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# Increased efficiency and accuracy in ultra-precision machining through adapted CAM software

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**Abstract**
CAM software is widely used through the last 40 years for a broad field of applications. The networkability of machine tools and the digitally integrated production as an existing trend for the next years and exponentially increasing computing power enable direct data transfer between CAD/CAM software and machine tool. Increments $a_r$ < 5 nm are common in ultra-precision CNC codes and are not supported by most traditional CAM software. Therefore, ultra-precision machining often remains a manufacturing process with high manual effort in the machine setting and the generation of CNC codes. In order to increase the degree of automation in ultra-precision machining, machine manufacturers are developing their own, customised CAM software. The studies presented in this paper investigate the influence of different process preparation on relevant parameters during ultra-precision face turning of an n surface with monocrystalline diamond tools. Machine-specific CAM software is compared with manual CNC code creation from a point cloud. The influence on the workpiece characteristics dimensional accuracy $G_F$ and average roughness depth *Ra* is investigated. The influence of the chosen strategy for the generation of the CNC code on the machining time $t_m$ is examined to compare the economics of the strategies. In order to keep the comparison significant, the cutting parameters cutting depth $a_p$ and feed *f* are kept constant in all strategies. Decreasing machining time $t_m$ increases efficiency in comparison to manual CNC code creation.

Keywords: ultra-precision turning, efficiency, CAM software

## 1. Introduction

Machining of non rotationally symmetrical optical grade surfaces by ultra-precision diamond face turing requires a slow slide servo process, where the X-, Z-, and C-axes of the machine tool are moved simultaneously. The CNC code for these operations cannot be generated by conventional commercial CAD/CAM-systems because of limited precision [1]. A common alternative is the use of mathematical software as MATLAB by MATHWORKS, Natick, USA to generate the CNC code derived from a mathematical function describing the surface or a CAD-model [2]. This requires high additional effort for tool path interpolation and path smoothing [3]. The dimensional accuracy $G_F$ of slow slide processes depends on the parameters set for CNC code generation. The most influencal parameters determined are angular increment $\Delta\alpha$, stroke *s* and feed *f* [4].

Due to this need for CAM software suitable for ultra-precision machining, machine tool manufacturers developed their own software solutions. These are limited to the machine tools offered by the manufacturer but offer a fitting solution for ultra-precision machining with the convenience of conventional CAD/CAM software [5]. This contribution investigates the influence of the CNC code generation technique on the surface roughness characteristics and economical key figures.

It is shown, that the average roughness depth *Ra* is not influenced by the method chosen. The machining time $t_m$ could be reduced by the CNC code generation by an specialised CAM software provided by the machine tool manufacturer.

## 2. Methodology

For this contribution tool path generation was investigated for machining a non rotanionally symmetrical workpiece by ultra-precision diamond turning. The CNC code was tested on the ultra-precision machine tool Nanotech 350 FG by MOORE NANOTECHNOLOGY SYSTEMS, LLC, Swanzey, USA with the axis configuration displayed in Figure 1.

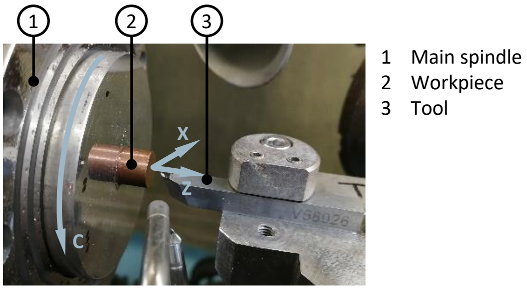


**Figure 1.** Machine setup

The geometry designed for this investigation ist illustrated in Figure 2. The diameter of the workpiece is $D$ = 10 mm and the stroke of the face is $s$ = 50 µm. Machining requires a controlled simultaneous movement of the X-, Z-, and C-axis of the machine tool performing a slow slide operation.

The tool path generation was performed in two diffent ways. A pointlist for the coordinates of the three axes was generated by the calculation of the mathematical functions that describe the tool path in the open source software Scilab 5.5.2 by Scilab Enterprises S.A.S, Orsay Cedex, France.

Another approach involved the use of the specialised CAM-software NanoCAM4 from the machine manufacturer Moore Nanotechnology Systems, LLC, Swanzey, USA. As most conventional CAM-software this software requires a CAD-model of the workpiece and the process parameters are entered into a graphical user interface (GUI). Identical parameters were used for both approaches. The spiral tool paths are resolved with the feed $f = 10$ µm and the depth of cut $a_p = 10$ µm. The angular increment was set to $\Delta\alpha = 0.1$ °. This results in an varying arc length $l_a$ between consecutive knot points. The examination of the machined parts was conducted on the whitelight interferometer (WLI) Zygo NewView 5000 by Zygo Corporation, Middlefield, USA to determine average roughness depth $Ra$ and the deviation of the stroke $s$ as indicator for the dimensional accuracy $G_F$ along the z axis. The WLI's vertical resolution is $a_v = 0.9$ nm. The cutoff wavelength $\lambda_C = 0.08$ mm and short-wave profile filter $\lambda_S = 2.5$ µm were adhered to, based on the standards of tactile roughness measurement. The machining time $t_m$ was determined as a key figure for the efficiency of the machining process.

