitive tasks, generate complex geometries, and seamlessly link design parameters with manufacturing processes.
In recent years, significant advancements have been made in leveraging CAD-based programming for automated design and assembly. For instance, (Chervinskii et al. 2023) introduced the "Auto-Assembly" framework, which facilitates automated robotic assembly directly from CAD models. This system encompasses design analysis, assembly sequence generation, and path planning, culminating in the execution of control code by robotic systems. The flexibility of this approach was demonstrated through its application to various input designs, highlighting its potential in streamlining the assembly process. The integration of Design for Manufacturing and Assembly (DfMA) principles within CAD environments has also been a focal point of research. (Campi et al. 2022) proposed a method to embed DfMA guidelines into 3D CAD systems, enabling designers to anticipate manufacturing issues and control costs during the product development process. This approach involves analyzing the 3D CAD model to identify potential manufacturing challenges, thereby reducing the effort and time required in design iterations. Moreover, CAD-based programming has been instrumental in advancing manufacturing simulations. (Michniewicz, Reinhart, and Boschert 2016) presented an approach that utilizes CAD data to automate assembly planning for variable products in modular production systems. By extracting necessary assembly processes and valid sequences directly from CAD files, the system assigns tasks to capable production resources after simulative verification, generating optimal assembly plans. This method takes into account the properties and geometry of production resources, as well as the layout and feasible material paths within the production system. The application of CAD-based programming extends to surface quality simulation, a critical aspect in ensuring the functional and aesthetic attributes of manufactured components. By integrating surface quality parameters into

CAD models, engineers can predict and simulate the outcomes of various manufacturing processes on surface integrity. The predictive capability allows for the optimization of process parameters to achieve desired surface finishes, thereby reducing the need for extensive physical prototyping and testing. The ongoing research in this domain aims to develop more sophisticated models that can accurately simulate surface interactions during manufacturing, further enhancing the precision and efficiency of production processes. In the work by (Tapoglou and Antoniadis 2012), the kinematics of face milling were simulated by employing similar API methods and CAD-based programming techniques. The programming for simulation in the manufacturing sector has achieved great success for other manufacturing processes, such as drilling (Kyratsis et al. 2011), burnishing (Felhő and Varga 2022), and gear analysis (Bartłomiej 2013) as well.

In conclusion, CAD-based programming has significantly transformed design and manufacturing workflows by enabling automation, enhancing integration of DfMA principles, and advancing manufacturing simulations. The continuous development in this field promises further improvements in efficiency, flexibility, and quality in product development and manufacturing processes. The present article utilizes the API of SolidWorks™ to develop an algorithm for predicting the surface roughness of machined components during the external turning process. The proposed methodology takes into account the microgeometry of the tool by employing a parametrically designed tool, without the implementation of specialized software or equipment.

2. MATERIALS AND METHODS

2.1. Machining simulation workflow

The workflow of the simulation is shown in Figure 1. It is divided into three major stages: the preparation, the simulation, and the results. The first stage includes the design of the 3D models involved in the simulation, the calculation of the necessary parameters, and the implementation of the kinematics responding to the turning process. It is noted that the workpiece is designed as a slice of the cylindrical workpiece to reduce simulation time and computational resources. In addition, the cutting tool is designed according to the ISO13399 norm, by including the full geometrical aspects of the cutting edge, with the aid of a software application developed by the author (Tzotzis et al. 2020b). The cutting conditions are calculated by using known formulas from the literature. For example, the cutting speed is calculated by considering the applied spindle speed and the cylindrical workpiece's diameter. Finally, the kinematics of the turning process is a combination of the translational movement of the tool on the workpiece's surface (feed) and its rotational movement around the workpiece, for each simulation step, by taking into account the initial position of the tool. As shown in Figure 1 (stage 1), the tool's motion can be considered helicoidal. To describe this motion, Equations (1) and (2) are used. Specifically, Equation (1) represents the translational movement and Equation (2) the rotational.

$$z_i = z_0 + i\frac{f}{a}, \quad i = 1...n \tag{1}$$

$$\varphi_i = \varphi_0 + i\frac{2\pi}{a}, \quad i = 1...n \tag{2}$$

where, z_i is the tool's position at the linear direction for step point i, z_0 represents the initial position of the tool, f is the feed in mm/rev and a is the number of points per revolution. Similarly, φ_i denotes the tool's angular position for step point i, φ_0 is the initial angle of the tool, and a are the points per revolution. It is noted that all angles and length values involved in the calculation process of the kinematics are implemented in rads and mm, respectively. Additionally, n denotes the maximum step point of the simulation that depends on the user's settings.

