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Ižol, P., Varga, J., Vrabeľ, M., Demko, M., Greš, M.

EVALUATION OF 3-AXIS AND 5-AXIS MILLING STRATEGIES WHEN MACHINING FREEFORM SURFACE FEATURES

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Abstract: *The article deals with the comparison and evaluation of milling strategies, which are available in CAM systems and are used for the production of components with freeform surfaces. For the purpose of the experiment a test sample with a repeating shape feature was designed. First half of the test sample shape features were machined using 3-Axis milling strategies while second half was performed with strategies available on 5-Axis CNC machining centre. Simulated machining times as well as virtually machined surfaces using color maps with deviation values were evaluated by employed CAM software. Obtained data was used to evaluate the performance of 3-Axis and 5-Axis milling centre both individually and mutually. These results will be used to compare software data with data obtained from real sample production. The main goal is to verify the reliability of the results provided by CAM systems in the production of parts with freeform feature surfaces.*
Key words: *CAM system, milling strategies, machined surface.*

Procena strategija glodanja sa 3 i 5 osa prilikom obrade karakterističnih površina slobodnog oblika. *Članak se bavi poređenjem i evaluacijom strategija glodanja koje su dostupne u CAM sistemima i koje se koriste za proizvodnju komponenti sa slobodnim površinama. Za potrebe eksperimenta dizajniran je probni uzorak sa karakteristikom oblika površine koji se ponavlja. Prva polovina karakterističnih površina oblika testnog uzorka je obrađena pomoću 3-osnih strategija glodanja, dok je druga polovina izvedena sa strategijama dostupnim na 5-osnom CNC obradnom centru. Simulirana vremena obrade kao i virtuelno obrađene površine korišćenjem mapa boja sa vrednostima odstupanja su procenjene pomoću korišćenog CAM softvera. Dobijeni podaci su korišćeni za procenu performansi 3-osnog i 5-osnog centra za glodanje kako pojedinačno tako i međusobno. Ovi rezultati će se koristiti za poređenje softverskih podataka sa podacima dobijenim iz stvarnog uzorka. Glavni cilj je da se proveri pouzdanost rezultata koje daju CAM sistemi u proizvodnji delova sa površinama slobodnih oblika.*
Ključne reči: *CAM sistem, strategije glodanja, obrađena površina.*

1. INTRODUCTION

At present, most activities in the manufacturing industry are carried out on CNC machines. 3-axis or 5-axis machines of various kinematic principles are most often used in milling applications. Each type has its field of employmentaccording to its advantages and disadvantages. For some activities, the possibilities of machines overlap and the user must decide on which particular machine will carry out the process. The decision is mostly based on the user's experience with similar tasks.

To an increasing number of manufactured products have shaped or free form surfaces, respectively. They very often occur on tools for mass production, such as molds, dies and press tools. However, in many cases it is not necessary to employ 5-axis machine tool. The rule is that if the product (molded plastic part, pressed parts) can be removed from the tool shape in the specified direction, the shape is available for the milling tool in the same direction. This corresponds to the use of 3-axis machine tool. But 5-axis machines also bring a number of benefits. One of them is the changing position of the axis of the milling tool relative to the manufactured shape to ensure suitable cutting conditions [1, 2].

During the production of parts with shaped surfaces, spherical and toroidal milling tools are used. Due to the changing geometry of the tool - workpiece contact, it is not possible to keep the cutting conditions at constant values. The variability of the contact geometry is described in several publications [4, 5, 6]. For this reason, the choice toolpaths is one of the critical parameters in the design of machining processes. In commercial CAM systems, toolpaths are selected from standard path libraries, and their shape is selected mainly with respect to the geometry of the finished surface [3].

2. EXPERIMENT METHODOLOGY

This paper is based on previous investigations [7-10], dealing with the comparison of strategies for 3-axis milling machines. The aim of the experiments was to compare the milling strategies used in the production of components with shaped surfaces. Since the shaped surface is usually manufactured by 3 and 5-axis milling, they were compared to identical strategies for both milling processes. Three strategies were chosen, namely Constant-Z, Radial and Linear. The Linear strategy took the opportunity to automatically generate additional paths rotated 90 ° to improve surface quality.

For the purposes of the experiment, a sample with six hemispherical surfaces on cylindrical protrusions was designed. The purpose of the protrusions is to allow

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good access of the tool and measuring device to the evaluated surfaces. The dimensions of the base are 100 x 67 mm, the radius of the hemispherical surfaces is 10 mm. The material of the sample is steel 1.2083, often plastic molds. The semi-finished product has the same floor plan dimensions as the sample, its height is 26 mm. The CAM system SolidCAM 2019 was chosen for the creation of NC programs. The advantage of the system is the ability to convert 3-axis milling operations to 5-axis while maintaining the main settings, which was fully utilized during the experiment. A postprocessor for the 5-axis continuous milling machine DMG Mori DMU 60 eVo was used to generate NC programs, on which the sample will be produced.