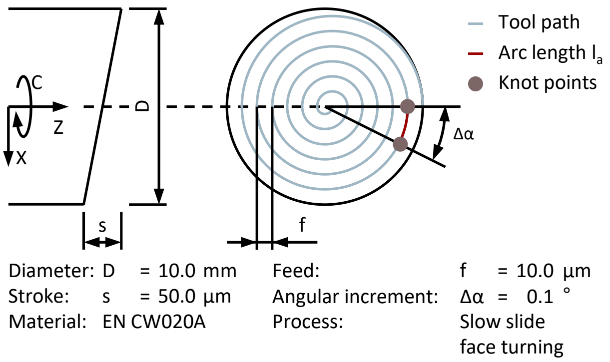


**Figure 2.** Workpiece and tool path for slow slide face turning

## 3. Results

Investigation on surface roughness characteristics show no difference between the surfaces machined with the differenty generated CNC code. The average roughness depth $Ra = 7$ nm was achieved. Further investigation on different surface roughness characteristics will be performed to examine possible surface deviations. When evaluating the machining time $t_m$, the superiority of the software from the machine tool manufacturer becomes apparent. As shown in Figure 3, the machining time $t_m$ could be reduced by $\delta t_m = -20$ % while the maching parameter feed $f$ is kept constant.

During machining with the CNC code created with Scilab the spindle speed $n$ varied and the velocity $v$ of the linear X- and Z-axes adjusted equivalently to maintain the set feed $f = 10$ µm. This effect did not occur with the CNC code generated by the software NanoCAM 4. The spindle speed $n$ was constant at $n = 80$ 1/min.

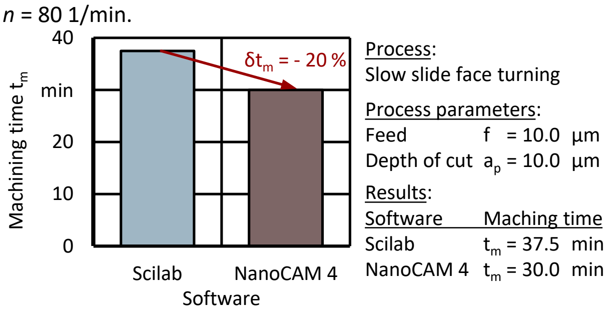


**Figure 3.** Reduction in machining time $t_m$ when using NanoCAM 4 compared to Scilab

## 4. Conclusion and Outlook

Non rotationally symmetrical optical surface generation with face turing operations can be achieved by different CNC code generation techniques without loss of dimensional accuracy $G_F$ or increased average roughness depth $R_a$. When economical considerations gain importance a reduced machining time $t_m$ can be achieved through the use of specialised software. The saving in machining time $t_m$ is due to optimised approach and exit movement . As the feed f was set to an constant value, the spindle speed $n$ and velocity of the z-axis $v_z$ is adopted automatically and limited by the machine tool's dynamic behaviour. As NanoCAM 4 is manufactured specifically for machine tools by Moore Nanotechnology Systems, LLC, Swanzey, USA, an internal optimisation of the CNC code is supposed to shorten the machining time $t_m$ further. When an overlay of different freeform geometries has to be manufactured, CNC code generation with a formula-based software as Scilab is very complex. CAD-model based CNC-software will reduce the effort for preprocessing. In outlook for previous research more complex non rotationally symmetrical surfaces as shown in Figure 4 will be investigated.

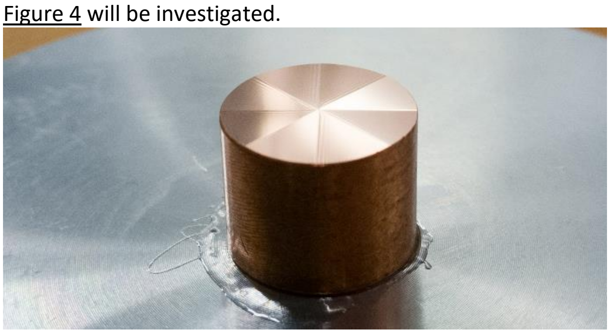

**Figure 4.** Workpiece with facets for further investigation

This specimen has $n = 8$ facets with the stroke $s = 75$ µm and the diameter $D = 10$ mm. Investigations on this structure will involve the influence of knot point generation with constant angular increment $\Delta\alpha$ compared to constant arc length $l_a$ on the surface roughness characteristics, dimensional accuracy $G_F$ and machining time $t_m$.

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