The second stage deals with the assembly of the mechanical system, comprising the portion of the workpiece and the cutting tool. The second stage includes the execution of the algorithm as well, which is responsible for the kinematics simulation, according to the parameters inputted during the initialization of the code.

Finally, during the third stage, all the typical calculations regarding the profile are made, such as the average surface roughness (*Ra*), the maximum height (*Rz*), and the total height (*Rt*) (Risbood, Dixit, and Sahasrabudhe 2003). This process is available once the profile points are extracted and stored in a Comma Separated Value (csv) file (Gella-Marín et al. 2021).

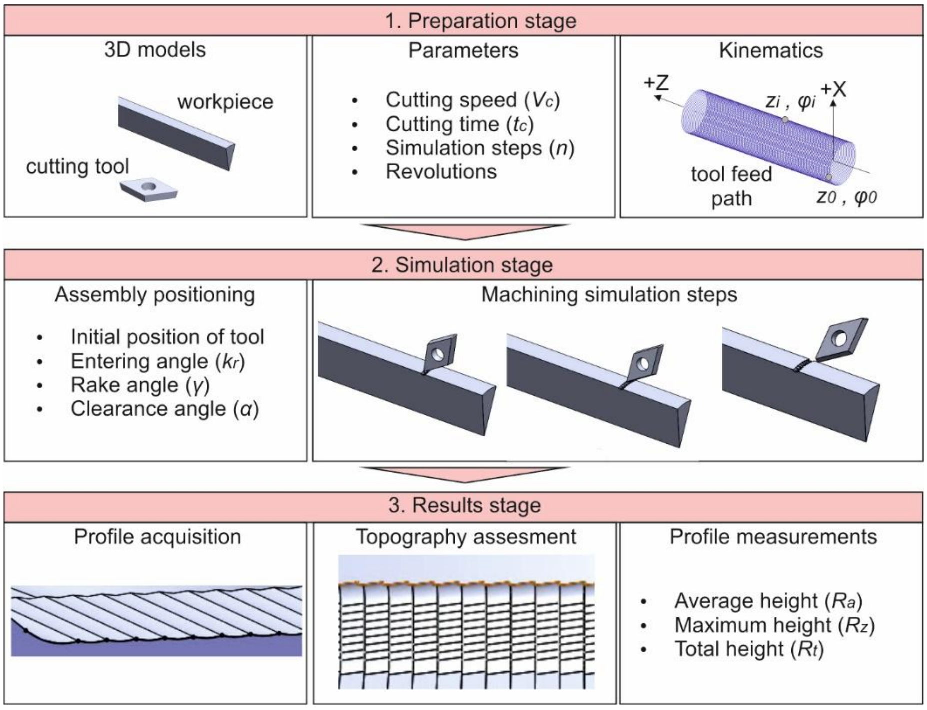

Fig. 1. The workflow of the simulation

2.2. Surface roughness measurements workflow

The surface roughness measurement process begins with the generation of multiple reference planes (Figure 2 - step 1) with respect to the simulation steps, by utilizing the "InsertRefPlane" API method. The use of API methods for the plane handling is described in the work by (Tzotzis et al. 2021). The use of these planes is to project the segmentation points, as discussed on a later step. Next, the intersection curve is designed on each plane (Figure 2 - step 2), with the "IntersectCurves" method. These lines intersect the machined surface of the workpiece with the intersection plane, generated in the previous step. Following, the intersection curve is segmented into equally spaced points (Figure 2 - step 3a) with the "EqualSegment" method. The coordinates of the points are then extracted with the "GetSketchPoints2" method to a CSV file (Figure 2 - step 3b). Finally, the *Ra*, *Rz,* and *Rt* values are computed for each plane. According to ISO21920, *Ra* is defined as the average absolute deviation of the irregularities from the mean line over a sampling length (*L*). To estimate *Ra,* equation (3) is used. *Rz* is the difference between the maximum and the minimum height within *L,* with *z* being one step point of the simulation. Equation (4) is used to determine *Rz*. In these formulae, *p* denotes the peaks and *v* the valleys within the length of the profile assessed. Moreover, *Rt* is the difference between the maximum and the minimum height within the evaluation length. Equation (5) is used to compute *Rt*, with *Rp* and *Rv* being the highest peak and lowest valley, respectively. To measure the mean values of all parameters, the calculation process is repeated for each one of the section planes (Figure 2 - step 4a). Finally, the roughness profile for each plane is plotted (Figure 2 - step 4b).

$$R_a = \frac{1}{n}\sum_{i=1}^{n}|z_i| \tag{3}$$

$$R_z = \frac{1}{n}\left(\sum_{i=1}^{n}p_i - \sum_{i=1}^{n}v_i\right) \tag{4}$$

$$R_t = R_p + R_v \tag{5}$$

2.3. Experimental testing

The experimental testing consists of nine experiments, by holding depth-of-cut equal to 0.5mm and varying cutting speed and feed between 150m/min to 250m/min and 0.04mm/rev to 0.12mm/rev, respectively. The Boxford 160TCL CNC lathe was utilized for the experimental work. A full factorial design was used, with three symmetric levels, leading to nine experiments.

