The tool path tolerance setting with respect to accuracy during 3axis milling

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ABSTRACT [1]

Article describes CNC milling center programing during 3 axis finish milling. Article is focused on setting the tolerance of toolpaths during finish milling in CAM systems. Finding of suitable toolpaths during finish milling is very time consuming and can be expensive.

Target is to recommend specific settings of tolerance in CAM system with the respect to achieved accuracy, machining time, surface roughness and quantity of NC blocks. The aim is also to compare the practical results of machining with predicted simulation.

The methodology evaluating this problem is based on the following steps: experimental sample design for 3axis milling, accuracy prediction of machined samples, production of samples using CNC milling center, analysis of accuracy and surface roughness with respect to shape of workpiece.

The result is the variance of shape accuracy deviations from the specified CAD model of the workpiece, focused on individual areas of its shape. The research results show milled surface errors depending on the toolpath tolerances. It is not preferred to set very low tolerance in the CAM system with respect to increasing machining time.

Key words: toolpath, tolerance, CAM system, Accuracy, 3axis milling,

[1] Acknowledgement of the final version of the paper_Peer-editor: assoc. prof. Josef Chladil, CSc. MSc., Brno Univerzity of Technology, Faculty of Mechanical Engineering, Dept. of Machining Technology. Address: Technická 2896/2, Královo Pole, 61669, Brno, Czech Republic.

1. INTRODUCTION

Machining accuracy is critical for the quality of a mechanical product and is an important consideration for any manufacturer [6] [11] [12] [14] [16] .

In the literature [2] [3] [4] milling errors caused by cutter deflection when machining a sculptured part using a ball-end milling tool can be found. In the literature [1] [4] [5] [9] [10] there is a flexible model for estimating the form error in three-axis ball-end milling of sculptured surface.

On Fig. 1 displayed toolpath tolerance when linear interpolation is used. This research was carried out e.g. in Fig. 1 describes one toolpath during 3axis operation. This toolpath creates a consistent scallop motion relative to stepover distance.

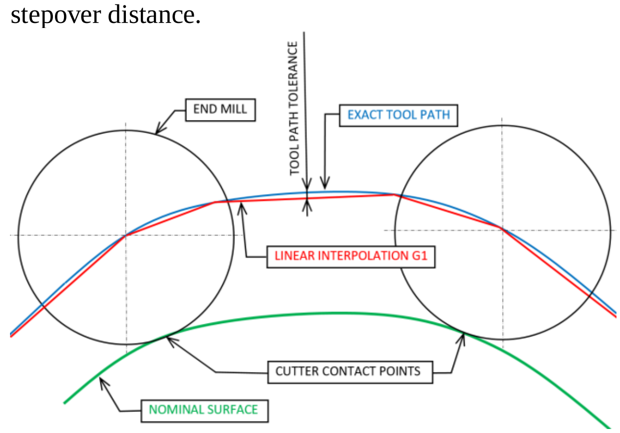


Fig. 1 Toolpath tolerance in front view

CAM systems offer to set toolpath tolerance. Fig. 2 shows Mastercam possibilities.

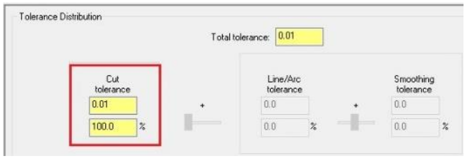


Fig. 2 Toolpath tolerance set in the CAM system (Mastercam)

2. EXPERIMENTAL WORK

This article is focused on the analysis of geometrical accuracies during milling. Milling of samples (see Fig. 3) has been realized on 5axis milling CNC center, with condition in Tab. 1 and Tab. 2. On Fig. 4 schematic diagram of the experimental work is displayed.

