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CAM Algorithm as Important Element by Achieving of Good Machined Surface Quality

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The paper deals with test of four different NC programs created by 4 different CAM algorithms using identical settings. The subsequent experimental verification has resulted in a conclusion that arrangement of the points on the tool path does have influence on the machining time and finish surface quality.

Keywords: CAM systems, toolpath optimization, NC programs, surface quality, machining time

0 INTRODUCTION

CNC toolpaths are based on NC programs which are created using CAM systems. These systems utilize different methods and mathematical algorithms for calculating or optimization of toolpaths, which can givevery different results with the same parameter settings [8] and [9]. In our past work we have noticed that arrangement of the points along the toolpath can have a substantial influence on the machining time and finished surface of the part.

1 EXPERIMENT PREPARATION

With the presented experiment we wanted to prove that the toolpath point arrangement could influence on machining time and a quality of the finished surface. We tested four different toolpaths, which were calculated with four different CAM algorithms using same settings.

The geometry of the part was presented by a half-sphere with a diameter of a 24 mm. On a bottom it transforms to a 3 mm radius (Fig. 1). The stock was a cylinder with a 30 mm diameter. The stock material was AlMgSi0.5.

All the experiments were made on a Sodick MC430L milling machine (Fig. 2 and Table 1).

The test tool had the following features:

- Tool manufacturer and type: OSG WXS-LN-EBD,
- Tool type: ball mill,
- Tool Diameter: 2 mm,
- Tool Radius: 1 mm.

The test toolpath had the following common parameters:

Toolpath strategy: all the tested toolpaths had identical programmed toolpath strategy – cutting the surface with the helical moves from top to bottom (Fig. 3).

Toolpath tolerance: 0.002 mm (Fig. 4)

Feed rate: we tested the toolpaths with two feed

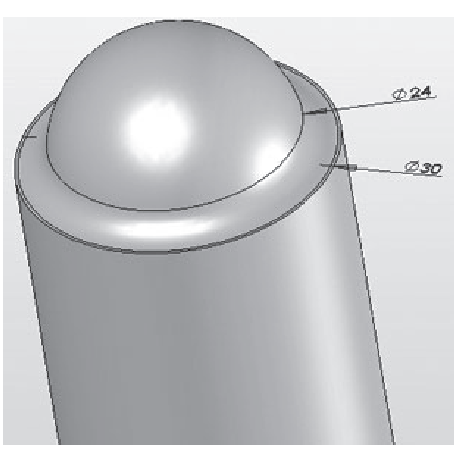

Fig.1. *Part CAD model*

Fig.2. *Sodick MC430L milling machine*

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Table 1. *Machine data*

Working area X × Y × Z	420 mm × 350 mm × 200 mm
Table size X × Y	600 mm × 400 mm
Spindle speed	6,000 – 40,000 min^{-1}
Max acceleration	1.0 G
Fast feed rate	36 m/min
Max tool diameter	Ø6 mm

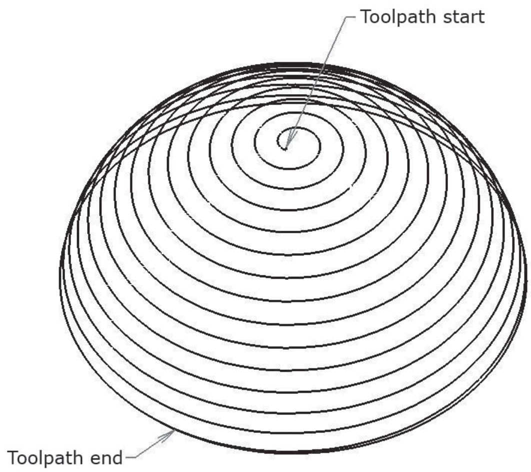

Fig. 3. *Toolpath strategy*

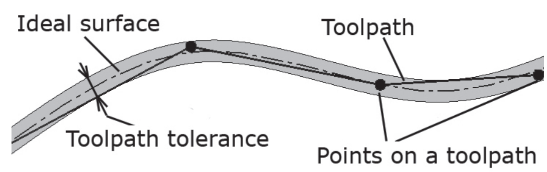

Fig. 4. *Toolpath tolerance*

rates (1,500 mm/min and 4,000 mm/min)
Spindle speed: 28,000 min^{-1}
Cutting depth: Ap = 0.1 mm
Cutting stepover: Ae = 0.008 mm (Figs. 5 and 6)