Fig. 1 illustrates the shape of a sample with the contour of the stock material and the position of the zero point.

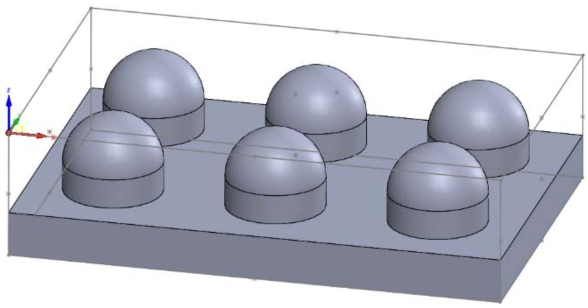

Fig. 1. Sample with the contour of the stock material and the position of the zero point

Software (CAM) data were evaluated, namely simulated machining times and virtually machined surfaces using color maps with deviation values. The acquired data were used to compare strategies for 3- and 5-axis milling as well as to their mutual comparison. The obtained software data will be aligned with data achived during real sample production. The ultimate goal is to verify the reliability of the results from simulations of CAM system and to compare the advantages and disadvantages of using 3- and 5-axis machines in the production of shaped surfaces..

3. EXPERIMENTAL WORK

The NR.RD.10,0.20 ° .Z4.HB.L TI400 milling cutter with the manufacturer's recommended cutting speed v_c = 150 m/minand and feed per tooth fz = 0.1 mm was chosen for the production of shaped surfaces. The same parameters were used in the settings of all assessed strategies, the main requirement was the height of the peaks (surface roughness) after machining, set to 0.005 mm

Generated toolpaths for 3-axis milling are shown in Fig. 2.

By converting 3-axis operations to 5-axes, the monitored settings were kept. The position of the tool axis was controlled by a curve (circle) sketched at a defined distance below the shaped surface. The inclination angle of the tool axis relative to the Z axis is controlled by the size of the circle and distance, respectively. The deflection of the tool axis improves the engagement ratios, because a tool area with a low cutting speed is excluded from cutting. The position of the tool at the top of the shape and at its bottom is shown in Fig. 3. The tool paths for 5-axis milling are shown in Fig. 4.

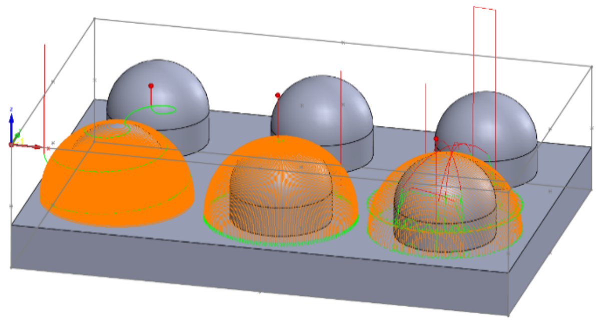

Fig. 2. Toolpaths for 3-axis milling. From the left : Constant-Z, Radial and Linear

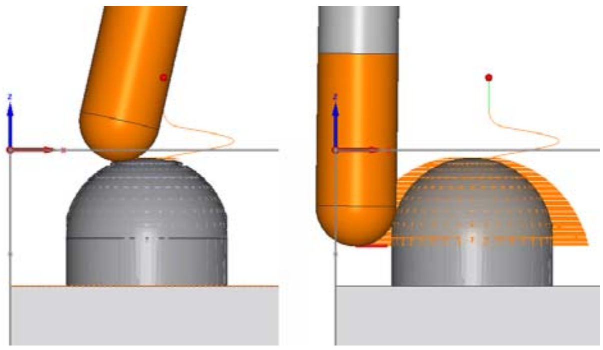

Fig. 3. The tool position at the top and bottom of the workpiece during machining simulation

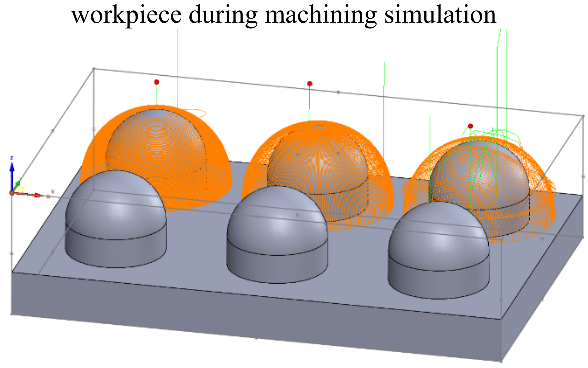

Fig. 4. Toolpaths for 5-axis milling. From the left : Constant-Z, Radial and Linear

The tool paths of the Constant-Z strategy were almost identical in both cases. Significant differences are noticeable in the other two strategies. Within the 5-axis variant, the tool paths are not regularly distributed. Fig. 5 represents a detailed view of the tool paths by employed radial strategy near the apex during 3-axis milling, while Fig. 6 shows the paths in 5-axis milling. The irregularity is caused by plotting tool paths for the cutting tool center (the top of the hemisphere), not for the tool - part touch point.

