THE INFLUENCE OF TOOL TRAJECTORIES UPON THE ACCURACY OF THE MANUFACTURATED PARTS

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ABSTRACT: This paper presents some experimental work upon the influence of the shapes of the tools trajectories upon the accuracy of the parts processed on CNC milling machine. Nowadays CAM software packages allow the user to select from a great variety of machining strategies, both for roughing and finishing operations. Each strategy is performed using different shapes of the tool trajectories (toolpaths), but usually the user does not know how to choose between them. An integrated process of simulation, machining and measurement was unfolded, in order to obtain some information about how to choose the most appropriate toolpath for a given shape of the part.

KEY WORDS: accuracy, CNC, milling, tool, toolpaths.

1 INTRODUCTION

Nowadays milling processes are unfolded on CNC milling machines, which allow the user to manufacture complex parts, with high productivity and accuracy. Computer aided manufacturing (CAM) packages are used to generate the NC code for the CNC controller of the machine-tool. Commonly used CAM programs and NC code generators are based on only the geometric and volumetric analysis, but they do not concern about the physics of the machining process (Erdim, Lazoglu & Ozturk, 2006).

Extensive researches has been performed to develop the existing CAM programs, or even to develop new CAM solutions (Lauwers et. al., 2000), in order to obtain better accuracies of the parts.

Some authors have studied the effects of the toolpaths, (Law & Geddam, 2001), (López de Lacalle et. al., 2007), (Toh, 2004) upon the manufacturing accuracy and developed methods for a proper selection of the trajectories, based upon different restrictions, such as minimum deflection cutting forces, which lead to a minimization of the dimensional errors. However, it is noticeable here that at the workshop level, the user has neither the time, not the ability to edit complex toolpaths. Normally, it has to relay on the cutting trajectories generated by general use CAM software packages.

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There are also reported in the literature researches upon integrated approaches which deal with integrated geometric error modeling, identification and compensation method for machine tools (Zhu et. al., 2012) or approaches dealing with identification and compensation of systematic deviations (Tsutsumi & Saito, 2004). Other approaches are to optimize the feedrate, in order to improve the machining efficiency and accuracy (Chen et. al., 2005), (Erdim, Lazoglu & Ozturk, 2006).

All of the above presented approaches are based upon post-editing the NC code generated by the CAM software package, an operation which requires a lot of time and it is rather complicated. While for very complex surfaces and for prototypes time is not a problem, at the workshop level the users have to achieve high productivity, so editing the NC code is generally not an economically efficient option.

This paper presents some experimental research about how to select the most recommended processing toolpaths, from the options available in a general purpose CAM program, balancing both the accuracy of the parts and the productivity

2 MACHINING THE PART

Generally, milling processes are divided into roughing and finishing operations Modern CAM programs allow the user to select from a wide range of machining options and/or strategies both for roughing and finishing. However, the software does not provide the user with the necessary recommendation in order to choose the optimal machining strategy for a given shape of the part.

In order to test the proposed method the part presented in figure 1 was manufactured on a 3 axis CNC milling machine.

The part was chosen because its shape includes both rectangular and circular surfaces. The material of the part was low-alloyed carbon steel.

In order to machine the part, a computer assisted manufacturing approach was used. A CAM software package, SprutCAM was the tool used for generating the NC code.

Normally, a CAM program automatically generates the toolpaths by means of the final shape of the 3D model of the part, taking into consideration the cutting tools and the cutting regime.

The part was manufactured using three operations:

A. roughing;

B. finishing;

C. supplementary finishing at the bottom of the part.

The A and C operations were similar for all the machined parts. For operation C, several different machining strategies were used.

In order to reduce the overall machining time, operations A and C were unfolded using contour curves as toolpaths.

Contour curves, which are obtained by cross-sectioning the 3D model of the part with horizontal planes, equally spaced on Z axis are the most used toolpahs in milling operations, offering the best ratio between manufacturing accuracy and productivity.