DIFFERENCES BETWEEN TOOLPATHS

The only attribute by which the toolpaths were distinctly different was the way the points were arranged along the toolpath. Algorithms that are used for toolpath point calculation differ from one CAM program to another. Even though the toolpaths look the same they don't have the same point arrangement along the toolpath. For our test we have used four different toolpaths:

Toolpath 1: Stochastically arranged points

Toolpath 1 had stochastically and unevenly arranged points along the toolpath. Because the calculating algorithm was not optimized the NC

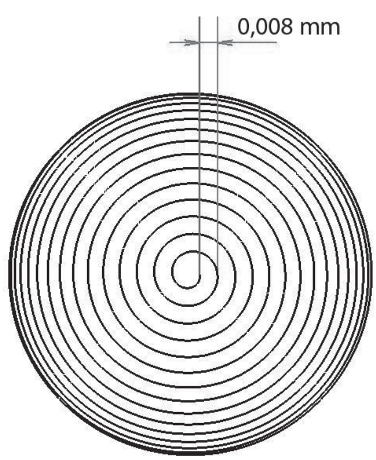

Fig. 5. *Toolpath stepover from top view*

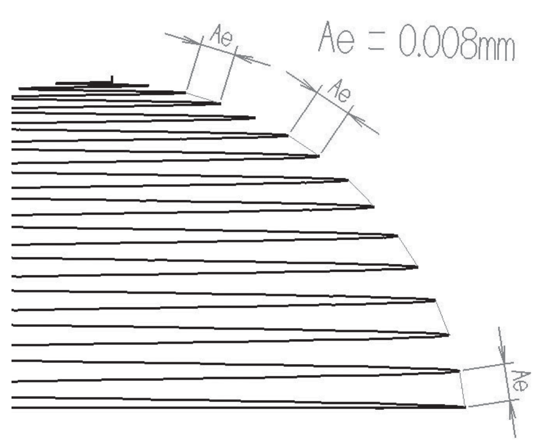

Fig.6. *Toolpath stepover from side view*

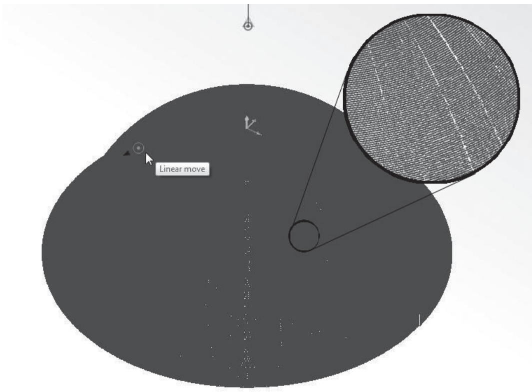

Fig. 7. *NC program simulation of toolpath 1*

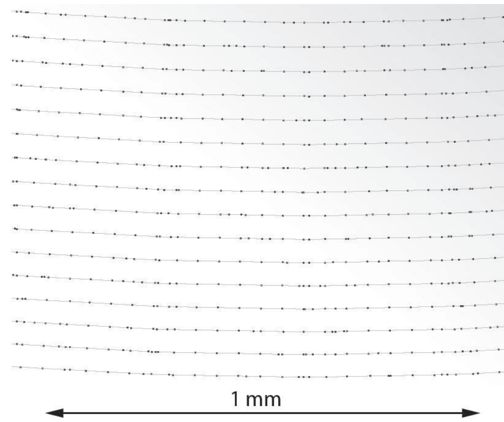

Fig. 8. *Section of toolpath 1*

program consisted of 10-times more points than any other tested toolpath (Fig. 7).