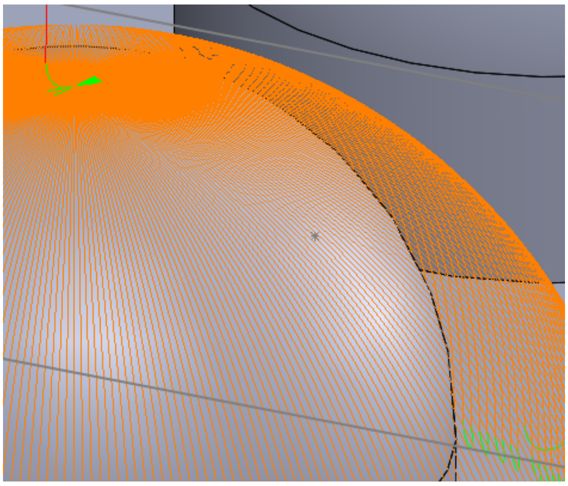

Fig. 5. Toolpaths for 3-axis milling with employed radial strategy

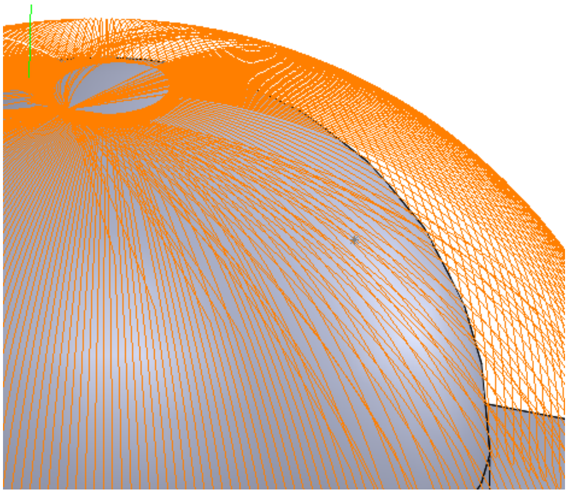

Fig. 6. Toolpaths for 5-axis milling with employed radial strategy

4. RESULTS

Machining times were also obtained when generating the tool paths. Their comparison is shown in the graph in Fig. 7. During 5-axis milling, the machining time was slightly extended It is about 3% for the Constant-Z strategy, 6% for the Radial strategy and 12% for the Linear strategy.

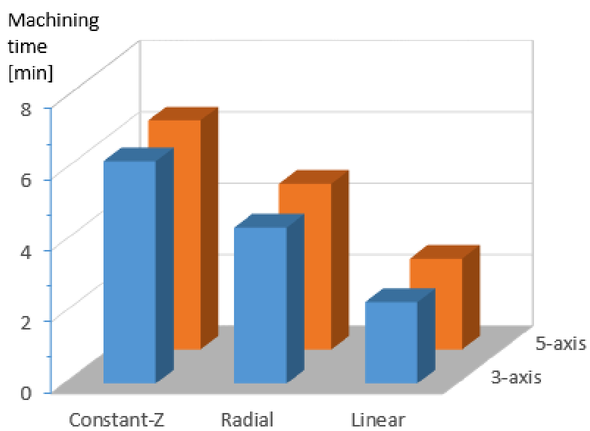

Fig. 7. Comparison of the machining times

Used CAM system allows an analysis of the virtual surface finish using color maps. It is possible to assign a value to colors and to determine the share of undercut or uncut areas in the total area of the produced shape by their gradual change.

In Fig. 8 is an overall view of the sample after simulation in a CAM system. The assignment of undercut and undercut values to the individual colors is shown in Fig. 9.

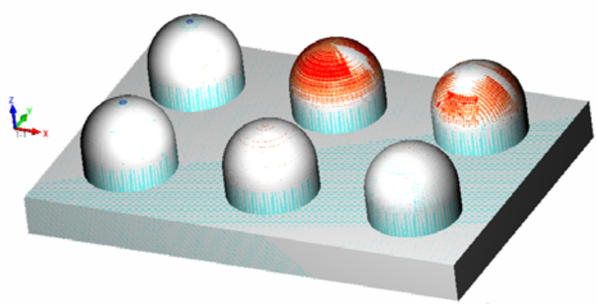

Fig. 8. Surface finish of the samples after simulated machining

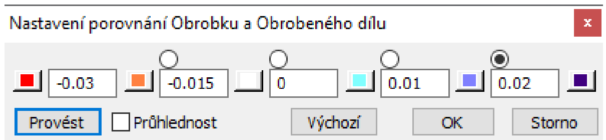

Fig. 9. Assigned values to colors for undercut and undercut analysis

When machining with Constant-Z strategy, almost identical surfaces were obtained, in the 5-axis variant, slightly higher undercut values were observed.

