WHITEPAPER

Ultrasonic-assisted grinding of quartz glass and aluminum oxide

Quartz glass and technical ceramics such as aluminum oxide are essential materials in numerous high-tech industries. For instance, quartz glass is used in the semiconductor industry for wafer holders and etching masks because it is both thermally and chemically stable. In optics, precision lenses, prisms and wave guides are made from quartz glass. In addition, quartz glass plays a key role in modern medical technology, for example in diagnostic devices and laser systems.

Aluminum oxide is also widely used in the industry. In the field of medical technology, for example, it is used for biocompatible implants such as artificial hip joint heads, which benefit from its high wear resistance and corrosion resistance. Other applications can be found in the aerospace industry, where it is used as heat protection for critical components or as a material for bearings and seals that must withstand extreme mechanical and thermal loads.

The material properties that make quartz glass and aluminum oxide particularly valuable also make them difficult to machine. Both materials are characterized by high hardness and brittleness, which can lead to microcracks, high tool wear rates and inadequate surface qualities. In addition, the grinding processes require high precision, especially for complex geometries, to meet the requirements of modern applications.

The use of ultrasonic assistance for grinding processes shows great potential for overcoming these challenges. By introducing high-frequency movements, process forces can be reduced, surface quality improved and tool wear minimized. This paper shows the effects and advantages of ultrasonic-assisted grinding technology for quartz glass and aluminum oxide. The ultrasonic system VibroCut *ultrasonic* is used to apply high-frequency movements to the grinding tool. The innovative system is characterized in particular by its high performance for high amplitudes and precise process behavior.

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Investigation into the use of ultrasonic assistance with VibroCut *ultrasonic*

As an example for the group of brittle-hard materials, the ultrasonic assistance grinding of components made of quartz glass and aluminum oxide is being investigated.

Figure 1: Machining situation

To implement ultrasonic assistance, a machine tool designed as a machining center was equipped with the VibroCut ultrasonic system. An ultrasonic movement is generated in the rotating tool holder and the kinematics of the cutting process are superimposed with this movement. The amplitude is specified in the NC program using M commands and can be set over a wide range. The ultrasonic frequency is automatically detected and readjusted by the system. The unique feature of the system is its high performance and precision, which is based on an internal sensor for highly dynamic control of the ultrasound.

The test parameters were varied depending on the materials to be processed and are summarized in Table 1.

Table 1: Parameters of the grinding tests

	Quartz glass	**Aluminum oxide**
Tool	mounted point - galvanically bonded diamond grit	mounted point - galvanically bonded diamond grit
Bore diameter	Ø10 mm	Ø10 mm
Cutting speed v_c	2.5 m/s	2.5 m/s
Infeed a_p	0.2 mm	0.06 mm
Contact width a_e	1 mm	2 mm
Feed rate v_f	120...200 mm/min	300...500 mm/min
Coolant pressure	Emulsion 30 bar	Emulsion 30 bar
Ultrasonic frequency	≈ 18.5 kHz	≈ 18.5 kHz
Amplitude $\hat{A}_{pp}$	4 µm / 8 µm / 12 µm	4 µm / 8 µm / 12 µm

In order to evaluate the effects of ultrasonic assistance, the passive forces of the grinding processes were recorded using a force measurement platform (Kistler) and compared for conventional and ultrasonic-assisted grinding.

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Technological effects and mechanisms

For the investigation of ultrasonic-assisted grinding of quartz glass, the component was ground flat on the face side. Figure 2 shows the progression of the feed forces for the different feed rates as well as the conventional and ultrasonic-assisted drilling process for the grinding of quartz glass with increasing amplitude between 4 µm and 12 µm. It can be seen that the feed forces increase with higher feed rates and that the forces of conventional grinding are at a maximum of 4.5 N. The cutting forces are an important evaluation criterion for grinding processes on brittle-hard materials due to the sensitive nature of the material, as they determine the efficiency of the removal process. Excessive forces limit productivity and surface quality and can lead to quality problems such as micro-cracks or chipping.