The toolpath section (Fig. 8) demonstrates that the distances between the adjacent toolpath points can vary between 0.002 mm and 0.05 mm.

Fig. 9 shows enlarged section of the toolpath. It can be noticed that there are 5 points on a section, which is only about 0.01 mm long.

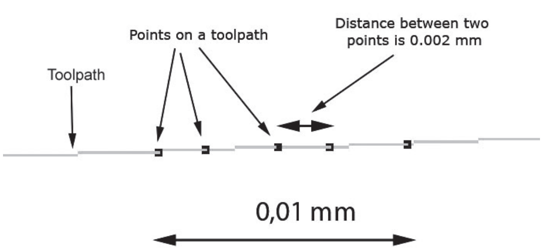

Fig. 9. *Section of the toolpath 1*

Toolpath 2: Evenly arranged points that don't show a pattern along Z-axis

This toolpath point's arrangement displays no recognizable pattern along Z-axis (Fig. 10). The distances between the adjacent toolpath points are relatively constant and vary between 0.25 mm and 0.35 mm (Fig. 11). When comparing Figure 10 to Figure 7 it can be clearly noticeable that toolpath 1 has much higher density of points then the toolpath 2.

Toolpath 3: Evenly arranged points that show a distinct pattern along Z-axis

This toolpath consisted of substantially smaller number of points than toolpaths 2 and 4 (see Tables 3, 4 and 5). In this was mainly the result of the CAM algorithm leaving out the points on the lover portions of the test part where the toolpath radius is larger. Some sections of the toolpath had

Fig. 10. *NC program simulation of toolpath 2*

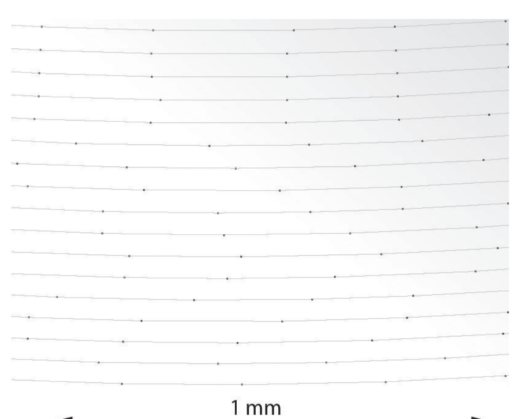

Fig. 11. *Enlarged section of toolpath 2*

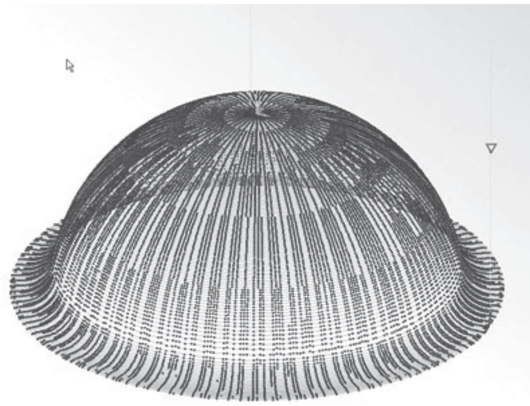

Fig. 12. *NC program simulation of toolpath 3*

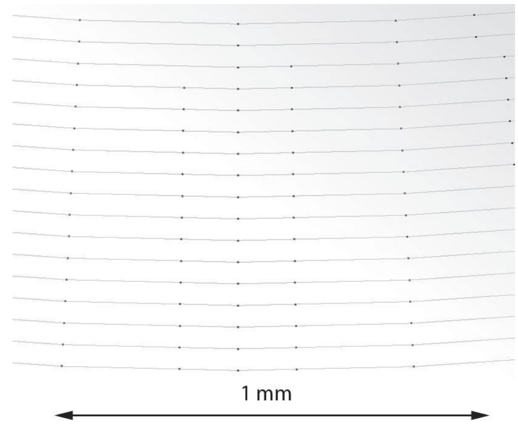

Fig. 13. *Enlarged section of toolpath 3*

smaller distances between adjacent points than other sections (Fig. 13). The toolpath simulation is shown on Figure 12.

