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This study aims to provide the recent advances in machining for modern manufacturing engineering, especially CNC machining, modern tools and machining of difficult-to-cut materials, optimization of machining processes, application of measurement techniques in manufacturing, modeling and computer simulation of cutting processes and physical phenomena.

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PREFACE

Machining is one of the most popular technique to change shape and dimensions of the objects. Machining operations can be applied to work metallic and non-metallic materials such as ceramics, composites, polymers, wood.

Cutting tools have been used since ancient times to remove excess material from forgings and castings. Nowadays, metal cutting became one of the primary manufacturing processes for finishing operations. In the last few years we have observed a rapid development in automation of manufacturing processes, especially in automatic control systems. Progress in cutting stimulates a significant increase in the metal removal rate and achieving high accuracy in terms of dimensions and shape of machine parts. New materials, which play the key role here, are used to produce cutting tools.

To meet today's high demands concerning accuracy and efficiency of the manufacturing process of machine parts, it is necessary to use computer methods for designing of technological processes.

This study aims to provide the recent advances in machining for modern manufacturing engineering, especially CNC machining, modern tools and machining of difficult-to-cut materials, optimization of machining processes, application of measurement techniques in manufacturing, modeling and computer simulation of cutting processes and physical phenomena.

Wojciech Zębala

PART 2

CAD/CAE/CAM Techniques

Chapter 2.1

STUDY OF Z-LEVEL FINISHING MILLING STRATEGY

Miko B.
Óbuda University, Budapest, Hungary

Abstract: *The article presents the z-level milling strategy, which is one of the most important strategy in a CAM system. In case of z-level milling, we can use end mill with corner radii for finishing milling of steep walls. The aim of this article is present the effect of the parameters of part (gradient of the surface, direction of the cutting), tool (corner radii) and cutting process (depth of cut, feed per teeth) to the surface quality.*

Keywords: *CAM systems, z-level milling, surface quality*

1. Introduction

A complex product, like an engine for a car, contains lot of different parts, which have different shape and require different manufacturing process. However the milling technology is not a primary manufacturing technology in case of automotive parts, because of the use of sheet metal, plastic and casted and forged parts, the production of manufacturing equipments, like dies and moulds etc., require the milling technology.

The conventional milling machines ensure the production of simple geometry, like planes and holes, but the complex part geometry is able to be manufactured by CNC milling machine. The 2.5D milling means that the milling cutters move in a curve in x-y plane and the z move means the depth of cut. The 3D milling means, that the milling cutter moves in 3 axes parallel, which ensures the manufacturing of complex surfaces.

In case of complex surfaces the CNC program is generated by CAM system, because the tool path generation needs complicated calculation. The CAM systems contain several milling strategies, which identify the type of the manufacturing step. During the definition of a step the engineer (user) selects the strategy, sets the date of the milling cutter, the parameters of the cutting and the path, selects the area of the manufacturing.

The most important strategies are the volume milling, the z-level milling and the surface milling (Fig.1). In general, the volume milling is applied for roughing, the z-level milling and the surface milling are applied for finishing.

