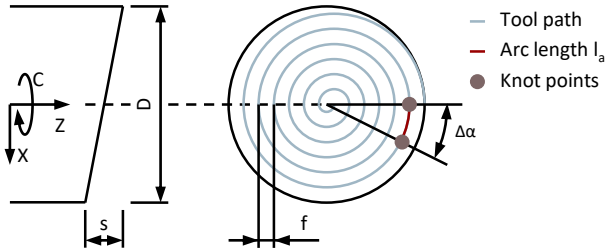
Another approach involved the use of the specialised CAM-software NanoCAM4 from the machine manufacturer MOORE NANOTECHNOLOGY SYSTEMS, LLC, Swanzey, USA. As most conventional CAM-software this software requires a CAD-model of the workpiece and the process parameters are entered into a graphical user 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 λ_C = 0.08 mm and short-wave profile filter λ_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.



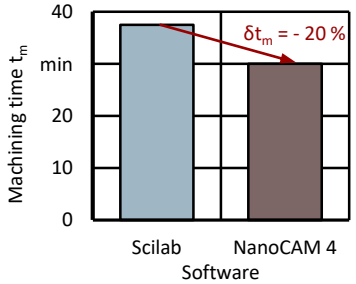
Diameter:	D = 10.0 mm	Feed:	f = 10.0 µm
Stroke:	s = 50.0 µm	Angular increment:	Δα = 0.1 °
Material:	EN CW020A	Process:	Slow slide face turning

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 δt_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.



Process:
Slow slide face turning

Process parameters:
Feed f = 10.0 µm
Depth of cut a_p = 10.0 µm

Results:

Software	Maching time
Scilab	t_m = 37.5 min
NanoCAM 4	t_m = 30.0 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.

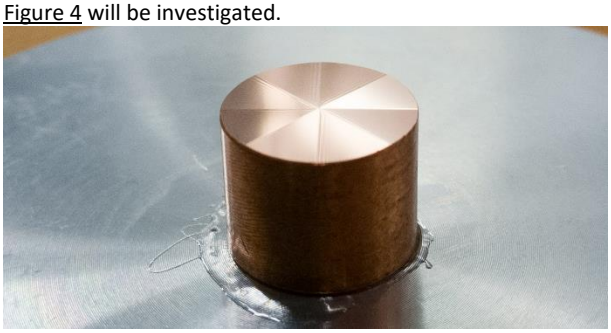


Figure 4. Workpiece with facets for further investigation

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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