Toolpath 4: Evenly arranged points that show a distinct sun-ray pattern along Z-axis

The points are evenly arranged along the toolpath and show a distinct sunray pattern along Z-axis (Figs. 14 and 15). This means that the distance between adjacent points on the toolpath is rising with the toolpath depth and radius of the surface.

3 TEST RESULTS

Each of the test parts has been machined with two programmed feed rates. Machining with the lower feed rate (f = 1500 mm/min) was used to produce finished surface, the higher feed rate was used to test machining time reduction. After running the tests we photographed the test parts under the optical microscope with 30x magnification. Each part was also checked by naked eye and photographed with a digital compact camera.

Toolpath 1

The results of test are summarized in Table 2. The first column represents measured parameters and the second column shows the results. Toolpath 1 machining time at 1,500 mm/min was 10% longer than theoretical machining time. The most probable two reasons for such a delay are the facts that toolpath consists of 10 times more points than other toolpaths and that in some sections we can find up to 5 points in only 0.01 mm length of the toolpath. The machine cannot process so many points with the programmed feed rate, which results in lowering the average feed rate. When we increased the feed rate to 4000 mm/min, the machining time

Fig. 14. *NC program simulation of toolpath 4*

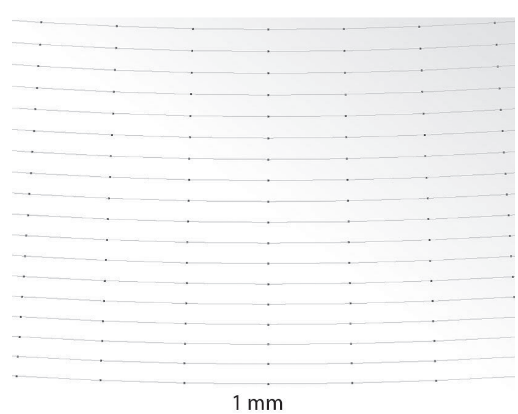

Fig. 15. *Enlarged section of toolpath 4*

Table 2. *Toolpath 1 test results*

Theoretical toolpath time (f = 1,500 mm/min)	571 s
Theoretical toolpath length	13,971 mm
Number of points	433,884
Toolpath density (average number of points on 1mm of toolpath)	31 points/mm
Measured toolpath time (f = 1,500 mm/min)	625 s
Measured toolpath time (f = 4,000 mm/min)	590 s
Minimum feed rate (f = 4,000 mm/min)	1,000 mm/min
Actual calculated feed rate (f = 1,500 mm/min)	1,341 mm/min
Actual calculated feed rate (f = 4,000 mm/min)	1,420 mm/min

decreased for only 6.5%. Minimum detected feed rate of 1000 mm/min at programmed 4000 mm/min shows that the toolpath had certain sections where the machine movement speed had to be largely reduced.

Figure 16 represents some issues regarding tool movement. In some sections of the toolpath the feed rate decreased rapidly which resulted in tool vibration and subsequently in gouges in the surface. Large gouge about 1 mm long and 0.5 mm wide can be seen in the upper left corner of Figure 16. As we can see on Figure 17 the gouges can be seen with naked eye. In the real world such part would be treated as a waste.

The other issue concerns faceted surface on the lover section of the part. The surface texture can be seen in Figure 17.

Toolpath 2

The results of the test are represented in Table 3. Toolpath 2 had 10 times less toolpath points than toolpath 1 even though theoretical machining time and toolpath length was the same as with toolpath 1.

