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# INFLUENCE OF MILLING STRATEGIES FOR ROUNDNESS

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***Summary:*** *Very important for CNC program generation is the choice of machining strategy. This strategy has influence on the final accuracy and final quality of machined. Machining strategy is tool movement in machine space. Milling is used also for the production of curved shapes. The article compares roundness profiles of components which were manufactured by different milling finished strategies. Used strategies were Constant Z with continuous spiral, Optimized constant Z with continuous spiral and Radial. Roundness was measured on the outer cylinder (two positions) and cone surface. Article presented not only the value of roundness but also graphically shows some roundness profiles. Accuracy of parts was measured by 3D optical measuring system GOM ATOS I 350.*

***Keywords:*** *CAM strategies, milling, CAD/CAM, Roundness, Roundness profile*

## 1. INTRODUCTION

The basic sign of CAM is to minimize human intervention into the course of the production process by the exploitation of computer data processed in main elements of activities [1]. The machining process is generally divided into roughing and finishing. Very important for CNC program generation is the choice of machining strategy. This strategy has influence on the final accuracy and final quality of machined. Machining strategy is tool movement in machine space [2]. Milling is used also for the production of curved shapes [3]. Off all the processes used to shape metals, it is in machining that conditions of operation are most varied. Computer aided in engineering is a powerful tool for shortening the time of continuous production, increase the flexibility of design and manufacturing process, reducing production costs and thus the price of the product [4].

## 2. MILLING AND APPLICATION OF STRATEGIES

For the experiment we had chosen 5 finishing strategies available from the program PowerMill: Radial, Constant Z, Optimized Constant Z, 3D offset, Raster. PowerMILL is multi axis milling product, a stand alone CAM system that produces NC toolpaths from CAD models quickly. PowerMILL can accept data from any CAD system, via IGES, VDA, STL or a variety of direct interfaces. It is extremely powerful, yet easy to use, and generates roughing and finishing toolpaths which optimise the productivity of CNC machine tools, while ensuring the highest quality machining of models and tooling [5].

The shape of part, which was used for experiment you can see in Fig. 1, part was created in CAD software PowerShape. PowerSHAPE CAD software provides a complete environment to take your product ideas from concept to reality. PowerSHAPE offers unrivalled freedom to manipulate surface form of the CAD model, to build from wireframe and make global changes with solid feature operations and editing [6]. Parts were first turned. Before importing parts into the CAM program PowerMill was necessary to create the blank workpiece at the CAD program PowerShape. On Fig.2 you can see part and blank workpiece.

Used tool was three tooth end ball mill with 10 mm diameter, cutting parameters were depth of cut DOC = 0.2 mm, width of cut WOC = 0.2 mm, feed rate per tooth 0.06 mm, cutting speed 235 m.min$^{-1}$. The part was milling in four-axis CNC milling machine EAGLE 1000, clamped to the three jaw chuck and cooling medium was dry air.