The Radial strategy showed only undercut deviations. In the 3-axis variant, the undercut occurred only locally near the apex; in the 5-axis variant, almost the entire surface of the sample was undercut. The maximum value of the deviation was also significantly higher. A visual comparison is shown in Fig. 10.

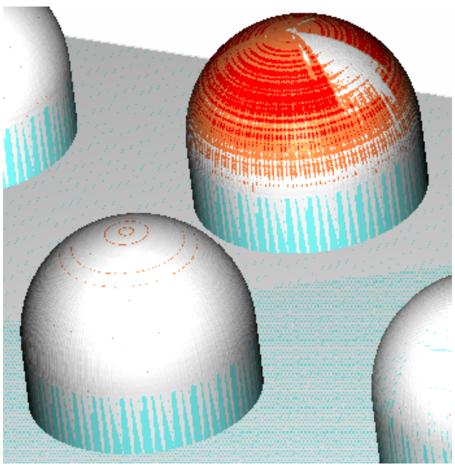

Fig. 10. Comparison of the machined surfaces made by Radial strategy - bottom 3-axis, top 5-axis milling

Within employed Linear strategy, identical deviations of uncuts were achieved; the 5-axis variants had a significantly higher maximum deviation value.

An overview of the maximum values of deviations for the assessed strategies and milling methods is given in Tab. 1. The comparison in the form of a graph is shown in Fig. 11.

Strategy		Undercut values max. [mm]	Uncut values max. [mm]
Constant-Z	3-axis	-0,012	0,03
	5-axis	-0,015	0,03
Radial	3-axis	-0,015	0
	5-axis	-0,039	0
Linear	3-axis	-0,014	0,015
	5-axis	-0,05	0,015

Tab. 1 Maximum values of undercut and uncut for evaluated strategies

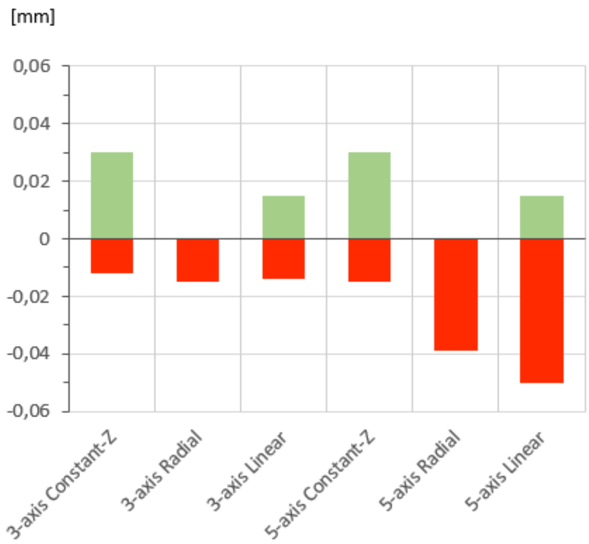

Fig. 11. Comparison of machined surface deviations (red – undercut, green - uncut)

5. CONCLUSIONS

The tool paths obtained by 3-axis milling were arranged regularly for all strategies. During 5-axis milling, with the exception of the Constant-Z strategy, the tool paths are irregularly arranged with obvious compaction and/or omission of some areas. The reason is above described way of plotting tool paths by the CAM software.

Simulated machining showed an increase in machining time of 3 to 12% in all 5-axis milling strategies, which was least pronounced in the Constant-Z strategy with regularly arranged paths.

Surface analyzes after simulated sample machining indicate higher undercut values in 5-axis milling. At the same time, undercutting affects a significantly larger area of the machined surface than with 3-axis milling. The smallest differences were achieved with the Constant-Z strategy.

Described results will be used for comparison with the results obtained during real production of the samples. The aim is to verify the reliability of the results from simulations and analyzes available in CAM systems during the production of parts with shaped surfaces.

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***Authors:* Assoc. Prof. Peter Ižol, Assist. Prof. Ján Varga, Assoc. Prof. Marek Vrabeľ, PhD Stud. Michal Demko, Res. Assist. Prof. Miroslav Greš,** Technical University of Košice, Faculty of Mechanical Engineering, Prototyping and Innovation Centre, Park Komenského 12A, 042 00 Košice, Slovakia, Phone: +421 55 602 3361.
E-mail: peter.izol@tuke.sk; jan.varga@tuke.sk; marek.vrabel@tuke.sk; michal.demko@tuke.sk; miroslav.gres@tuke.sk