Toolpath 2 machining time was 2.2% longer than theoretical. When we increased the feed rate to 4,000 mm/min, the machining time was shortened by 56%. Average feed rate at programmed 4,000 mm/min was 3,435 mm/min, which shows that the toolpath 2 is much more optimized for high feed rate than toolpath 1 (Table 3). Minimum detected feed rate of 2,500 mm/min at programmed 4,000 mm/min confirms that the toolpath did not have any sections where the machine movement speed had to be largely reduced.

The other reason of round and smooth finished surface was the fact that individual cuts overlay previous cuts and the toolpath did not show a sunray pattern along Z-axis (Figs. 18 and 19). The finished surface was therefore automatically better.

Figure 18 represents the finished surface photographed under the microscope with 30x magnification. Surface had no gouges; all the moves were smooth and did not produce any facets. The same result can also be observed on Figure 19, which shows the naked eye image of the part. Surface quality is very good. No facets or gouges can be seen on the surface.

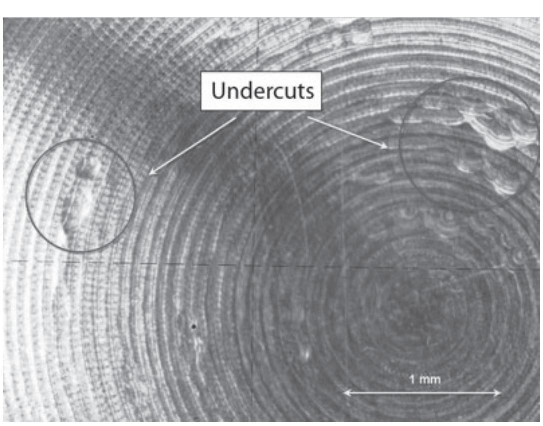

Fig. 16. *Finished part after toolpath1 (enlarged 30-times)*

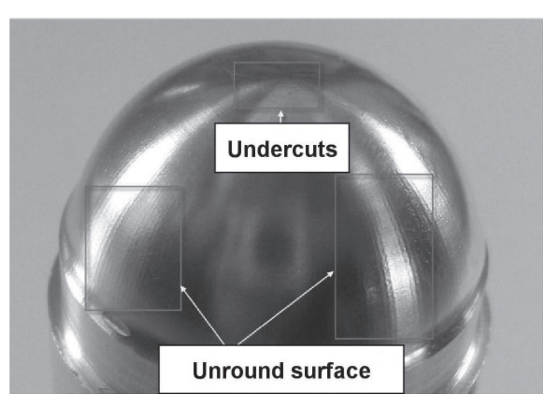

Fig. 17. *Finished part after toolpath1*

Table 3. *Toolpath 2 test results*

Theoretical toolpath time (f = 1,500 mm/min)	571 s
Theoretical toolpath length	13,971 mm
Number of points	47,634
Toolpath density (average number of points on 1mm of toolpath)	3.4 points/mm
Measured toolpath time (f = 1,500 mm/min)	559 s
Measured toolpath time (f = 4,000 mm/min)	244 s
Minimum feed rate (f = 4,000 mm/min)	2,500 mm/min
Actual calculated feed rate (f = 1,500 mm/min)	1,499 mm/min
Actual calculated feed rate (f = 4,000 mm/min)	3,435 mm/min