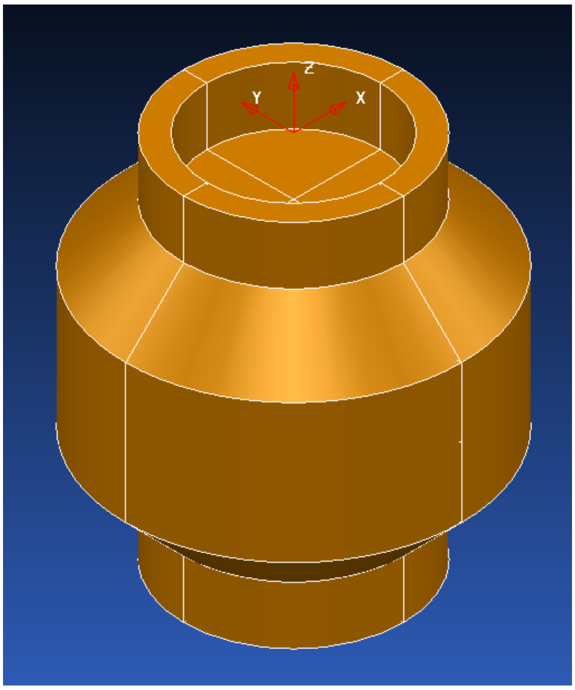



**Figure 1:** CAD model part in software PowerShape

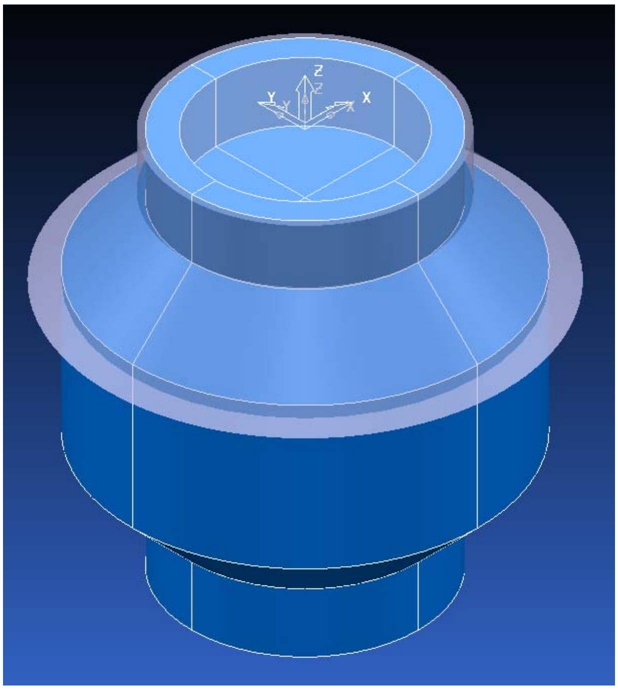



**Figure 2:** Blank workpiece a CAD model part in software PowerMill

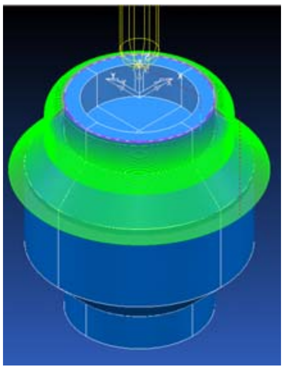
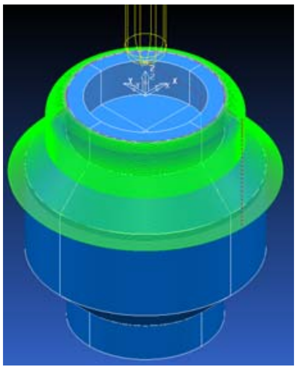
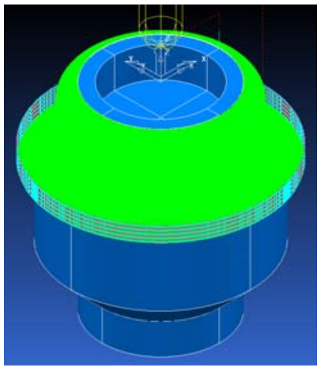
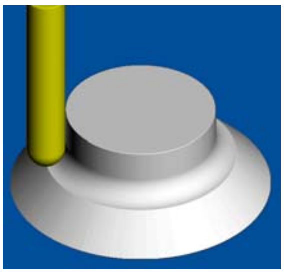
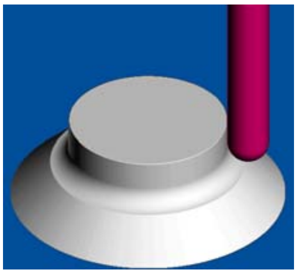
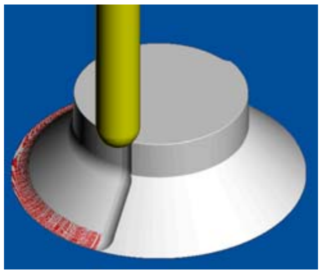
In software PowerMill 9.0 were generated finishing toolpaths [5]:

1. Radial - strategy can be employed to provide maximum efficiency. Full control of the leads and links ensures smooth toolpath transitions, improving both tool life and surface finish.
2. Constant Z with continuous spiral – here the tool cuts at Constant Z levels. There is also an option to lead in and out between Z levels which eliminate 'witness marks'. There is now the added benefit of this type of toolpath being a continuous spiral.
3. Optimized constant Z with continuous spiral - consistent tool loading and the fewest possible sudden changes in direction are needed for high-speed finishing. To meet these priorities, a combination of strategies is recommended, with 3D offset finishing used on flatter areas and Z-level finishing used on steeper areas.
4. 3D offset finishing - this type of finishing gives an excellent surface finish because the step over is constant across all surfaces irrespective of whether they are steep walls or shallow contoured areas. Spiral offset finishing prevents 'witness marks' since the tool stays in constant contact with the model in one smooth spiraling shape.
5. Raster finishing – strategy can be employed to provide maximum efficiency. Full control of the leads and links ensures smooth toolpath transitions, improving both tool life and surface finish.

Each one strategy was simulated in PowerMill software environment. A simulation showed that the strategy is available and unavailable. Available strategies were Constant Z with continuous spiral, Optimized constant Z with continuous spiral, Radial (Table 1) and unavailable strategies were 3D offset finishing and Raster finishing. In strategy raster and 3D offset would be chatter in the machining of cylindrical surfaces, where the depth of cut by the tool was up to 10 mm.

**Table 1:** Available strategies and used parameters for these strategies.

| | Constant Z with continuous spiral | Optimized constant Z with continuous spiral | Radial |
|---|---|---|---|
| Depth of cut/Width of cut* | 0.2 mm | 0.2 mm | 0.2 mm* |
| Feed rate per tooth | 0.06 mm | 0.06 mm | 0.06 mm |
| Cutting speed | 235 m/min | 235 m/min | 235 m/min |
| Time of milling | 13:48 min | 15:03 min | 44:35 min |
| Tolerance | 0.01 | 0.01 | 0.01 |

| | | | |
|---|---|---|---|
| Generated toolpath |  |  |  |
| Simulation |  |  |  |

## 3. MEASUREMENT OF ROUNDNESS

Roundness is usually assessed by rotational techniques by measuring radial deviations from a rotating datum axis, this axis remains fixed and becomes the main reference for all measurements. There are two common ways of measuring roundness. One method involves rotation of the part while keeping the measuring transducer fixed and the other involves keeping the component fixed while rotating the measuring transducer [7]:

*Component rotation* - Here the component is rotated on a highly accurate spindle that provides the reference for the circular datum. The axis of the component is aligned with the axis of the spindle, using a centring and levelling table. A transducer is then used to measure radial variations of the component with respect to the spindle axis.

*Rotating stylus* - An alternative method is to rotate the stylus while keeping the component stationary. This is usually performed on small high precision components but is also useful for measuring large, non-circular, for example measurement of a cylinder bore using this method would not require rotation of the complete engine block. This type of measuring system tends to be more accurate due to continuous loading on the spindle however is limited by the reach of the stylus and spindle.

The measurement of roundness deviation for parts produced, made in the measuring device MK 300C (Figure 3). This device works method rotating stylus.
For each component were measured three profiles (Fig. 3):

- at the beginning of the cylindrical surface (approximately 1,5 mm from the front surface) – profile A,
- at the end of the cylindrical surface - profile B,
- in the center conic surface - profile C.

