Investigations on a Novel Polishing Technology for Machining Ultraprecise Freeform Surfaces

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Abstract

The compact design and in particular the complex forms of optical surfaces of innovative optical products require the highest level of precision during the entire chain of the manufacturing process. Being a part of this chain, the polishing process is characterised by its high flexibility in order to finish optical key components for high precision technology. In addition, this technique can be used to correct surface errors and to realize high quality surfaces − including freeforms. To enlarge the spectrum of forms which can be manufactured using computer controlled polishing methods, and to be able to machine freeform surfaces with small radius of curvature, an innovative polishing method has been developed.

The surface quality realized with this technology strongly depends on process optimization as well as alignment of the workpiece and the polishing tool. This paper presents results of a simulation tool to predict the generated microtopography that strongly depends on the tool alignment. In order to verify the simulation results, experimental investigations were carried out. The microtopographies of the polished surfaces were measured and compared with those calculated in the simulation.

1 Introduction

Modern optical systems in the field of medical science, automotive and industrial application as well as in projection and display systems rely on leading-edge production technologies. For this reason many activities are aiming at the development of manufacturing technologies that are more accurate, reliable and cost-effective.

Computer controlled polishing (CCP) is the corrective polishing step in the classical process chain for the fabrication of optical elements with high dimensional accuracy, flatness and minimal sub-surface damage. In order to predict the generated deviation and the surface roughness depending on the alignment of the polishing tool, simulations have been carried out and compared with experimental results.

2 Setup for the elastic spherical polishing head

Figure 1 shows, on the left hand side, the schematic setup of the novel elastic spherical polishing method with a misaligned tool in *x*-direction. The polishing load, applied in the negative *z*-direction, and the rotation speed around the two axis ω_1 and ω_2 respectively, are kept constant during the experiments. The spherically shaped polishing head, having a radius of $r_K = 21$ mm, is rotating around an axis tilted by 45° with respect to the *z*-axis. The test samples used in the experiments were made out of Zerodur®. As shown on the right hand side of Figure 1, the polishing apparatus is flange mounted to an industrial robot and connected to the controller and the polishing slurry supply.

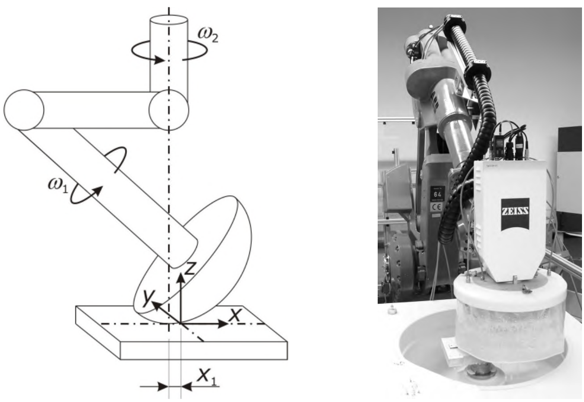

Figure 1: Schematic setup and tool-displacement in *x*-direction (left) as well as the experimental CCP setup for polishing ultraprecise surfaces (right)

3 Modelling of the experimental setup

To quantify the influence of a misaligned polishing tool in *x*- and/or in *y*-direction a mathematic-geometrical simulation model has been developed. The process parameters, determined by the experimental setup, and the influence function, i.e. the measured shape of the polishing tool footprint, have been implemented in the model. In this first study the stiffness of the robot, the material properties of the workpiece, vibrations of the overall machine system and the physical as well as the chemical influence of the polishing slurry have been neglected.

4 Results and discussion

To identify the influence and to quantify the extent of a misaligned spherical polishing tool in *x*- and/or in *y*-direction, a large number of simulations have been carried out. In order to characterize the machined surface quantitatively, the surface deviation as well as the roughness *RMS* have been calculated and evaluated. The results of the simulations are shown in Figure 2. The eccentric polishing head position x_1 (see also Figure 1) has a significant effect on the machined surface. Furthermore there is a connection between tool-displacement and the peak-to-valley deviation of the surface as well as between tool-displacement and the roughness *RMS*.

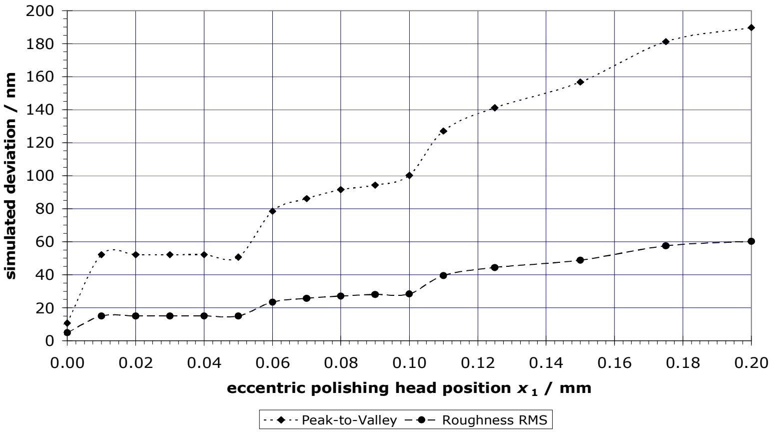

Figure 2: Simulated surface deviation and roughness *RMS* versus eccentric tool position in *x*-direction

Figure 3 shows a picture of a polished surface with a tool-displacement $x_1 = 0.1$ mm. As predicted by the simulation the polished surface shows a periodic surface microtopography having the same order of magnitude. Hence there is a good correlation between the simulated model of the CCP process, depending on the alignment of the polishing tool, and the experiments. The differences between simulated and experimental results are mainly due to the large number of variables influencing the polishing process. Therefore the simulation should primarily be improved with respect to material properties, vibrations of the overall machine system as well as the stiffness of the robot to minimize differences.

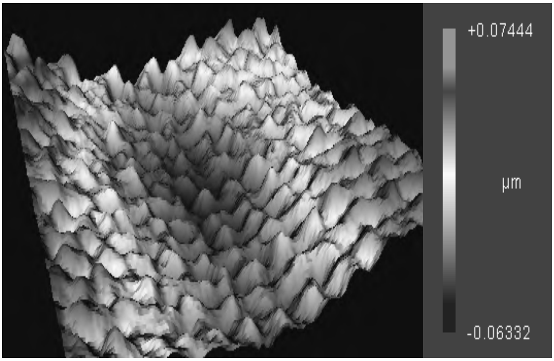

Figure 3: Microtopography of a surface polished with a tool-displacement $x_1 = 0.1$ mm

5 Conclusion

A novel polishing process has been developed experimentally. Furthermore effects of tool-displacement on polished surfaces have been simulated and the results have been verified by experimental investigations. Based on the experimental results, the developed polishing system is applicable to manufacturing surfaces with optical quality. In order to improve the precision of tool alignment and to minimize surface deviations at the same time, further investigations have to be carried out.

References

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