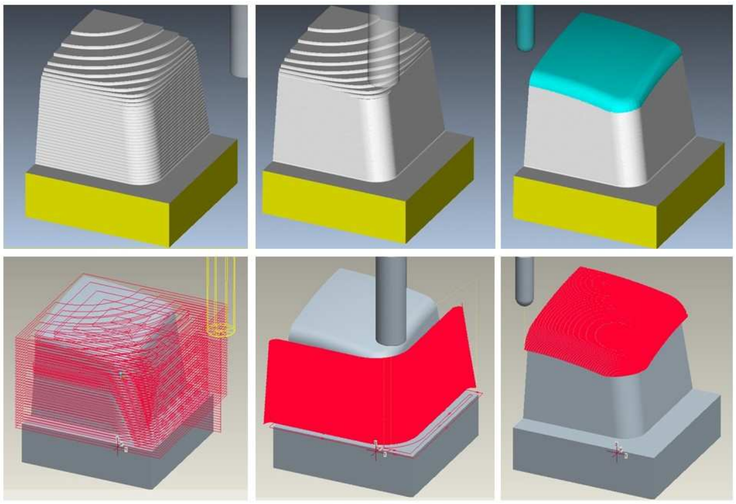

Fig. 1. Volume milling, z-level finishing and 3D surface milling

In this article, the z-level milling was studied. In case of z-level milling we can use end mill with corner radius for milling of steep walls. The aim of this article is to present the effect of the parameters of part, tool and cutting process to the surface quality.

2. Test environment and equipments

The test part was made of non-alloyed structural steel S355 (Fe 510). The part contains two different test surfaces with different gradients. Three different gradients were defined: A_1 = 65° / 75° / 85°. Every test surface contains two surfaces: the first one ensures parallel milling with the *x* axes (A_2 = 0°), and the second one is angled with *x* axes (A_2 = 45°) (Fig.2).

The CAD model and the NC programs was generated by *Pro/Engineer WildFire 4* integrated CAD/CAM software, and the machining was performed by *Mazak Nexus 410-A II* machining centre. The surface roughness was measured by *Mitutoyo SJ-301*. The surface roughness is determined by average of 3 measured values.

Two milling cutters were used for the tests: *Fraisa U5250.445* and *U5250.450*, the cutting diameter is 10 mm, in both cases, and the corner radii are 0,5 and 1 mm. The number of teeth is 6, the cutting speed (v_c) 200 m/min, the revolution (n) 6.400 1/min. The feed per teeth (f_z) and the depth of cut (a_p) were varied based on tool catalogue [1], feed per teeth were: 0.08/0.12/0.16 mm (feed speed: v_f = 3000/4500/6000 mm/min) and the depth of cut: 0.15/0.20/0.25 mm. The profile milling strategy was selected in the CAM system, and conventional milling was used.

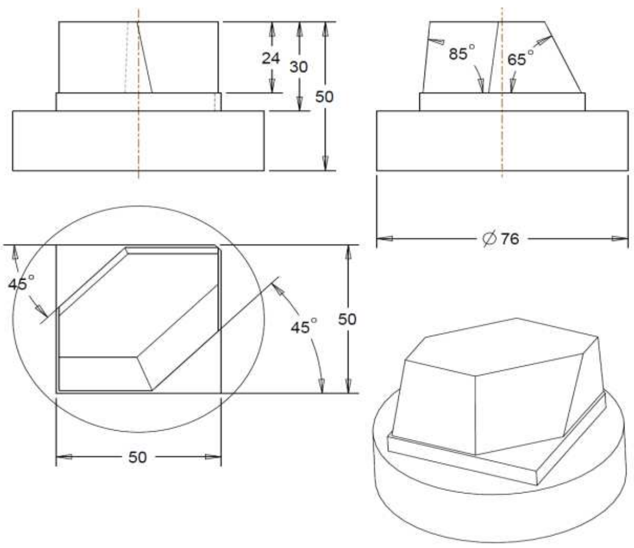

Fig. 2. Test part

Table 1. Test sets

Test part	No	R_{tool}	v_f	a_p	A_1
		mm	mm/min	mm	°
1	1	0.5	3000	0.15	65
	2	0.5	6000	0.15	85
2	3	0.5	4500	0.20	75
	4	0.5	6000	0.25	65
3	5	0.5	3000	0.25	85
	6	1	6000	0.15	65
4	7	1	3000	0.15	85
	8	1	4500	0.20	75
5	9	1	3000	0.25	65
	10	1	6000	0.25	85

The Table 1 shows the 10 test sets, which was determined by design of experiment (DOE) method. The DOE method ensures less number of tests with same effectiveness.