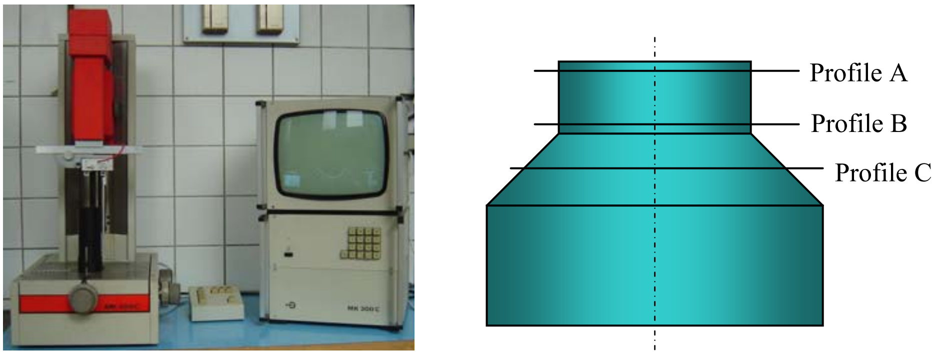



**Figure 3:** Measuring device MK 300C and profiles measured for components

## 4. RESULTS OF ROUNDNESS

In measuring the roundness can be used to filter circular profile. Therefore are in this article roundness values for the filter from 2 to 500, filter from 2 to 15 and filter from 16 to 150. All values are presented as mean values, which were processed into graphs. Here was used the same scale for better comparison. Graphs are presented for individual profiles (Figure 4 – profile A, Figure 5 - profile B and Figure 6 - profile C). Figures 7 and 8 presented roundness profile A measured components produced by strategy constant Z, optimized constant Z and radial.