Operation A, as roughing operation is intended to remove material from the workpiece as fast as possible, without any accuracy requirement. The accuracy of the part is determined by the operation B, finishing, which is intended to remove all the remaining material between the workpiece and the part. The objective of the operation is to obtain a shape of the part as close as possible to the theoretical 3D model of the part.

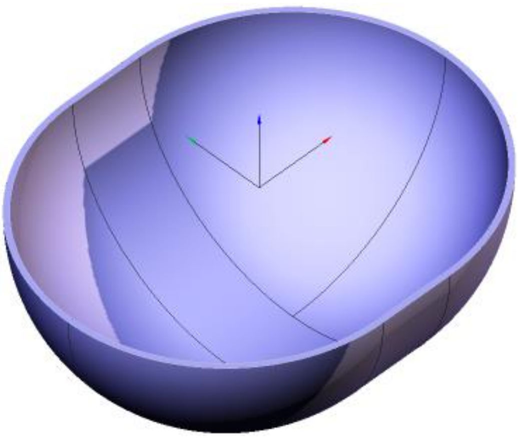


Figure 1. 3D model of the manufactured part

Operation C was introduced in order to provide a supplementary finish at the bottom of the part, because the shape of the part does not allow the tool used during operation B to reach every area.

The toolpaths for operation A (roughing) and B (supplementary finishing) are presented in figures 2 and 3.

For operation B (finishing), five different strategies and consequently five different toolpaths shapes were used:

Contour curves, named waterline finishing (figure 4)

Curves obtained by cross-sectioning the shape of the part with planes parallel with XZ plane, and parallel to each other, named plane finishing at 0º (figure 5)

Curves obtained by cross-sectioning the shape of the part with planes parallel with YZ plane, and parallel to each other, named plane finishing at 90º (figure 6)

Curves obtained by cross-sectioning the shape of the part with planes oriented at 45º to the planes XZ and YZ and parallel to each other, named plane finishing at 45º (figure 7)

A combined strategy which used both curves from both the second strategy and the third strategy, named combined finishing (figure 8 a, b)

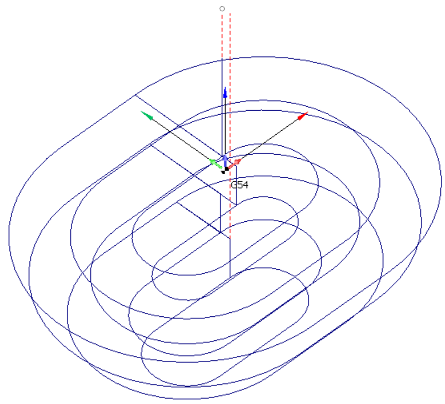


Figure 2. Toolpaths for operation A (roughing)

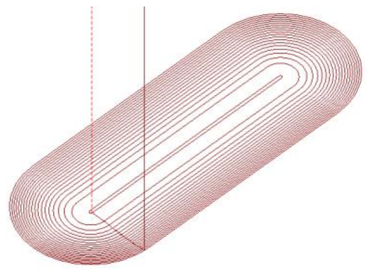


Figure 3. Toolpaths for operation C (supplementary finishing)