3. Results

The tests sets make possible several analyses. The Fig. 3 shows the measured Ra surface roughness values. The first curve (continuous curve) shows the surface roughness in case of *x* axes parallel milling, and the second curve (interrupted curve) shows the 45° milling. Based on the test in case of parallel milling the surface roughness is larger in nine cases, the maximum difference is up to 35% in case of 6th test surface. The cause of it is the less vibration, because the parallel motion of the *x* and *y* axes don't permit to develop the harmful vibration.

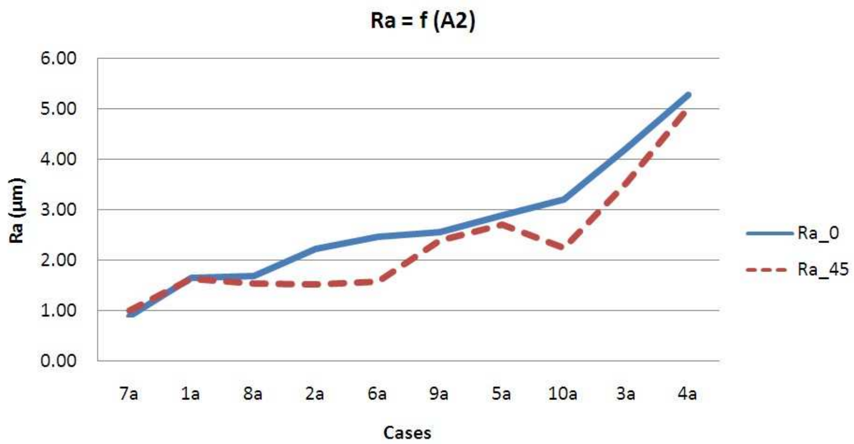

Fig. 3. Surface roughness in function of milling direction

The Fig. 4 shows the effect of the other parameters to the surface roughness, the parallel and 45° are separated.

The larger a_p cause larger surface roughness, it is evident. However, in case of 45° milling and smaller a_p it has smaller effect.

The wall gradient has advantageous influence to the Ra, because the high of the rest material is smaller, as it will be presented later on. This is the reason why the z-level milling is used for steep wall finishing. The milling direction does not have a significant effect.