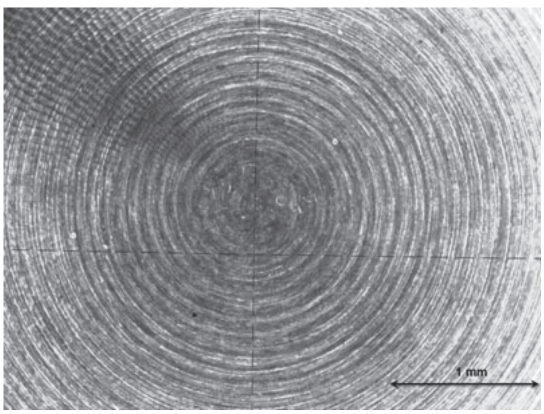

Fig. 18. *Part after toolpath 2 (enlarged 30-times)*

Fig. 19. *Finished part after toolpath2*

Toolpath 3

The results of the test are represented in Table 4. Toolpath 3 had smaller density of points then toolpath 2 but the actual average feed rate was lower than feed rate on toolpath 2. Toolpath 3 machining time was 5% longer than theoretical machining time. Compared to toolpath 2 this toolpath had certain areas where the points were more densely packed than others (Fig.13). When we increased the feed rate to 4,000 mm/min the machining time shortened by 20%. This toolpath had smaller density of points (number of points on 1 mm of toolpath) compared to toolpath 2 but the time gain from increasing the feed rate was smaller.

This shows that the toolpath was not as much optimized for high feed rates as toolpath 2 (Table 4). Minimum detected feed rate of 1000 mm/min at programmed 4000 mm/min shows that the toolpath had certain sections where the machine movement speed had to be largely reduced.

Figures 20 and 21 clearly reveal that the finished surface included facets. They are result of the large distance between adjacent points on the toolpath. On some sections (Fig. 21) they can be as large as 0.6 mm. The influence of large distances between adjacent points could be minimized if the points would not show pattern along Z-axis (like toolpath 2).

Table 4. *Toolpath 3 test results*

Theoretical toolpath time (f = 1,500 mm/min)	393 s
Theoretical toolpath length	9,823 mm
Number of points	27,243
Toolpath density (average number of points on 1mm of toolpath)	2.8 points/mm
Measured toolpath time (f = 1,500 mm/min)	414 s
Measured toolpath time (f = 4,000 mm/min)	330 s
Minimum feed rate (f = 4,000 mm/min)	1,000 mm/min
Actual calculated feed rate (f = 1,500 mm/min)	1,423 mm/min
Actual calculated feed rate (f = 4,000 mm/min)	1,786 mm/min

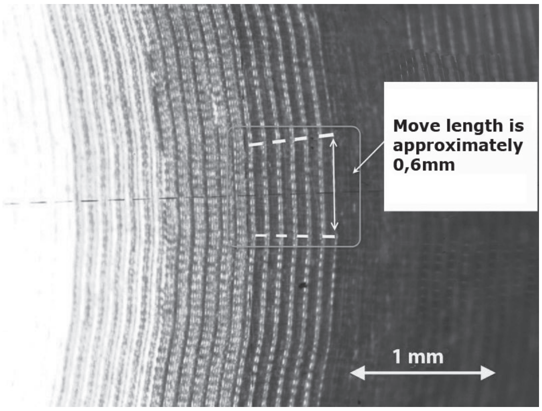

Fig. 20. *Part after toolpath 3 (enlarged 30-times)*

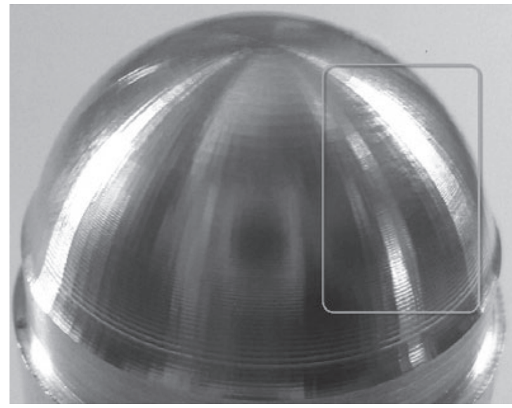

Fig. 21. *Finished part after toolpath3*

The facets are clearly seen even with naked eye (Fig. 21). In real world such part would most probably be considered as scrap part.