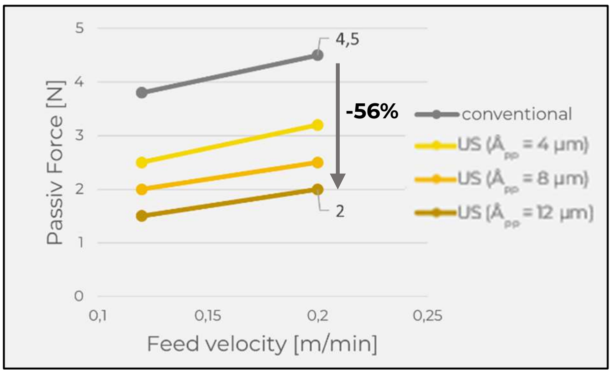

Figure 2: Diagram of passive forces quartz glass

Figure 2 shows that ultrasonic assistance leads to a significant reduction in passive force for both feeds. The forces decrease with increasing amplitude. At a feed rate of 0.2 m/min and an amplitude of 12 µm, the passive force drops from 4.5 N to 2 N with ultrasonic assistance. This corresponds to a drastic force reduction of 56%. This effect is due to the "micro-hammering" of the ultrasound, which breaks up the brittle material microscopically and thus enables controlled material removal. In addition, the rapid movement of the tool leads to changed kinematics and multi-axial loads on the abrasive grains.

For the second material, aluminum oxide, the forces were measured in a comparable procedure. Figure 3 shows the values of the passive forces for grinding the ceramic. Here too, the forces increase with increasing feed rates. For the conventional grinding processes and a feed rate of 0.5 m/min, the passive force for the aluminum oxide is 21 N. The cutting forces are also decisive for the efficiency of the grinding processes for this material. The ultrasonic assistance of the grinding process also leads to drastically reduced machining forces. At a feed rate of 0.5 m/min and an amplitude of 12 µm, the passive force is reduced by 43% to 11.9 N. In contrast to quartz glass, the amplitude has a smaller influence here. In this context, the effects of the amplitudes between 4 µm and 12 µm are almost identical. Due to the brittle material behavior, the

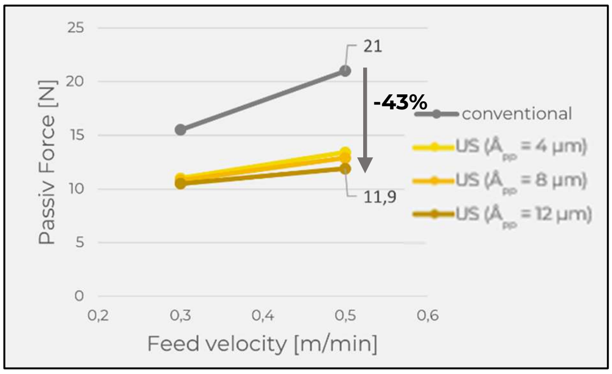

Figure 3: Diagram of passive forces Aluminum oxide

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material removal by ultrasound is also more efficient and controlled here, which has a positive effect on the performance of the grinding processes.

The results show that ultrasonic assistance has a positive effect on the properties and performance of the grinding processes. The ultrasonic tool holders cause the grinding tool to move at a high frequency, which changes both the process kinematics and the mechanisms of action during chip formation. The effects and impacts can be summarized as follows:

1. **Ultra-fast movement of the abrasive grain**

The abrasive body is set in an extremely fast motion by the ultrasound, causing each individual abrasive grain to oscillate in addition to its rotational movement in the axial direction. This significantly influences the contact conditions of the abrasive grains.

2. **Efficient material removal**

The ultrasound causes “micro-hammering”, which breaks up the brittle-hard material on the surface. This makes material removal more efficient and controlled.

3. **Self-cleaning**

The ultrasound reduces deposits on the grinding tool and prevents clogging. This maintains the sharpness and cutting ability of the tool for longer.

4. **Sharpening of the grit**

The multi-axis and impact load leads to small breakouts on the abrasive grain, resulting in the formation of new sharp cutting edges.

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Customer benefits

The drastically reduced machining forces have a positive effect on the limits of the grinding processes in terms of productivity, process reliability and component quality. Figure 4 summarizes the advantages of ultrasonic assistance when grinding brittle-hard materials such as quartz glass or ceramics such as aluminium oxide.