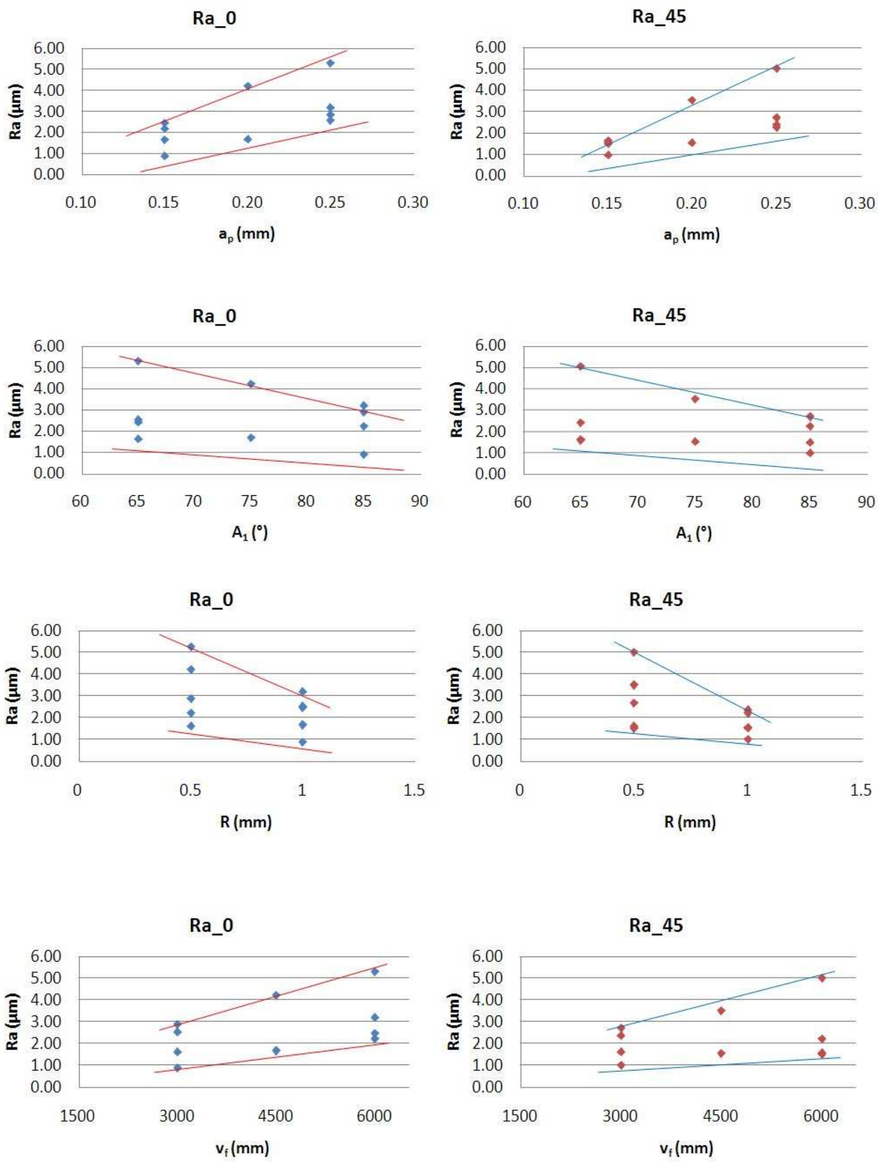

Fig. 4. Effects of different parameters to the surface roughness

The tool corner radius shows inverse proportionality, the larger radius causes better Ra, and significant difference between the parallel and 45° milling is experienced.

The last parameter is the feed speed (v_f) in the Fig. 4. The larger feed speed cause worse surface roughness, the influence of the A_2 is not significant.

The cause of the surface roughness is the rest material between the slices of the milling. This rest material is characterized by the cusp height parameter. As the Fig. 5 shows, the cusp height (Ch) is determined by the tool corner radius (R), the depth of cut (a_p) and the angle of the wall (α, in the actual research it was marked A_1).