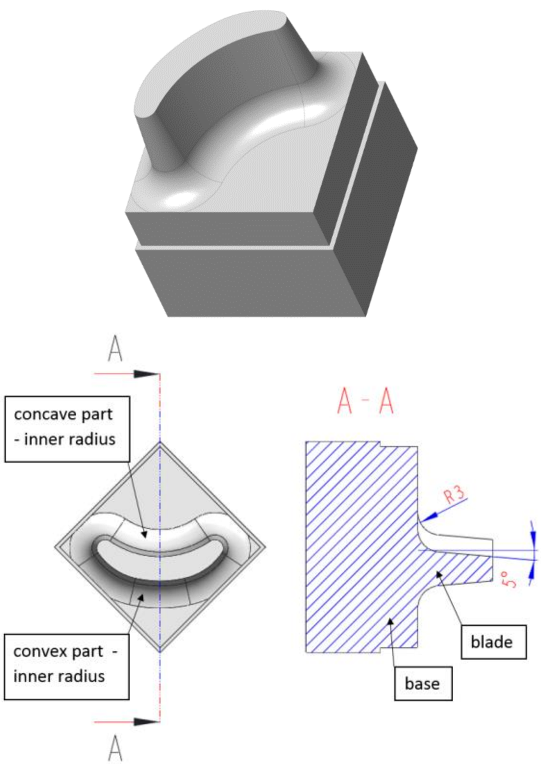


Fig. 3 Design of samples

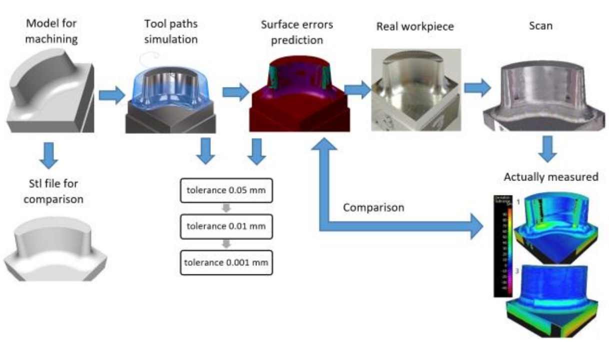


Fig. 4 Scheme of the experimental work

Table 1 Technological parameters of the cutting process

Machine	DMG MORI DMU 50	
Control system	Heidenhain iTNC 530	
CAM system	Mastercam 2017	
Material of workpiece	Aluminium alloy EN AW-6060 – AlMgSi0,5 F19	
Workpiece	20x20-26 mm	
Clamping	Vice KSX-L 125 (SCHUNK)	
Tool	Solid carbide ball end mill, D6 mm (R216.42-06030-AP06G 1620)	
Tool holder	High-precision hydraulic chuck - CoroChuck 930	
Tool overhang	60 mm	

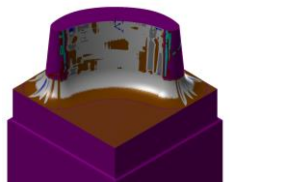
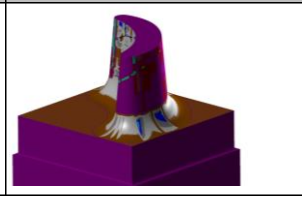
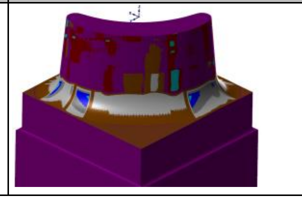
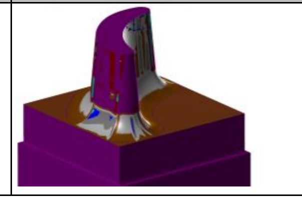
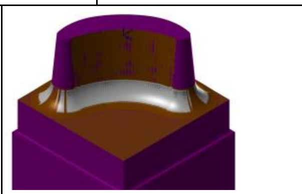
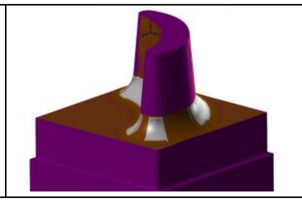
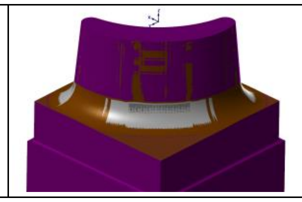
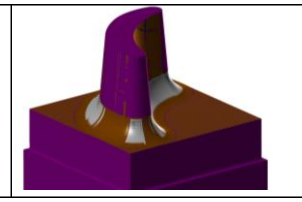
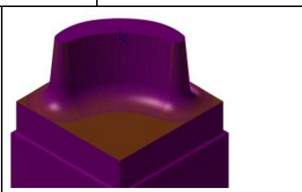
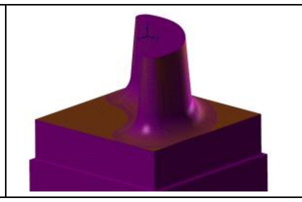
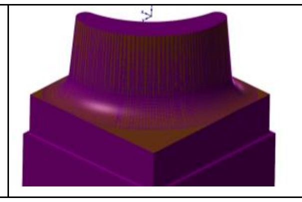
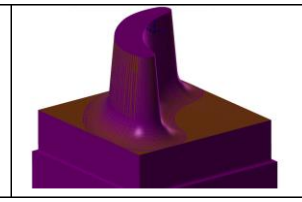
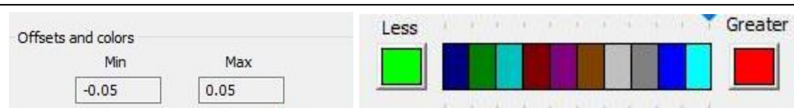
Table 2 Cutting conditions for finishing in 3axis milling operation

