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Investigations on the production of optical freeforms applying the advanced wheel polishing process

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Abstract. The growing interest in providing additional degrees of freedom to the design of high-end optical systems has led to an increased demand for freeform optical elements. The efficient fabrication of such elements requires a polishing process that provides high removal rates and a stable removal function while working with a relatively small spot size. Taking these constraints into consideration this paper focuses on the successful implementation of polishing processes applying the A-WPT (Advanced Wheel Polishing Tool) technology. Addressing the requirements regarding its removal characteristics as mentioned before, it represents an appropriate choice for providing an efficient pre-polishing as well as corrective polishing technique. In order to maintain perpendicularity towards the freeform surface to be polished, the A-WPT is run on a 5-axis simultaneous machining system. First investigations of the achieved surface accuracy after pre-polishing were carried out as well as an assessment of residual surface features within different spatial frequency regions. In addition, the polished surface is being checked for remaining SSD using an OCT technique.

1 Motivation

Freeform optical elements are of growing importance to provide additional degrees of freedom to the design of optics in the field of beam shaping for laser welding and ablation, off-axis imaging for projection and imaging systems (e.g. head-up-displays), for aberration correction and lens count reduction in optical systems [1]. When reaching into increasingly more complex optical applications the achievable accuracies become more important. Together with the size of the parts this drives the processing times to increase drastically, as only point-like interacting tools are used during grinding and polishing [2]. One approach towards an efficient process chain for the fabrication of optical freeforms therefore is the implementation of polishing processes providing a high removal rate in combination with a temporal stable and highly predictive removal function. This led to our investigations focused on the application of the A-WPT technology to meet these requirements.

2 Freeform, Tool and Machine Set-Up

The Advanced Wheel Polishing Tool (A-WPT – shown on the left hand side picture in Fig. 1) had been introduced by OptoTech back in 2013 as the outcome of an internal R&D project. Wu *et al.* have recently published some closer investigations on the removal behaviour of such tools [3]. The A-WPT provides the specific advantages of a standard wheel polishing tool rotating around only one axis (high removal rates even at small polishing spot sizes, reduced tool wear) while combining them with a homogenization of the resulting micro texture on the polished surfaces by adding a second rotational axis. This second rotational axis is oriented perpendicular to the workpiece surface. To keep the perpendicularity on a freeform surface, the A-WPT needs to be run within a multi-axis machining centre providing at least five CNC-controlled axis.

Fig. 1. The A-WPT approaching the starting point of the tool path (left) and 6-axis polishing center MCP 150 CNC (right).

Within our actual investigations a state of the art 6-axis machining centre has been used – the OptoTech MCP 150 CNC as shown on the right hand side picture in Fig. 1. Besides the ability to make use of all different polishing technologies out of the OptoTech MultiTool Concept (spherical polishing using HydroSpeed®; aspherical and freeform polishing using A-FJP, membrane tools, sub-aperture pitch tools) it is equipped with an exchangeable

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workpiece probe. Measuring against predefined reference surfaces it allows for a precise alignment of the freeform within the machine coordinate system.

As a first demonstrator for the proof of the polishing process performance a freeform surface was designed. It is defined by the equation given here below.

$$z = f(x,y) = \frac{(2\cdot x+25)^2-2.5}{1000} - \frac{(2\cdot y+5)^2}{380} \qquad (1)$$

A graphical representation of the height profile is shown in Fig. 2. It provides concave as well as convex radii of curvature. For the experimental tests the size of the part was set to 25 x 25 mm² with a maximum sag height of 4.87 mm.

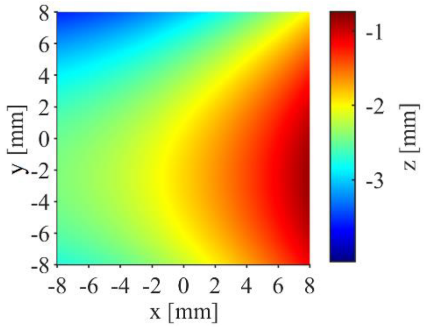

Fig. 2. Surface profile of the freeform to be polished.

3 Experimental Results and Discussions

As mentioned before, for the polishing process tests the A-WPT was used within an MCP 150 CNC machine centre. After alignment of the freeform within the machine using the workpiece probe, the tool was driven across the part in a meandering tool path with a line spacing of 1 mm and a polishing spot size of 6 mm in diameter. After a total polishing time of approx. 50 minutes the pre-polishing was completed and the surface figure was measured using a MarForm MFU200.

Fig. 3 shows the resulting shape accuracy when comparing the polished surface with the designed free-form surface. The P-V error of approx. 13.7 µm partly remains from the grinding process but mainly was introduced during the non-optimized pre-polishing step.

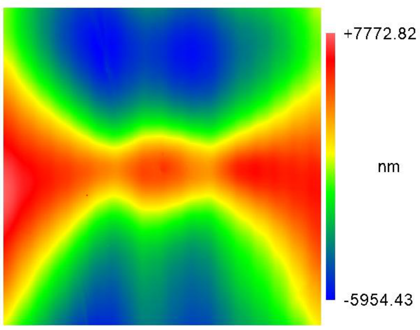

Fig. 3. Shape accuracy measurement of the freeform surface after pre-polishing.

As we first focused on the demonstration of the pre-polishing performance, the result was filtered using a high-pass filter with a cut-off wavelength of 2 mm and was compared to the measurement results achieved from the freeform surface after grinding (Fig. 4). It can clearly be seen that the high spatial frequencies introduced during grinding efficiently could be removed. Residual periodic structures on the polished surface are related to the raster path increment and can be avoided by properly choosing the process parameters in future investigations.

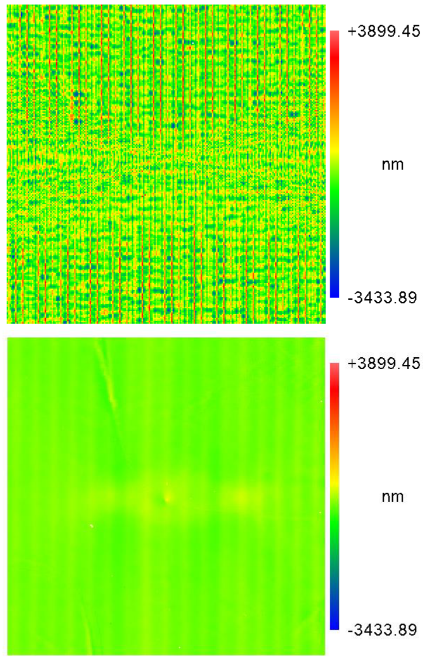

Fig. 4. High-pass filtered measurement results of the freeform surface after grinding (top) and after pre-polishing (bottom).

4 Conclusions and Outlook

The A-WPT technology has proven to be an appropriate choice if an efficient pre-polishing is required. High spatial frequencies as generated during grinding are removed successfully. As the polishing spot size can be varied over a wide range pre-polishing and corrective polishing can be accomplished with the same tool by only changing the process parameters.

Further investigations will focus on the optimisation of the pre-polishing process in order to reduce the PV error occurring in-between as well as on the implementation of correction cycles in order to reduce the total shape error once the pre-polishing has been completed. For an error as shown in Fig. 3 our simulations of the process time needed (polishing spot size of 2 mm in diameter, removal rate of approx. 0.2 mm³/min) gives an estimated cycle time for the correction of about 20 min.

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