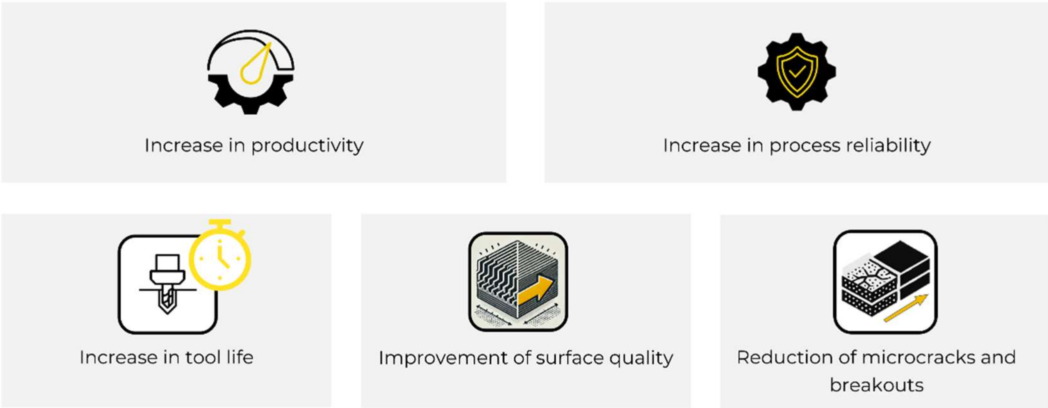

Figure 4: Advantages of ultrasonic-assisted grinding

The efficient and controlled material removal improves the component quality in terms of surface roughness and prevents microcracks and breakouts. In addition to the increase in tool life, the potential to increase the cutting values and thus the productivity of the grinding processes is a key factor in realizing cost savings through the use of VibroCut *ultrasonic*. An example of a profitability calculation is shown in Figure 5. In many applications, a return on investment of less than one year is realized.

Cost savings VibroCut *ultrasonic* for grinding brittle-hard materials

Calculation example cutting parameter increase

- Machine hour rate: 75,- € / h
- Planned occupancy time: 4000 h / year
- Machining main time share grinding on cycle time: 80 %

Increase in cutting parameters	Increase in productivity	Savings per machine and year
20 %	13.3 %	39,900 €
50 %	26.7 %	80,100 €
100 %	40 %	120,000 €

Figure 5: Example calculation of the economic benefit of increasing the cutting value

Another major advantage of ultrasonic assistance is the increase in process reliability. Efficient and gentle processing using ultrasound is particularly helpful for complex and cost-intensive components in order to reduce the risk of process disruptions and quality-relevant deviations, thereby avoiding costly and time-consuming rejects.

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Further information

VibroCut *ultrasonic* is a patented system by VibroCut GmbH. We act as a product and technology provider and integration partner for the use of ultrasonic-assisted machining in your production. We sell ultrasonic systems for equipping new and existing machines and offer related services.

The VibroCut *ultrasonic* system represents the strongest and most precise ultrasound on the market. Thanks to its enormous power, high amplitudes are achieved and even larger grinding tools are set into movement. An integrated sensor measures the ultrasonic movements directly. Highly dynamic control ensures reproducible performance characteristics and raises the precision of ultrasound to a new dimension.

Performance parameters VibroCut *ultrasonic*

Ultrasonic frequency	f_{Vib}	=	16 ... 50 kHz
Amplitude	$\hat{A}_{pp}$	=	0.1 ... 80 µm
Performance	P_{Max}	=	100 ... 1,000 W

Figure 6: Ultrasonic tool holder for VibroCut ultrasonic

The system is available in various performance classes, dimensions and interfaces to suit your machine tool. Depending on the requirements of the machining process, users can choose from four different power classes - from the Precision Line for delicate tools with speeds of up to 30,000 rpm to the Performance Line for applications with large, high-mass tools. The Precision-Line (100 W), Standard-Line (250 W) and Performance-Line (500 W) are intended for machining centers with automatic tool changes.

Feel free to contact us directly or find more information on our website:

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