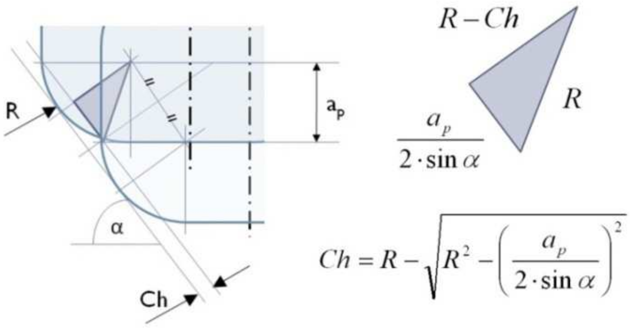

Fig. 5. Cusp height in case of z-level milling

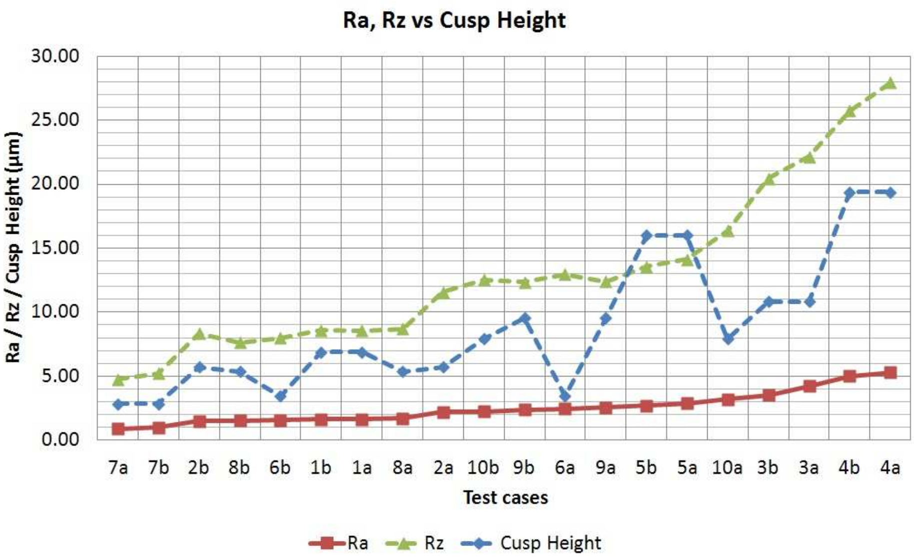

Fig. 6. Ra, Rz and cusp height in case of z-level milling

The connection between the cusp height and the surface roughness is evident, but based on Fig. 6, it is not a simple linear function, and other parameters have significant effects too.

The next two estimation formulas were created by the MiniTab v14 analysis software. As the result of numerous iterations, beside the cusp height, the feed speed and the angle of the wall, which was defined in radian, in this case, were important effect to the surface roughness. The R-Sq(adj) is 83.8 %, which is not too good result, but based on cusp height values (see Fig. 6) better result is not realistic goal. The second suggested formula works in the logarothmic space, the structure and the R-Sq(adj) value are similar (R-Sq(adj) = 85.0 %).

v1 : $Ra = 0.93 + 192\ Ch + 0.000309\ v_f - 1.17\ A_{1\_rad}$ (1)

v2 : $\ln Ra = - 0,52 + 0,660 \ln Ch + 0,563 \ln v_f - 0,603 \ln A_{1\_rad}$ (2)

Fig. 7 shows the estimated and the measured values of Ra. The estimated values follow the measured curve generally, but in some cases, there are larger error.

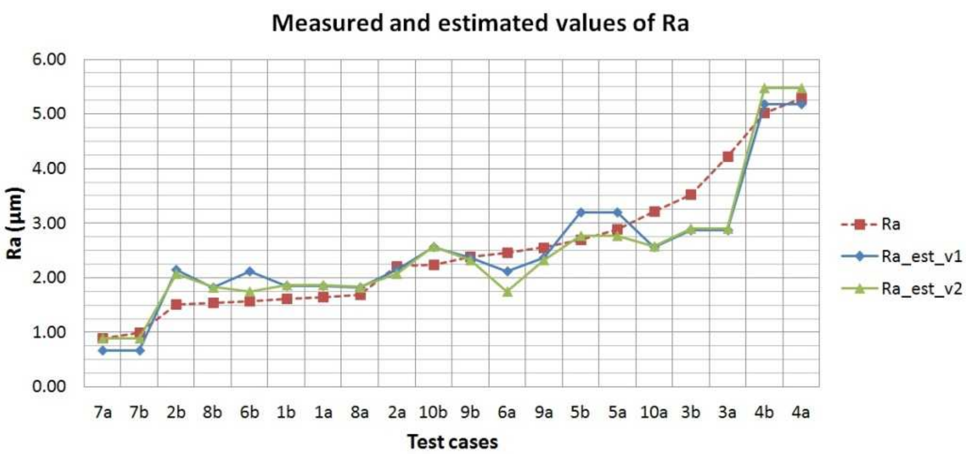

Fig. 7. Estimation of the surface roughness

4. Conclusion

Z-level milling is essential milling strategy for finishing of free form surfaces. Based on the tests, beside the tool parameters, the cutting parameters and the surface gradient, the milling direction has also influence to the surface quality.

The regression analysis showed the mathematical connection between the cusp height, which can be calculated, and the surface roughness parameter. In order to eliminate the error of the estimation of the surface roughness additional tests are required.

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[1] Fraisa (2011/12) *High-performance end mill tools 2011/12*; Fraisa SA Bellach.