Endmill diameter	d	[mm]	6
Spindle rev.	n	[min^{-1}]	17500
Cutting speed	v_c	[m·min^{-1}]	330
Axial cutting depth	a_p	[mm]	0.15
Radial cutting depth	a_e	[mm]	0.15
Feed per tooth	f_t	[mm]	0.1
Feed	f	[mm·min^{-1}]	3713
Coolant	Blasocut 2000 CF, Art. 875-12		
Milling strategy	Climb milling		

2.1 Prediction of milled surface errors

CAM system enable to compare CAD model with prediction of milled surfaces. This prediction allows to determine size of errors of calculated surfaces before machining. Tolerance of the model and tool shape was set at 1 μm. The predicted errors (residual material) are in the range of -40 to 50 μm with a toolpath tolerance 50 μm, see Tab. 3.

Table 3 Predicted surface errors

Toolpath tolerance [μm]	View 1	View 2	View 3	View 4
50				
Predicted errors	-40 to 50 [μm]			
10				
Predicted errors	-15 to 15 [μm]			
1				
Predicted errors	-2 to 2 [μm]			
Offsets and colors				

The Table 4 shows toolpath tolerance and their influence on machining time and number of NC codes.

With more precise tolerance the number of NC codes increases. Thanks to the time then required to process the NC code by the CNC machine the machining time also increases. CAM simulation does not include this time for processing the NC code so it remains same (with minimal deviation during calculation when set very precise tolerance).

Table 4 *Machining time*

Toolpath tolerance [mm]	Number of NC blocks [-]	CAM simulation time [min:sec]	Machining time [min:sec]	Time increasing [%]
0,050	5625	01:17	01:58	-
0,010	9315	01:17	01:58	0
0,001	21944	01:19	02:08	8.5

2.1 Accuracy measurement

Machined samples measurements were carried out with an optical three - dimensional microscope Alicona Infinite Focus G5. The optical 3D micro coordinate measurement system is suitable for accuracy and surface roughness measurements.

Fig. 5 Real scan by Alicona Infinite Focus G5

The measured samples were compared with the model created in the CAD system Inventor. The models were saved with the input format necessary for Alicona Infinite Focus G5 (software IF MeasureSuite) in the format *. stl with a tolerance of 0,1μm for comparison.

A range of the variance scale was selected from -50 to +100 μm for all samples. Machined surfaces colored dark blue has minimal deviations (range of -10 to 10 µm), see Fig. 6,7,8.

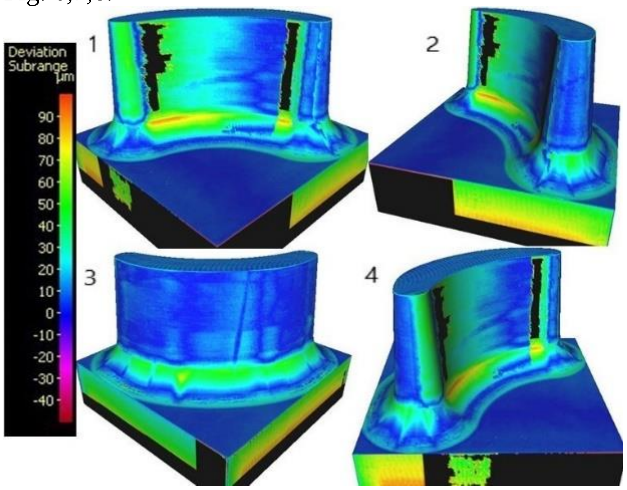


Fig. 6 Comparison of the original CAD model with the workpiece after milling (toolpath tolerance 50µm)

As the toolpath tolerances in the CAM system are reduced, surface deviations are also reduced.