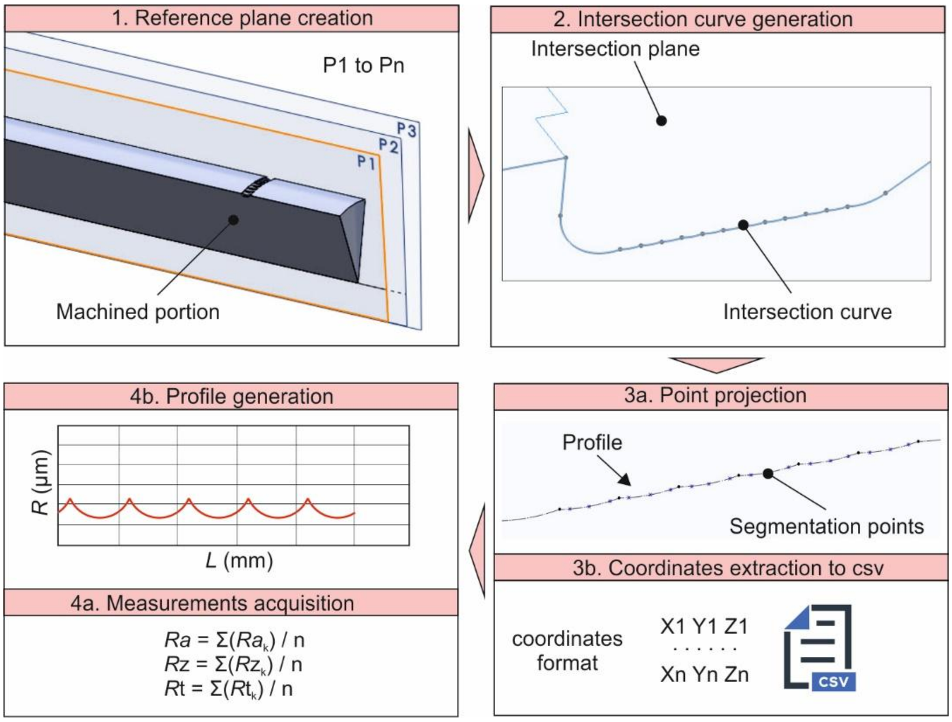

Fig. 2. The workflow of the measurements

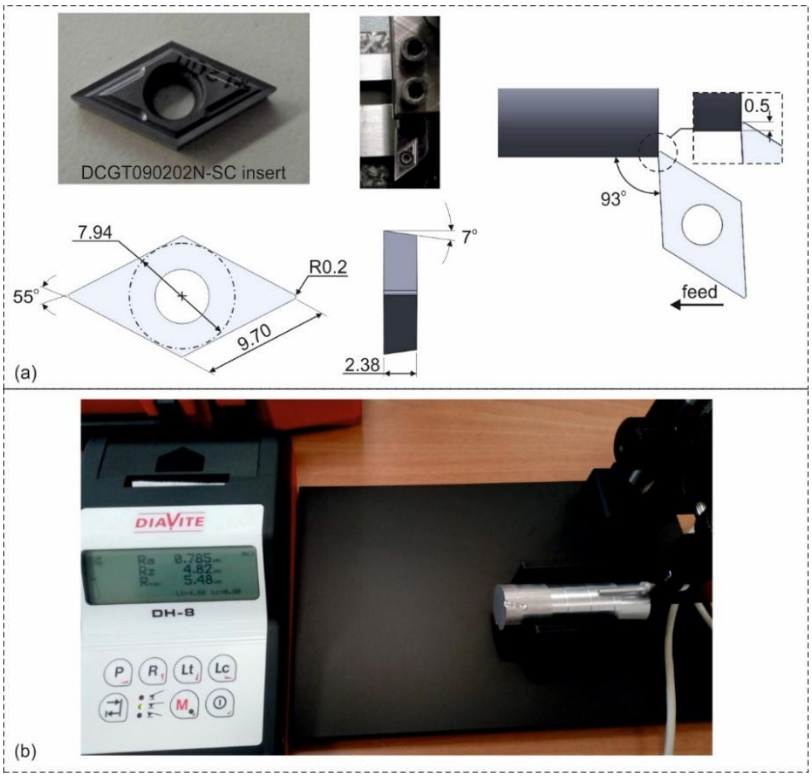

Fig. 3. The experimental setup: the cutting system and its properties (a), the measurement gauge (b)

Figure 3a illustrates the most important specifications and geometrical aspects of the used insert, namely DCGT090202N-SC. To secure the insert, the SDJCL 1010-03S tool holder was used. A typical aluminium billet, series 2000, with a 30mm diameter, was selected as the work material, and three pieces of equal length (~100mm) were prepared. Figure 3b depicts the measurement process of a sample workpiece. Three cuts, 10mm wide each, were machined on the workpieces. The measurements were carried out with the DIAVITE DH-8 mechanical gauge system, in accordance with the ISO21920 standard. As already discussed, only Ra, Rz, and Rt parameters were measured, since they constitute the most common roughness measurements for a machined profile. To estimate the experimental values of these parameters, the mean of four different measurements was used, which were taken at four anti-diametral points of the cuts. The cut-off length λc was set to 0.8mm by considering both the expected surface roughness range (within a few microns) and the probe's tip radius, as instructed by the ISO21920 standard.

3. RESULTS AND DISCUSSION

To validate the algorithm, a comparison was made between the experimental and the simulated measurements for the nine experiments. Figure 4 includes the comparison bar charts for the three measured parameters.

