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Investigations on a novel process chain for manufacturing of freeform surfaces

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Abstract. Freeform optical surfaces have become increasingly important in recent years, as they can be used to construct optical assemblies with a reduced number of optical surfaces compared to systems without freeform surfaces, and thus optical systems can get more compact and lighter. However, the flexible and efficient production of precise optical freeform surfaces poses a major problem. This manifests itself in insufficient precision of the optics, long delivery times and high prices. It is shown, that ultrasonic grinding processes, combined with an ultra-fine grinding process and subsequent plasma jet polishing, are very well suited for the production of freeform optics and have a high technical and economic potential. Therefore, the aim is to validate an industrially suitable process chain based on this combination, in order to produce freeform optics of high accuracy (shape deviations <100 nm RMS) that can be manufactured in significantly fewer steps than before.

1 Research approach of a novel process chain

The application of freeform surfaces in optical systems offers many advantages compared to the use of conventional optical elements like spherical lenses. The possibility of optical assemblies with a reduced number of optical surfaces enables more compact and lighter systems, reduces losses of optical radiation power and can even lead to completely new optical functionalities. Unlike spherical or aspherical surfaces, freeform surfaces do not have rotational symmetry, but generally have six degrees of freedom that can be described mathematically with polynomials or splines. To exploit the full potential of freeform optics, both manufacturing and metrology must keep pace with the design. [1]

Therefore, a novel fabrication process chain is currently under development, which combines abrasive grinding processes with a thermal based plasma polishing process as shown in Fig. 1.

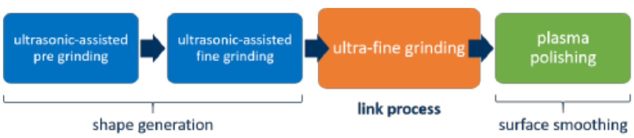

Fig. 1. Schematic representation of novel process chain for freeform fabrication

First, the desired shape of the part geometry made of glass (for example fused silica) is created in a 5-axis CNC-grinding process. It consists of a coarser pre grinding process for fast material removal and a fine grinding process for gradual approximation to the desired surface shape. Both process steps can further be enhanced with ultrasonic (US) assistance, using a high frequency tool oscillation in the micrometre-range. This results in lower grinding forces in the interaction zone and less stress is introduced into the surface, which leads to a reduced area of sub-surface damages. Depending on the glass material and the grinding parameters, force reductions from 10% up to 40% could be determined in the direction of the US oscillation [2]. Tool wear can also be reduced by more than 50% compared to grinding with identical processing parameters without ultrasonic-assistance [3].

Subsequently, an ultra-fine grinding process to further reduce the damage level and the micro-roughness is applied. In this process special resin bond tools from company *Effgen* are used with fine diamond grain size D16. The bond material is highly porous and slightly elastic, which has a damping effect and leads to a reduction in the penetration depth of the abrasive grains into the workpiece material. Thus, it is possible to achieve a surface roughness of ca. Rq=10 nm in fused silica processing [3]. The ultra-fine grinding process has a decisive link function in the process chain, as it is capable of producing already partially transparent surfaces with a particularly favourable roughness and topography for the plasma process.

This plasma polishing process is applied as the final step in the manufacturing chain, to achieve a smooth and ideally defect-free surface of the freeform workpiece. Plasma-beam assisted polishing is based on local heating and softening of the glass surface. Due to the smoothing

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through thermally induced material redistribution and minimisation of surface tension, no material removal takes place under correct conditions, so that the shape of the before fine grinded surface is preserved. In addition, damage close to the surface is removed, which leads to a significant increase in the laser strength of the surfaces. [4]

2 Freeform definition and digital manufacturing preparation

An important part of the freeform fabrication process is the appropriate definition and digitalisation of the desired geometry. Since its much higher degree of freedom compared to a sphere, the definition of the freeform surface is far more complex. Usually it can be defined using a mathematical function, as an arrow-height table or as a point cloud. In the presented case the freeform is designed according to its desired optical functionality with the optic design software *Zemax* using a mathematical definition of an Alvarez lens. The primary data is then exported as a volumetric body using the STEP format, which is a universal standard for CAD/CAM programs. The resulting file is imported to the program *Creo* for the implementation of CAM-programming. In this, the so-called grinding cycles and processing parameters are chosen and the tool path is planned and simulated (see Fig. 2). Under the use of a post-processor the generated CAM-program is translated into the language and input variables of the specific CNC-machine, which is an Ultrasonic 20 linear from *DMG*.

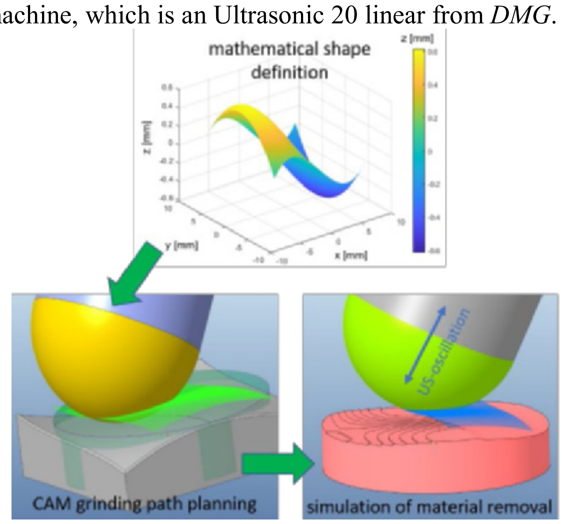

Fig. 2. Digital preparation of freeform grinding process, including geometry definition, optical design and CAD/CAM programming

This approach has proven to be efficient, as well as being able to ensure the necessary digital resolution for a subsequent precise CNC-grinding process of complex geometries.

3 First results of basic grinding experiments and outlook

The individual processes of the manufacturing chain and their interactions are currently under investigation. In addition to fundamental experiments to examine and optimise the processes, the advantageous coupling of the grinding processes with the subsequent plasma polishing is of particular interest. The special kinematic properties of freeform grinding are characterised by a point-shaped tool-surface contact zone and a line-by-line path processing. This usually results in periodic surface structures. For optimal surface smoothing by plasma polishing these structures should ideally be minimised in amplitude and have a short spatial wavelength. Fig. 3 shows an example of the difference topography between the nominal surface geometry and the actual geometry after grinding for an Alvarez freeform before polishing. Local peaks and the described periodic structures can be found.

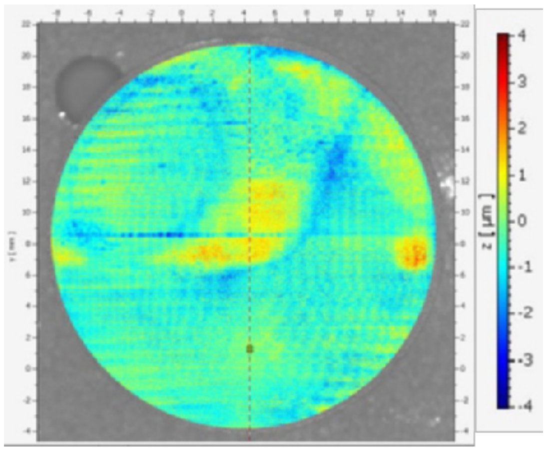

Fig. 3. Difference topography of a grinded fused silica Alvarez freeform (ø 1 inch) measured by white light interferometry

A main approach for the upcoming investigations is therefore the research of the interactions in the freeform grinding process and therefore the control and optimisation of the resulting surface shape and topography.

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