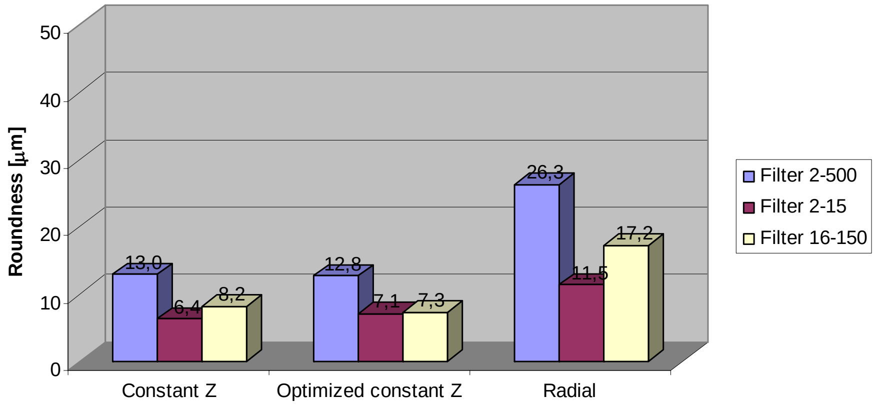



**Figure 4:** Roundness measured components - profile A

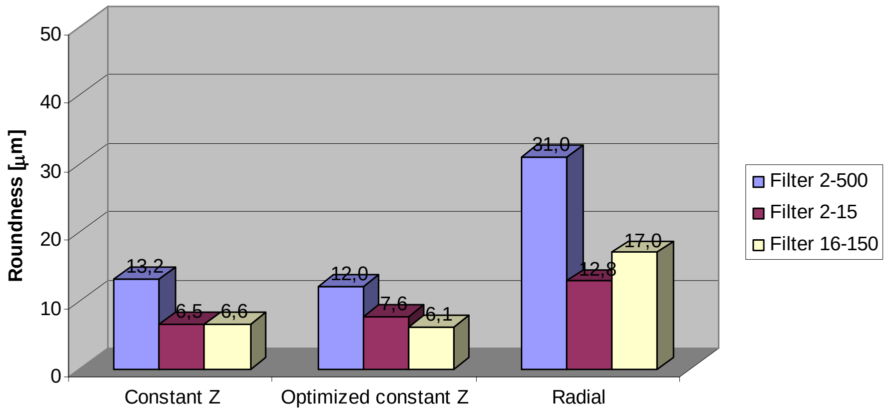



**Figure 5:** Roundness measured components - profile B

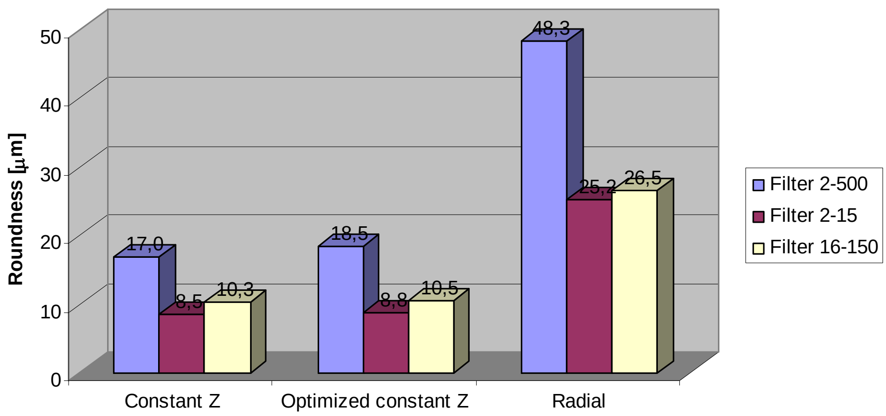



**Figure 6:** Roundness measured components - profile C

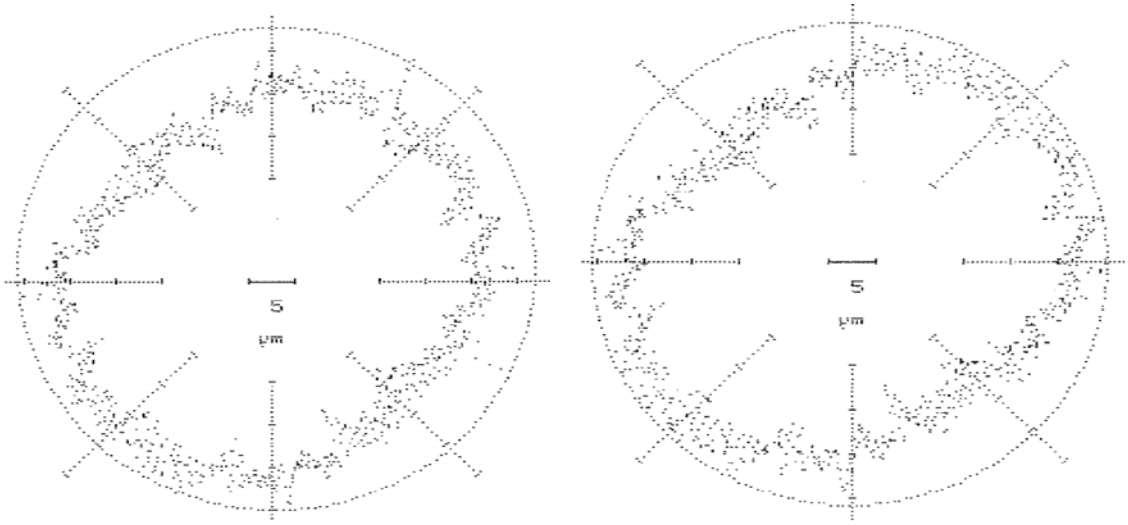



**Figure 7:** Roundness profile A measured components – constant Z and optimized constant Z

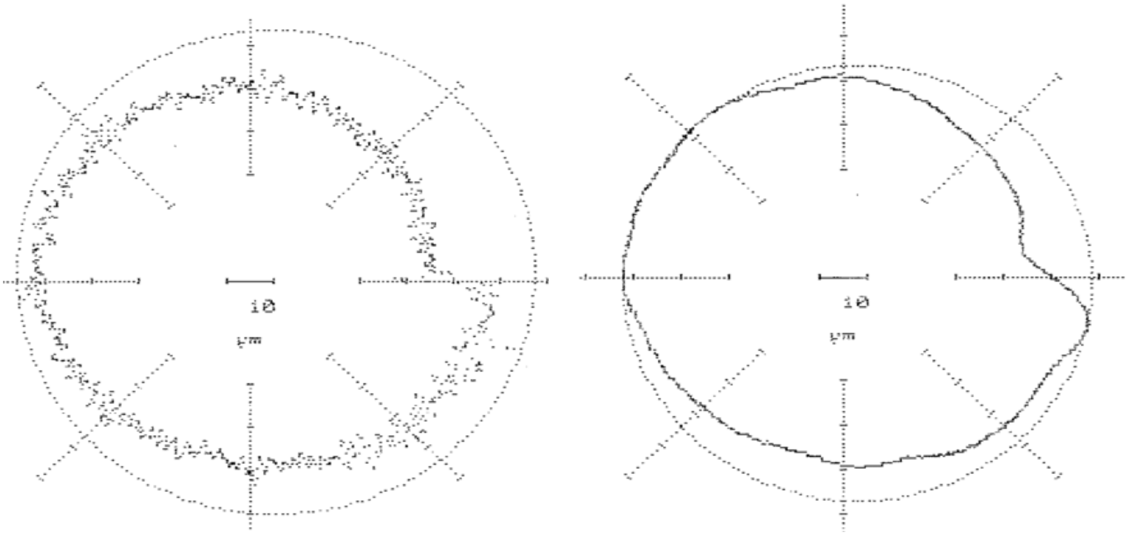



**Figure 8:** Roundness profile A measured components – radial (filter 2 - 500 and 2 – 15)

## 6. ACCURACY MEASUTEMENT OF PARTS

For measurement of parts accuracy was used 3D optical measurement system ATOS I 350. The ATOS I 350 (Fig.9) (Advanced TOpometric Sensor) is a digital optical measuring system. The ATOS I 350 system mainly consist of the sensor comprising two cameras, projector and stand, the control unit for the sensor head and a high-performance PC. The ATOS I 350 optical 3D scanner projects fringe patterns onto the object and uses two CCD cameras to analyze the resulting images. For the all around measurement of complex objects, several partial views are joined together. Using reference points, the system automatically defines the actual sensor position and transforms the partial measurement into a common object coordinate system [8].