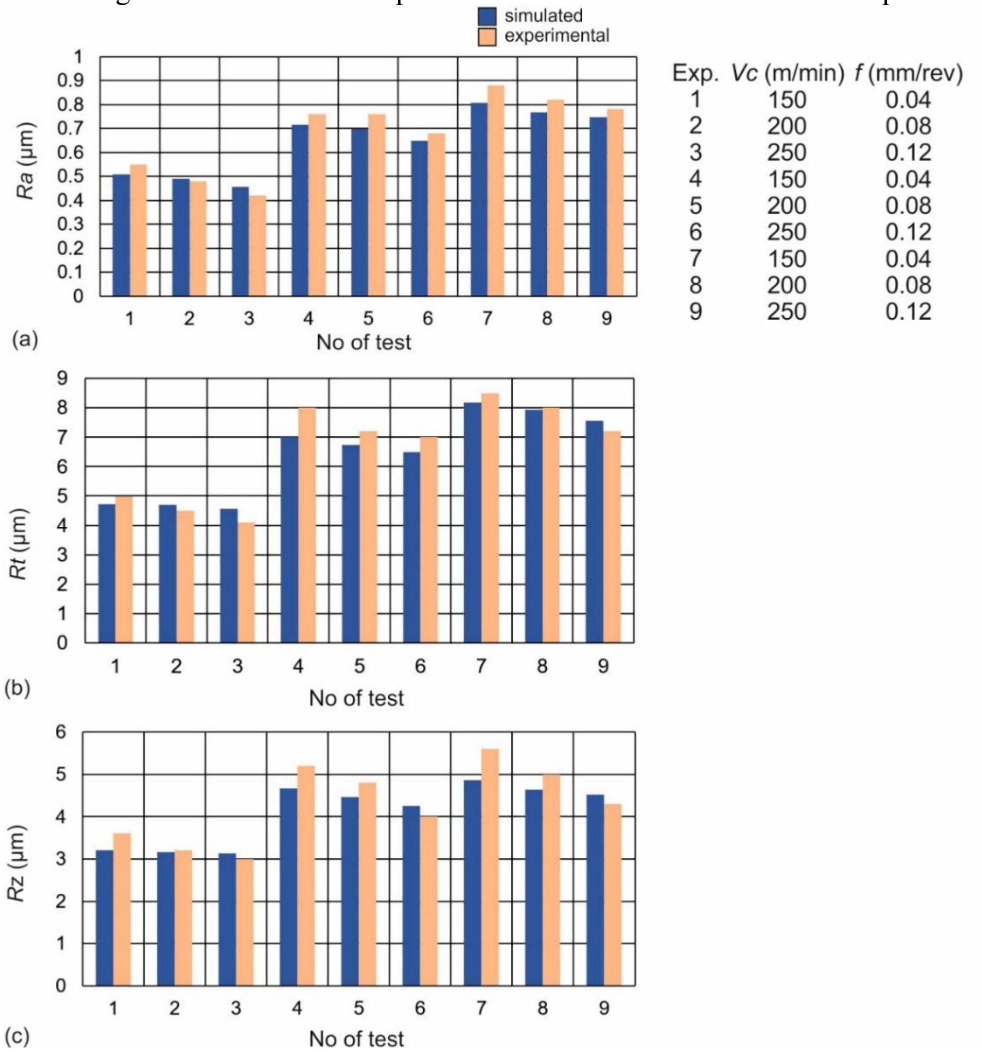

Fig. 4. Experimental and simulated surface roughness measurements comparison for *Ra* (a), *Rz* (b) and *Rt* (c)

In specific, Figures 4a, 4b and 4c depict the *Ra*, *Rz* and *Rt* respectively. It is evident that the simulated values are comparable to the experimental ones. By calculating the relative error between the experimental and the simulated values, the following approximate ranges were determined: −9% to 8%, −15% to 6% and −14% to 5% for *Ra*, *Rz* and *Rt* respectively. It is shown that as expected, lower feed values produced better surface quality. The expected behaviour (Tzotzis et al. 2023), in addition to the effects of the tool's microgeometry (Tzotzis et al. 2020a), were successfully captured by the simulated process. This comparison proves the validity and the accuracy of the developed algorithm, which can be used to estimate the surface roughness of a machined workpiece without any specialized equipment or similar resources.

4. CONCLUSIONS

The demand for CAD-based simulations is rapidly increasing due to their simplicity and ease of use, without the need for setting up costly software or devices. An alternative approach for simulating a widely applied process, such as external turning and the acquisition of surface roughness measurement, is proposed. The developed algorithm exhibits increased accuracy and robustness in generating the results, as proved by the experimental testing. Concluding, the next remarks are stated:
The proposed method contributes towards reducing preparation time, costs, and resources.

It provides quick and accurate preliminary measurements for the surface roughness of machined parts.
It takes into account both geometrical and conditional aspects.
The algorithm can be edited in order to be used for other similar machining processes.
Finally, the results are comparable to other simulation methods, such as the Finite Element Method (FEM).

