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New polishing concepts for optical components in flexible and efficient process chains

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Abstract. The flexible and efficient production of precise optical free-form surfaces requires advanced kinematic operating principles. Due to the complex surface geometries, polishing processes with point or linear contact are used. These generally result in longer polishing times due to the smaller footprint compared to large-area polishing tools. The creation of a high precision, polishable surface in the shaping steps of the process chain is therefore of great importance. This applies in particular to minimising the roughness, but also the depth of SSD (sub-surface damage) and the mid-spatial frequency errors before the polishing process. The article describes selected process chains for the production of free-form optics and presents options for optimising the required polishing steps.

1 Introduction

Polishing is the final process step in the production of optical surfaces in the optical component manufacturing chain before coating. It is the most important finishing process for the production of high-quality optical components. With regard to the reproducibility of the surface quality, there is often only a relatively low level of process reliability. Efforts are therefore being made to optimise the polishing process. With the increasing demands on high-performance optics, polishing processes have developed further in recent years and new polishing methods have become established. This is also based on the increased requirements for producing complex shaped aspherical surfaces, including the use of free-form surfaces, the potential of which will need to be further developed in the coming years. [1]

2 Description of the polishing process

While PRESTON 's equation is based on a linear approach, i.e. polishing pressure, friction coefficient, polishing surface and PRESTON coefficient are assumed to be constant, more recent models are based on a non-linear approach. WRSCHKA describes the chemical-mechanical polishing (CMP) of compact and structured aluminum films using a polyurethane pad and a slurry based on aluminum oxide particles as abrasive and hydrogen peroxide as oxidant [2]. The PRESTON equation cannot exactly describe the dependence of the removal rate on pressure and velocity, instead the following power function is proposed by WRSCHKA et al.

$$\frac{dz}{dt} = -C_p \cdot p^{\alpha} \cdot v_c^{\beta}$$

STROH and SCHWALB present a polishing method ‘ADAPT’ (Aspherical Deterministic Adaptive Polishing Technology), which also provides for a change in pressure distribution for the deterministic polishing process. [3] This likewise non-linear polishing model results in the following dependency of the removal work according to STROH and SCHWALB

$$\frac{dz}{dt} = f(C_p, p, v_c, WE) \qquad WE \text{ - Tool properties}$$

Another interesting aspect of this model and this procedure is the consideration of the tool properties, which enable a targeted change in pressure distribution during the polishing process.

The GRIN Pad Polishing process [4] is a new method of specifically adapting the tool hardness properties to the required removal profile of the polishing process. Varying the hardness of the polishing tool via the diameter makes it possible to set adapted removal functions.

$$W_a = \mu \cdot A \cdot \int_0^{da} p \cdot v_c \cdot t_P \qquad da \text{ - outer diameter}$$

3 Process chain solutions

In general, optical manufacturing process chains are divided into the steps of dressing, pre- and fine grinding, (optionally lapping), pre- and fine polishing and, if necessary, corrective polishing. The selection of the individual grinding and polishing processes depends on the parameters of shape and geometry, material, kinematics, etc.

Fig. 1. New process chain models with plasma polishing [5]

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A new type of process chain as depicted in Fig. 1 was developed and tested in a current research project [5]. Plasma polishing was selected as the polishing process. Beam-based processes offer the advantage that they can be used very flexibly in combination with multi-axis machine systems for free-form machining. In addition, there is no tool wear compared to foil or pitch polishing. In addition to the plasma process, laser beam-based polishing processes are also the subject of development for the final polishing step. Ion beam processes have been firmly established in the process chains of optical production for many years.

In order to optimise the processes with regard to the required polishing times and polishing results, particular emphasis was placed on the provision of polishable surfaces [5]. The roughness values Sq and the SSD depths in the shaping process can be further minimised by adding an ultra-fine grinding process with resin-bonded tools before plasma polishing.

4 Solution approaches

The polishing of free-form optical surfaces requires processing with sub-aperture tools (the tool diameter is small compared to the surface to be polished). Pre-polishing and fine polishing are usually carried out with different tool diameters, and the feed rate and polishing pressure are usually selected differently (Fig. 2). In contrast to the cup tools, the proportion of medium-frequency defects increases as a result of 'abrasion' or 'spiralling of the surface' with sub-aperture tools.

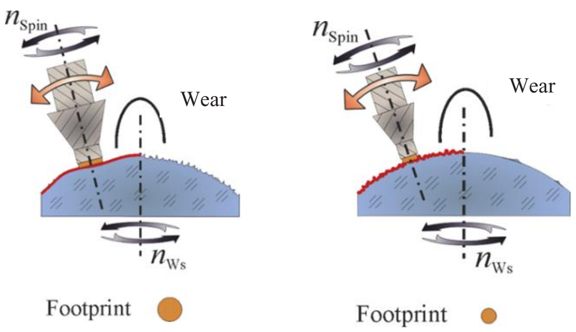

Fig. 2. Principle of pre-polishing and fine polishing with sub-aperture tools

For very high requirements on optical components, the polishing sequence is often not sufficient, so that a correction polishing operation must be carried out after the fine polishing. The aim is to remove residual defects on the surface in a targeted manner using a path-time-controlled removal process (Fig. 3). This requires an exact topographical evaluation of the optical surface after fine polishing. Process- and procedure-related mid-frequency shape deviations are also to be expected in this process stage, but these are significantly lower compared to the fine polishing operation.

For machining tasks in which periodic residual structures (mid-spatial frequencies errors) are not permitted, an additional smoothing polishing step follows. However, this should be as short as possible so as not to generate any additional shape errors.

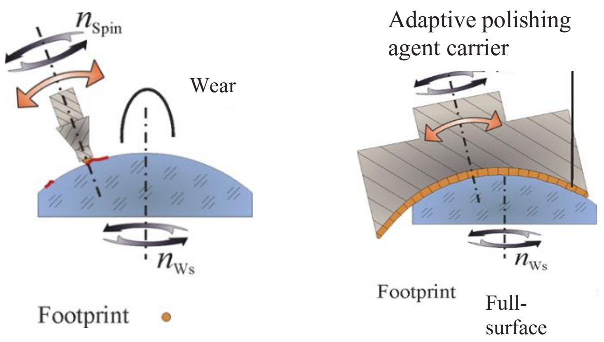

Fig. 3. Principle of correction and smoothing polishing

5 Adaptive polishing tools

Adaptive polishing agent carriers are usually used to remove the periodic structures in the smoothing polishing step. Using the possibilities of additive manufacturing, customised polishing agent carriers were developed and tested in [4] (Fig. 4). These have the advantage that they are very flexible and can be printed and customised for any surface shape.

Fig. 4. 3D-printed polishing tools for a radius of 88,845 mm

6 Conclusion

Modern process chains for the production of free-form optical surfaces require the availability of flexible polishing processes and very good surface preparations by the shaping process stages. Beam-based processes are a very good alternative for many polishing tasks. 3D-printed tools with specially calculated hardness curves have been successfully tested for smoothing polishing.

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