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Optimization of grinding processes on fused silica components using in-process vibrometry and dynamometer measurements

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Abstract. The presented investigations deal with real-time evaluation and recording of vibrations and forces during a CNC grinding process, as well as the analysis and control of process influences on the surface quality of optical components. The experiments were carried out on a 5-axis CNC machine. Rapid subsequent analysis of the topography resulting from grinding is achieved with the aid of white light interferometry. The aim of the investigations is to reduce the surface deviations (roughness, mid-spatials, waviness) influenced by process factors. It is shown that the vibration data measured during the grinding process correlate to a high degree with the recorded topography data.

1 Motivation

The use of CNC-controlled processing machines for grinding inorganic non-metallic materials allows the production of increasingly complex components for various sectors such as the optical industry, semiconductor industry or medical technology. Using modern 5-axis CNC technology, it is possible, for example, to create freeform surfaces or monolithic components from silicate glasses. Conventionally, the grinding process with bonded grain is used for coarse shape production of a component, which is then followed by several fine machining processes with loose grain, such as lapping and polishing, with gradual reduction of the abrasive grain size. [1] However, the application of grinding processes using bound grain has some advantages regarding better process reproducibility, efficiency and less waste of resources compared with loose grain processes. Lapping and polishing are also very time-consuming and are characterized by high cleanliness requirements. This results in the goal to replace loose grain processes by grinding as far as possible. By application of strategies like ductile regime grinding or usage of novel partial elastic resin bond grinding tools, it is already possible to achieve low roughness values comparable to pre-polishing down to Rq ≈ 10 nm (planar grinding of fused silica) [2]. While such high frequency surface deviation values can be already reduced, grinding processes of optical materials have to face the problem of the influence of unwanted vibrations and other influencing factors, mainly resulting in low and medium frequency surface deviations. The waviness and the so-called mid spatial frequency, periodic defects or grinding structures are undesirable surface phenomena. These remaining periodic surface structures are particularly hard to remove afterwards, which explains the fact that the processes with loose abrasive grain have so far continued to be indispensable.

Therefore, an essential objective of the investigations is to draw conclusions between chosen grinding parameters, primary process parameters like vibrations and forces and the resulting surface topography and quality. By gaining knowledge of the more precise process correlations, it should be possible in future to influence the described periodic structures in a targeted manner and ideally to prevent them completely.

2 Experimental set-up

All vibrations and small-scale movements that occur during machining in the interaction area between the machine, the tool and the optical component are meant to be considered. This requires highly dynamic and contactless laser vibrometric measuring systems that allow a high amplitude resolution (sub-µm range) and can simultaneously also record a very broad frequency spectrum. Therefore, the application of different laser vibrometry systems from company *Polytec* is considered, including a fibre vibrometer for space-saving installation and the relatively new QTec system for improved signal to noise ratio in difficult measurement environments. One of the investigated preliminary set-ups installed in the grinding machine is shown in Fig. 1. A dynamometer 9129AA from company *Kistler* is also included for in-situ

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grinding force measurement. The data acquisition of both vibrometer and dynamometer is synchronized in time.

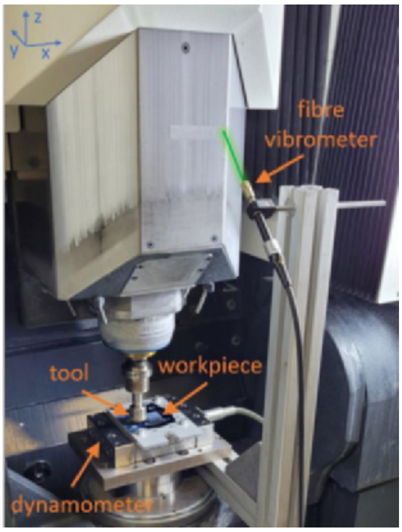

Fig. 1. Preliminary measurement set-up including vibrometer and dynamometer measuring devices

After grinding, the surface topography of produced component surfaces is recorded. Two white light interferometry (WLI) systems from *Polytec* are used, a microscopic measuring instrument (TMS-1400, TopMap Micro.View) and a macroscopic instrument (TMS-500, TopMap Pro.Surf). This enables surface defect analysis from low to high frequencies. On a gained topographical map, the effect of the influencing variables on the grinding process can also be analysed, in analogy to the vibration analysis.