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REFERENCES

1. Bartłomiej, Sobolewski. (2013) *Method of Spiral Bevel Gear Tooth Contact Analysis Performed in CAD Environment*. Aircraft Engineering and Aerospace Technology 85(6), 467–474, https://doi.org/10.1108/AEAT-11-2012-0207.
2. Campi, Federico, Claudio Favi, Michele Germani, Marco Mandolini. (2022), *CAD-Integrated Design for Manufacturing and Assembly in Mechanical Design,* International Journal of Computer Integrated Manufacturing 35(3), 282–325, https://doi.org/10.1080/0951192X.2021.1992659.
3. Chervinskii, F, S Zobov, A Rybnikov, D Petrov, K Vendidandi, (2023), *Auto-Assembly: A Framework for Automated Robotic Assembly Directly from CAD*, In 2023 IEEE International Conference on Robotics and Automation (ICRA), 11294–11300, https://doi.org/10.1109/ICRA48891.2023.10161376.
4. Felhő, Csaba, Gyula Varga, (2022), *CAD and FEM Modelling of Theoretical Roughness in Diamond Burnishing*, International Journal of Precision Engineering and Manufacturing, 23(4), 375–384, https://doi.org/10.1007/s12541-022-00622-5.
5. Gella-Marín, Rafael, Anastasios Tzotzis, César García-Hernández, José-Luis Huertas-Talón, Panagiotis Kyratsis, (2021), *CAD Software Integration with Programming Tools for Modelling, Measurement and Verification of Surfaces*, In Experiments and Simulations in Advanced Manufacturing, 91–116, https://doi.org/10.1007/978-3-030-69472-2_5.
6. Kyratsis, Panagiotis, Nikolaos Tapoglou, Nikolaos Bilalis, Aristomenis Antoniadis, (2011), *Thrust Force Prediction of Twist Drill Tools Using a 3D CAD System Application Programming Interface*, International Journal of Machining and Machinability of Materials, 10(1–2), 18–33, https://doi.org/10.1504/IJMMM.2011.040852.
7. Michniewicz, Joachim, Gunther Reinhart, Stefan Boschert, (2016), *CAD-Based Automated Assembly Planning for Variable Products in Modular Production Systems*, Procedia CIRP, 44, 44–49, https://doi.org/10.1016/j.procir.2016.02.016.
8. Risbood, K. A., U. S. Dixit, A. D. Sahasrabudhe, (2003), *Prediction of Surface Roughness and Dimensional Deviation by Measuring Cutting Forces and Vibrations in Turning Process*, Journal of Materials Processing Technology, 132(1–3), 203–214, https://doi.org/10.1016/S0924-0136(02)00920-2.
9. Tapoglou, Nikolaos, Aristomenis Antoniadis, (2012), *3-Dimensional Kinematics Simulation of Face Milling,* Measurement, 45(6), 1396–1405, https://doi.org/https://doi.org/10.1016/j.measurement.2012.03.026.
10. Tzotzis, Anastasios, César García-Hernández, José-Luis Huertas-Talón, Panagiotis Kyratsis, (2020), *Influence of the Nose Radius on the Machining Forces Induced during AISI-4140 Hard Turning: A CAD-Based and 3D FEM Approach*, Micromachines, 11(9), 798, https://doi.org/10.3390/mi11090798.
11. Tzotzis, Anastasios, Cesar García-Hernández, José Luis Huertas-Talón, Panagiotis Kyratsis, (2020), *CAD-Based Automated Design of FEA-Ready Cutting Tools,* Journal of Manufacturing and Materials Processing, 4(4), 1–14, https://doi.org/https://doi.org/10.3390/jmmp4040104.
12. Tzotzis, Anastasios, Athanasios Manavis, Nikolaos Efkolidis, Panagiotis Kyratsis, (2021), *CAD-Based Automated G-Code Generation for Drilling Operations*, International Journal of Modern Manufacturing Technologies, 13(3), 177–184, https://doi.org/https://doi.org/10.54684/ijmmt.2021.13.3.177.
13. Tzotzis, Anastasios, Apostolos Tsagaris, Nikolaos Tapoglou, Panagiotis Kyratsis, (2023), *High-Precision CAD-Based Simulation for Turning Considering Tool Microgeometry*, International Journal of Mechatronics and Manufacturing Systems, 16(1), 83–95, https://doi.org/10.1504/IJMMS.2023.132023.

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