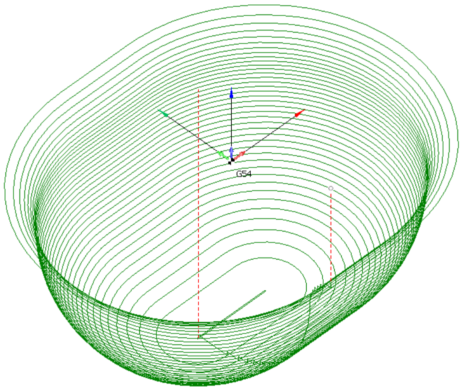


Figure 4. Toolpaths for the first strategy of operation B

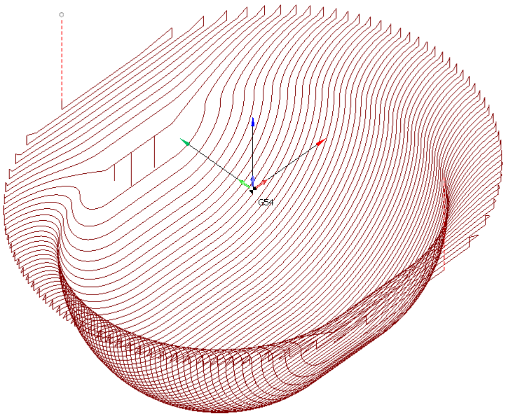


Figure 5. Toolpaths for the second strategy of operation B

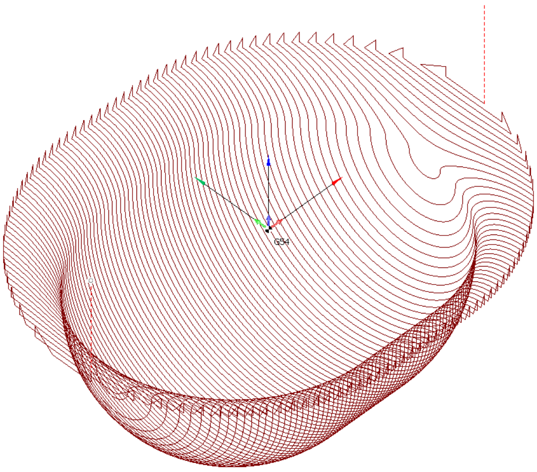


Figure 6. Toolpaths for the third strategy of operation B

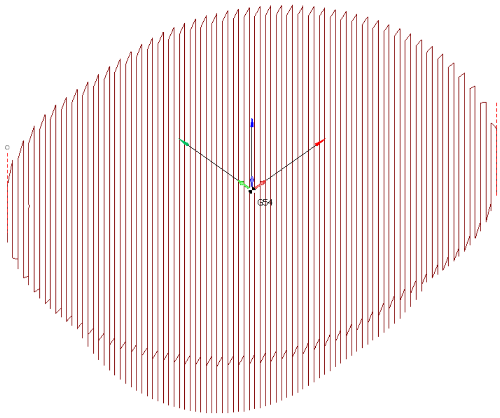
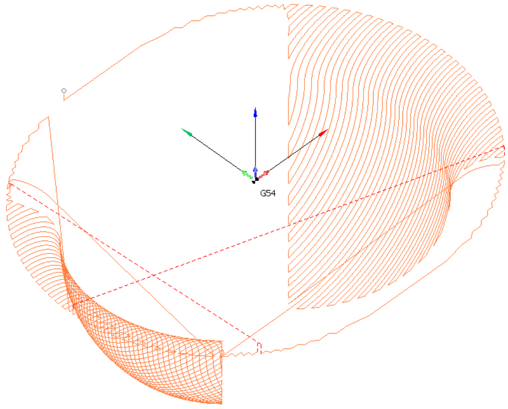
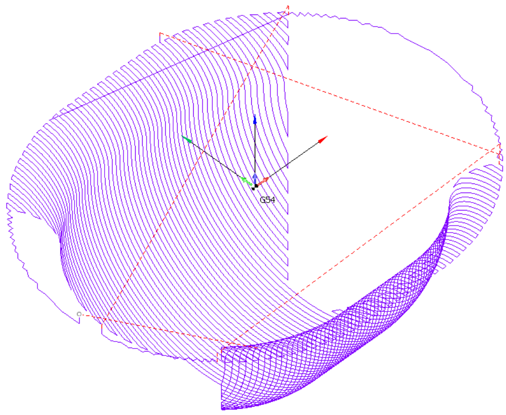


Figure 7. Toolpaths for the fourth strategy of operation B



a.



b.