3 Examinations & Results

In order to gain an initial understanding of the process behaviour and its effect on the topography of the workpiece, a simple kinematic strategy was chosen first to detect the influences of the individual parameters. This consists of a linear grinding path using a metal-bonded ring tool of diameter 24 mm and grain size D64. The processed material is fused silica (*Corning* 7980 5F) with sample dimensions of 20 x 20 mm².

In the first preliminary investigations, interesting aspects could already be observed and insights into the processing machine were gained. Noticeable were distinct "steps" on the component surface, which appeared along the grinding path on the entire component but differed in their height. Figure 2 shows the surface topography, recorded with the TMS-500, of a machined workpiece in which periodic structures are visible that are reminiscent of "chatter marks" from the milling process. They were found to be caused by an integrated machine regulation called "temperature compensation". A sensor therefore detects a temperature dependent expansion or contraction of the machine spindle in the micrometre range and a regulation process automatically compensates this by slightly readjusting the z-axis position during the process. Since this should improve dimensional accuracy, the resulting distinctive structures are disadvantageous regarding surface quality.

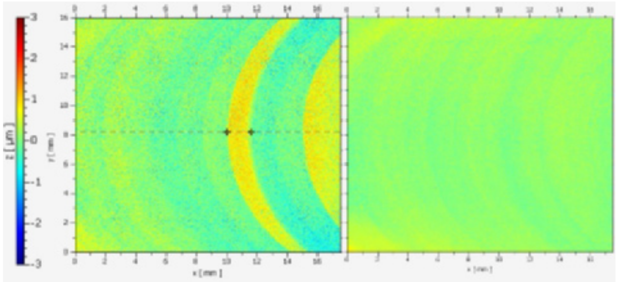

Fig. 2. Sample topographies (area 17,5 x 16 mm²) grinded with temperature compensation on (left) and off (right)

Furthermore, correlations between the in-process-measurements and the resulting sample surface topography were already successfully demonstrated for the first time, as can be seen in Fig. 3. The signal of vibrometry, force measurements and topography have been superimposed in the diagram. The positions of topography steps (blue) and vibrometer distance variation (green) are rather well correlated. The force signal (orange) also shows short peaks on the same positions, which represent the moments the temperature compensation triggers a z-axis regulation.

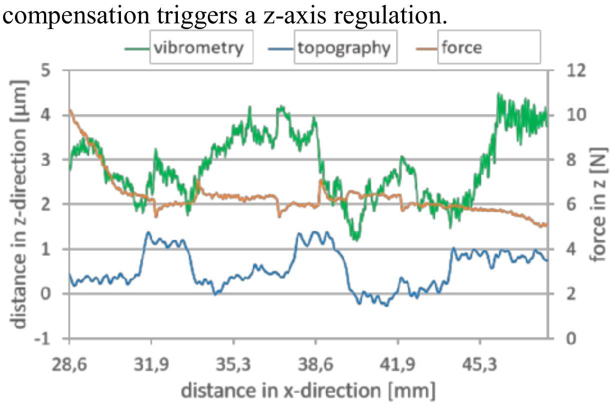

Fig. 3. Synchronized vibrometry, force and topography data for a sample surface (temperature compensation active)

This shows, that it is possible to find the characteristic vibrations dependent on the grinding parameters as surface structures on the components, which makes it possible to predict the surface quality produced in the process. For future investigations a robust AI model will subsequently be created. By means of AI algorithms, possible correlations and thus effects of the error influencing variables on the processing result should be able to be directly concluded. If successful, process regulation could then be carried out with relatively high predictive probability on the basis of the model.

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