**Figure 9:** 3D optical system ATOS I 350.

Figures 10, 11, 12 show colour deviation maps of milled parts. From these colour deviation maps we can get informations about accuracy of milled surfaces. By comparing the color deviation maps are seen minimal differences between the measured data. These differences are causes minimum of accuracy optical 3D scanner. The accuracy of optical 3D scanner is 0.04mm.

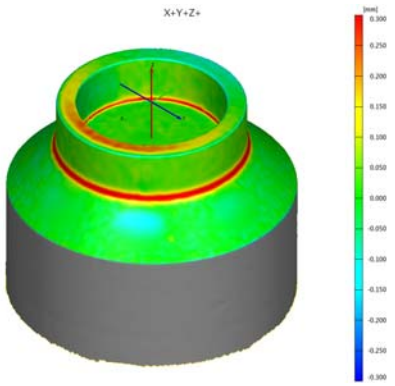


**Figure 10:** Constant Z with continuous spiral

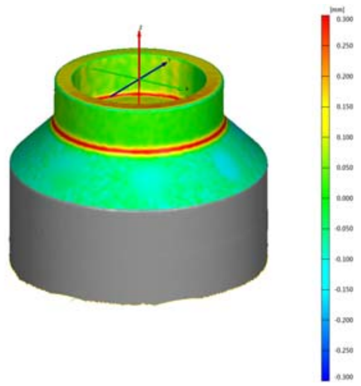


**Figure 11:** Optimized constant Z with continuous spiral

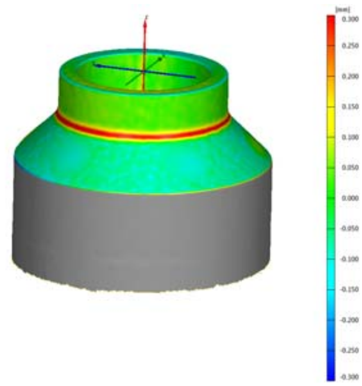


**Figure 12:** Radial finishing strategy

## 7. CONCLUSION

Based on the results of our research we can state:

1. Strategy milling constant Z and constant optimized Z have a similar roundness. The only difference is the time of machining.

2. Radial milling strategy is compared with strategies optimized constant Z and constant from 2 to 2.8 times greater roundness.

3. Roundness on the profile of A and B have similar values - in strategies optimized Z a constant from the roundness of the short cylindrical surface negligible changed. In the radial strategy is partially changed (up to 18%).

4. Roundness significantly deteriorated in the conic surface(profile C) - Strategies constant Z and constant optimized Z the roundness deteriorated by 30 to 55% (filter from 2 to 500), strategy radial roundness increase up to 84% (filter from 2 to 500 ) - compared with the profile of A.

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