Figure 8. Toolpaths for the fifth strategy of operation B a. first pass b. second pass

Table 1

Operation	Tool	Cutting regime n – spindle speed (revs/min) F – feedrate (mm/min)	Other characteristics
A. Roughing	8 mm end mill	n = 2500 revs/min F = 250 mm/min	Depth of cut t = 3.6 mm
B. Waterline finishing	8 mm ball-end mill	n = 2000 rot/min F = 200 mm/min	Depth of cut t = 0.4 mm
B. Plane finishing at 0º	8 mm ball-end mill	n = 2000 revs/min F = 200 mm/min	Distance between toolpaths t = 0.4 mm
B. Plane finishing at 90º	8 mm ball-end mill	n = 2000 revs/min F = 200 mm/min	Distance between toolpaths t = 0.4 mm
B. Plane finishing at 45º	8 mm ball-end mill	n = 2000 revs/min F = 200 mm/min	Distance between toolpaths t = 0.4 mm
B. Combined plane finishing	8 mm ball-end mill	n = 2000 revs/min F = 200 mm/min	Distance between toolpaths t = 0.4 mm
C. Supplementary finishing	8 mm ball-end mill	n = 2000 revs/min F = 200 mm/min	Depth of cut t = 0.01 mm

3 ACCURACY OF THE PARTS

In order to assess the influence of the toolpaths upon the machining accuracy, a measuring process of the machined parts has to be unfolded. In order to obtain accurate results of the measurements, a coordinate measuring machine (CMM) was used, DEA Global Performance type.

Usually, CMM are used to measure the dimensional accuracy of a part by measuring only a limited number of specific dimensions of the part. The measurement is done by touching some points on the part and comparing their coordinates with the theoretical one.

However, the main goal of the researches was to assess the influence of the machining trajectories upon the entire surface of the part. Scanning the entire surface of the part is a cumbersome and time-consuming process. Moreover, when scanning a large number of points, usually the controller of the CMM machine generates an error, due to the large amount of data which has to be processed.

Consequently, it was needed to develop a process to evaluate the machining accuracy of the surfaces, without the need of scanning a large number of points and processing a large amount of data.

A four stage process, described below was proposed for evaluating the accuracy of the machined parts.

In the first stage, the touch probe of the CMM is driven to scan only four specific curves of the machined parts, instead of probing the whole surface. The geometrical information acquired is stored in a special file named “points cloud file”. The four curves were obtained by cross-sectioning the part with a a vertical plane at 0º, 45º, 90º and 135º.

In the second stage, the points cloud files, one for each scanned curve is converted into igs-type files, which stores the coordinates of every points lying on the curve (figure 9 and figure 10). This conversion has to be made using a general-purpose CAD software package which has the ability to process point cloud files.

The third stage involved the extraction of the coordinates of the points from the curves, which was made by means of a CAM software package.

The fourth step involves the use of a software package which can process and plot the coordinate of the points, compared to the points within the theoretical profile in every section. The plots allow the user to make both a quantitative and qualitative assessment of the accuracy of the part.

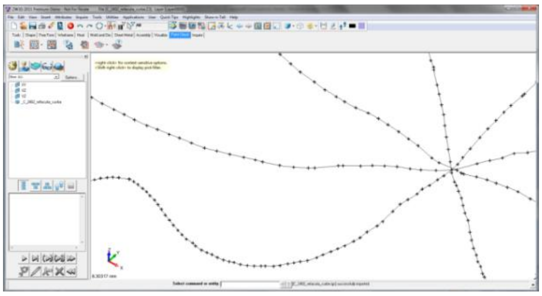


Figure 9. Converting the points cloud file (detail)

Figure 10. The four curves for a machined part

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Figure 11 presents a detail from the plots for the 0º curve, while figure 12 presents a detail from the plots for the 90º curve.

Figure 13 presents a detail from the plots for the 45º curve. The results for the 135º were not presented, because they were quite similar with the ones for the 45º curve.