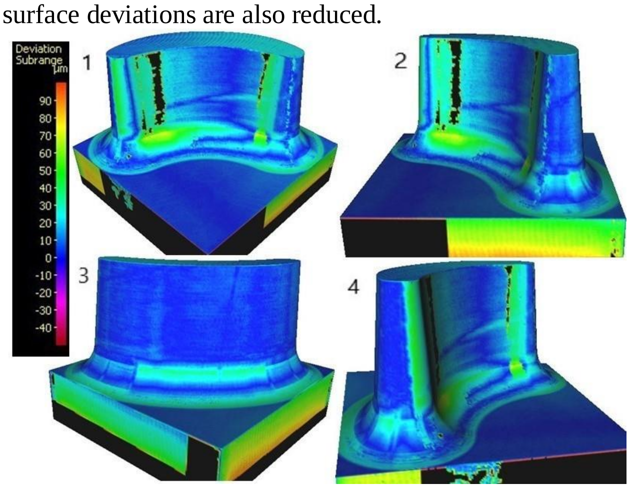


Fig. 7 Comparison of the original CAD model with the workpiece after 3axis milling (toolpath tolerance 10µm)

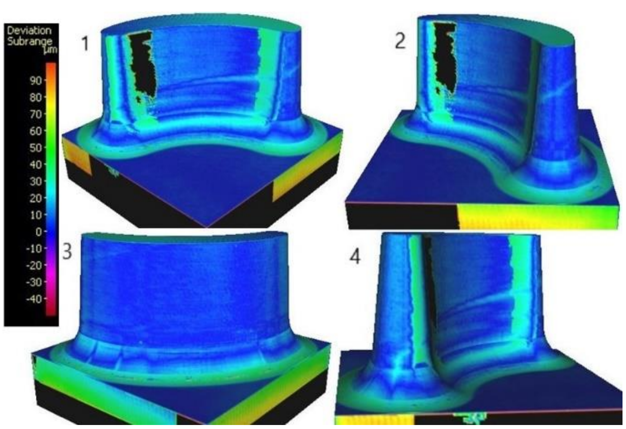


Fig. 8 Comparison of the original CAD model with the workpiece after milling (toolpath tolerance 1µm)

Displayed black color on the scan means wrong part of workpiece scan, but this do not influence comparison results.

Problematic area of cutting is inner radius of convex and concave part of blade, see Fig.9 and 10. The largest surface deviations are placed according to colored deviation in concaved part of inner radius of blade. The maximum surface deviations are 89 µm.

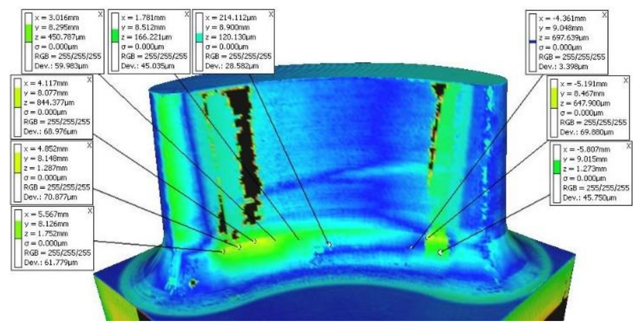


Fig. 9 Comparison of the original model with the workpiece, view 1 (toolpath tolerance 10µm)

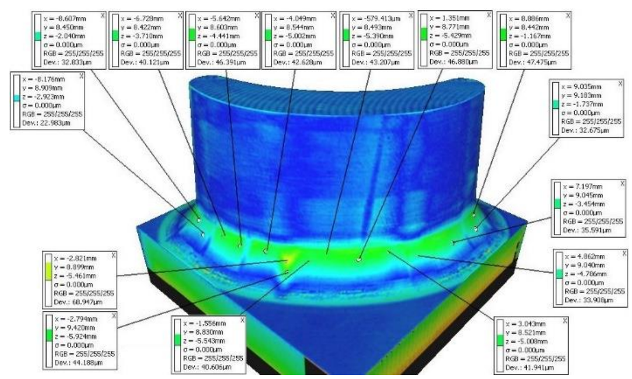


Fig. 10 Comparison of the original CAD model with the workpiece, view 3 (toolpath tolerance 10µm)

Fig. 11 represents values of deviations on the real surface compared to toolpath tolerance set in CAM system. Shape of blades out of inner radius have smallest surface deviations up to 48 µm. Deviations mentioned above are acceptable for production.

These real surfaces were also compared with the predicted surfaces calculated in the CAM system Mastercam, see Table 5.