Toolpath 4

The results of the test are summarized in Table 5. Even though the toolpath density was higher than the toolpath density of toolpaths 2 and 3 the machining time was only 2% longer than theoretical machining time. When we increased the feed rate to 4,000 mm/min, the machining time was decreased by 60%. Minimum detected feed rate of 2,000 mm/min at programmed 4,000 mm/min confirms that the toolpath did not have any sections where the machine movement speed had to be largely reduced.

The average recorded feed rate was 3,603 mm/min, which shows that the toolpath was well optimized for high feed rate cutting.

Figure 22 represent the finished surface photographed under the microscope with 30x magnification. They demonstrate that the surface

Table 5. *Toolpath 4 test results*

Theoretical toolpath time (f = 1,500 mm/min)	623 s
Theoretical toolpath length	15,196 mm
Number of points	74,040
Toolpath density (average number of points on 1mm of toolpath)	4.9 points/mm
Measured toolpath time (f = 1,500 mm/min)	636 s
Measured toolpath time (f = 4,000 mm/min)	253 s
Minimum feed rate (f = 4,000 mm/min)	2,000 mm/min
Actual calculated feed rate (f = 1,500 mm/min)	1,433 mm/min
Actual calculated feed rate (f = 4,000 mm/min)	3,603 mm/min

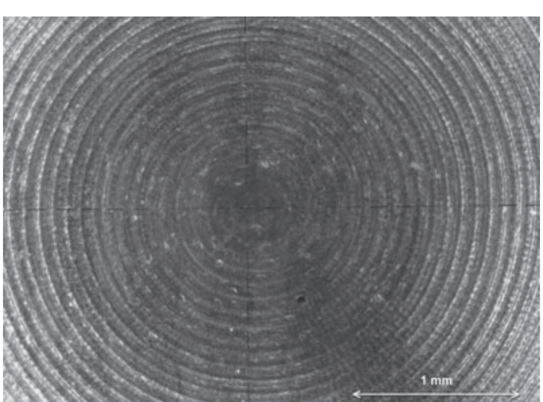

Fig. 22. *Part after toolpath 4 (enlarged 30-times)*

Fig. 23. *Finished part after toolpath 4*

did not include any gouges; the moves were smooth and short enough that they did not produce facets.

Figure 23 shows that the quality of surface is as predicted. There are no special marks or facets seen on the surface.

4 CONCLUDING REMARKS

Test results clearly show that point arrangement along the toolpath has a distinct influence on a surface quality of finished part and machining time.

1. Influence of the toolpath points arrangement on the surface quality

When comparing Figures 17, 19, 21 and 23 it can be clearly seen that surface quality differs from one toolpath to another. When we look at the parts 2 and 4 we can see that the surface is smooth and round, while the surface on the parts 1 and 3 has gouges and facets. The results clearly demonstrate that the toolpath tolerance is not the only parameter that influences the quality of the finished surface.

Results (Figs. 8, 11, 13, 15 and Tables 2, 3, 4 and 5) show that the toolpaths that had most evenly arranged points (toolpaths 2 and 4) showed the best results on the surface quality.

The toolpath density is important factor for getting good surface finish quality. If the density is very low this means that the toolpath tolerance was not correctly set. On the other side very high average density of points does not guarantee a good surface quality. This is clearly presented by comparing toolpath 3 and toolpath 4. Toolpath 4 had almost 2 times lower average point density than toolpath 3 but the surface quality was much better. The reason for lower surface quality in toolpath 3 is the fact that the points were not evenly arranged.

2. Influence of point arrangement on the machining time

At relatively small feed rates the influence of point arrangement to the machining time is not very large. Even with toolpath 1, which had very low quality of point arrangement, the machining at 1500 mm/min, was only 10% longer than theoretical machining time.

The influence gets noticeable when the feed rate is increased. When the feed rate was increased to 4000 mm/min the toolpaths with more evenly arranged points (toolpaths 2 and 4) showed noticeable decrease of machining time. On the other side toolpaths 1 and 3 did not demonstrate almost any decrease of machining time.

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