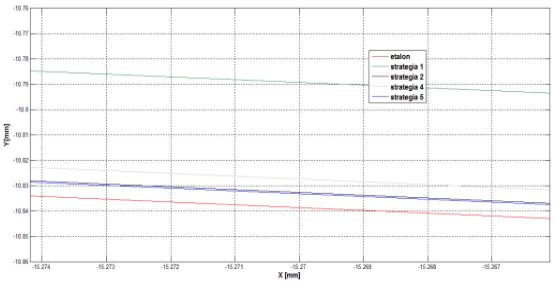

Figure 11. Graphical display of the accuarancy of the machine part (curveshe four curves at 0°, detail)

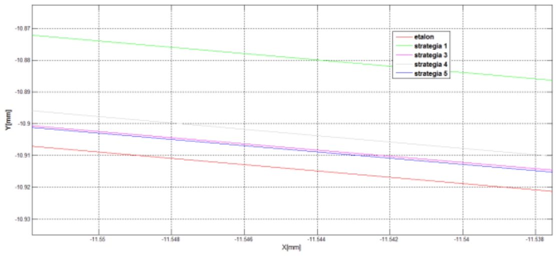

Figure 12. Graphical display of the accuarancy of the machine part (curveshe four curves at 90°, detail)

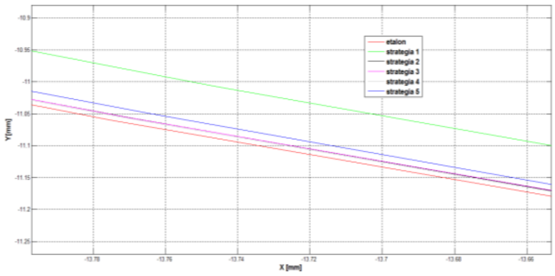

Figure 13. Graphical display of the accuracy of the machine parte (curves at 45°, detail)

4 CONCLUDING REMARKS

The experimental researches have shown that using contour curves as toolpaths (waterline finishing) is the most disadvantageous approach, leading to the highest difference between the theoretical profile and the current one, no matter which type of surface was machined.

The accuracy of the parts machined by plane finishing are highly dependent of the angle between the surface and the toolpath, mainly at high Z-levels. The surfaces lying along a parallel direction with the toolpaths had shown bigger differences between the theoretical profile and the current one. Better results were obtained were the toolpaths were perpendicular on the machined surfaces.

Plane finishing at 45º strategy, as expected, shows results which are in-between the results of the second and third finishing strategies: better than plane finishing at 0º on surfaces which are closer to 0º and worse than plane finishing at 90º at the same surfaces, worse than plane finishing at 0º on surfaces which are closer to 90º and better than plane finishing at 90º at the same surfaces.

The most accurate parts were the one which were machined using the combined finishing strategy, fact which is now clear, taking into consideration the previous results.

For this strategy, the surfaces which are oriented mostly parallel with XZ plane were machined using a plane finishing at 90º, while he surfaces which are oriented mostly parallel with YZ plane were machined using a plane finishing at 0º. It can be noticed that this approach combines the advantages of both second and third finishing strategies, while eliminating their drawbacks. It is also important to mention the fact that this kind of combined plane operation is available as standard within the software package and the CAM program makes an automatic distribution of the 0º and 90º, according to the orientation of the surfaces of the part. Nevertheless, the user is allowed to change this distribution manually.

It is also noticeable the fact that the differences between the overall machining times where quite small between the last four finishing strategies (under 5%), while the machining time for the first strategy was significantly shorter (more than 20% shorter).

Finally, the paper has presented an integrated hands-on approach which allows the user to take some decisions about choosing the toolpaths based upon the shape of the part (the orientation of the surfaces), the required manufacturing accuracy and the machining time, at the workshop level.

5 ACKNOWLEDGEMENTS

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