Table 5 Range of surface deviations

Range of surface deviations			
	Toolpath tolerance [µm]		
	50	10	1
Predicted deviations µm	-30 to 30	-15 to 15	-2 to 2
Measured deviations µm	1 to 89	0 to 71	1 to 77

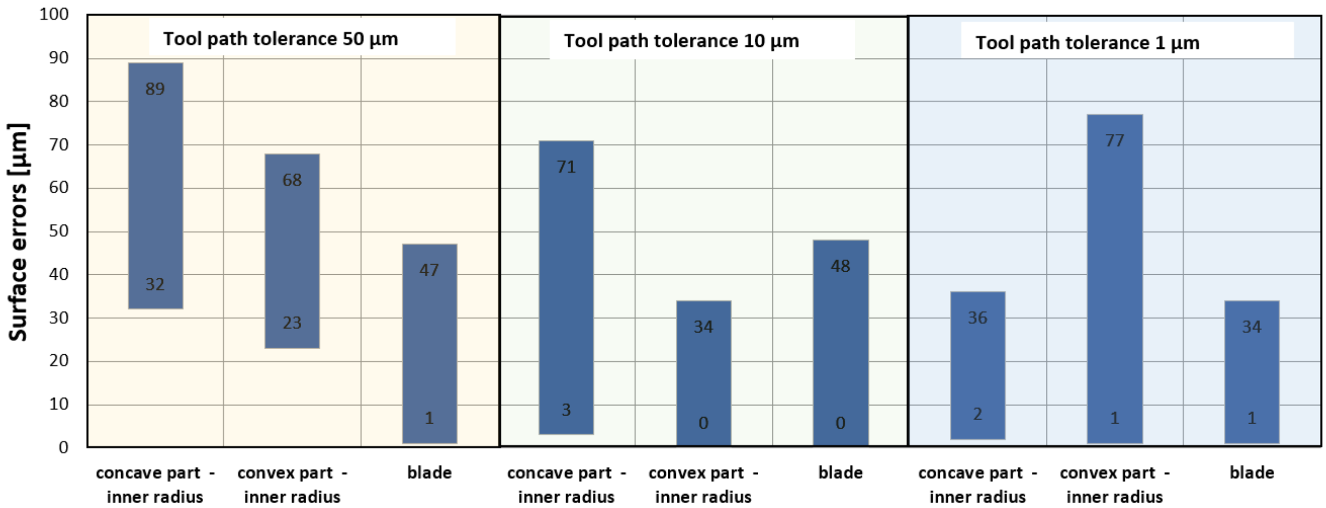


Fig. 11 Surface deviations according to toolpath tolerances

2.1 Surface roughness

Surface roughness is often classified in two directions: pick feed direction and feed direction during milling.

The surface roughness in feed direction is theoretically formed by copying the roughness of the cutting edge and practically formed by friction of the tool back and the machined surface [5] [6].

The roughness of pick feed direction is created by copying the rounded tool edge onto machined surface with effect of plastic deformation and tool wear [7] [13] [15] .

Fig. 12. shows the surface roughness (parameters Ra - the arithmetical mean deviation of the assessed profile and Rz - the maximum height of the profile) according to toolpath tolerances set in CAM system measured in pick feed direction and feed direction. Lower tolerance cause decreasing surface roughness.

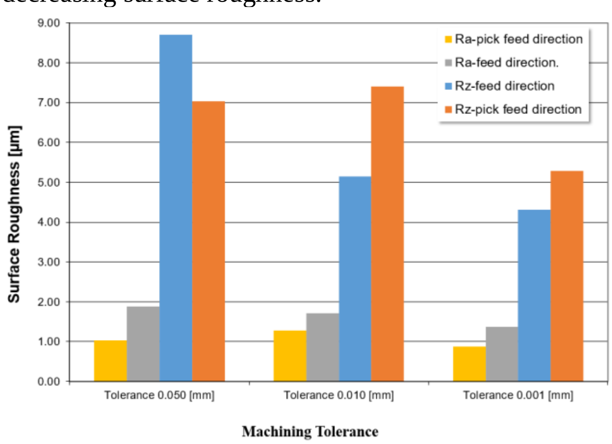


Fig. 12 Surface roughness according tool path tolerances

3. DISCUSSION AND CONCLUSIONS

Research results confirm the assumption that decreasing toolpath tolerance will increase machining accuracy.

Tool path tolerance 1 µm will increase machining time of 8.5 % but the accuracy and surface roughness are very similar to tolerance 10 µm. The recommendation is using toolpath tolerance 10 µm in CAM system.

The prediction (calculation) of residual material in the CAM system is the most consistent with the real-measured residual material. The results show the quality of the computational algorithm used in the CAM system.

ACKNOWLEDGMENT

This paper was supported by project MPO TRIO "FV40115 Development of a new series of medium-pressure valves, their manufacturing technology and testing methodology, simulating 60 years of service life" financed by the Ministry of Industry and trade, Czech Republic. This research was funded by project Innovative and additive manufacturing technology - new technological solutions for 3D printing of metals and composite materials, reg. no. CZ.02.1.01/0.0/0.0/17_049/0008407 financed by Structural and Investment Founds of Europe Union.

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