

MACHINING HARD, BRITTLE MATERIALS

Ultrasonic-assisted grinding with PRIMINER C500ultrasonic

EXECUTIVE SUMMARY

Ultrasonic-assisted grinding of quartz glass and aluminium oxide

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

Aluminium oxide is likewise widely used in industry. In medical technology, for example, it is used for biocompatible implants such as artificial femoral heads, which benefit from its high wear resistance and corrosion resistance. Further applications are found in aerospace, where it serves as heat protection for critical components or as a material for bearings and seals that have to withstand extreme mechanical and thermal loads.

The very material properties that make quartz glass and aluminium oxide so valuable also make them difficult to machine. Both materials are characterised by high hardness and brittleness, which can lead to microcracks, high tool wear rates and inadequate surface quality. Grinding is therefore the machining process of choice. The grinding process demands high precision, particularly with complex geometries, in order to meet the requirements of the applications mentioned above.

The use of ultrasonic assistance in grinding processes shows great potential for overcoming these challenges. Introducing high-frequency vibrations reduces process forces, improves surface quality and minimises tool wear. This whitepaper presents the effects and benefits of ultrasonic-assisted grinding technology for quartz glass and aluminium oxide. The VibroCut *ultrasonic* system is used to apply high-frequency vibrations to the grinding tool. This innovative system is distinguished in particular by its high performance for large vibration amplitudes and by its precise process behaviour.

Executive Summary	02
Ultrasonic-assisted grinding of hard, brittle materials	03
Technological effects and mechanisms	04
Results	05
Customer benefits	06
Further information on VibroCut	07
The PRIMINER C500-5X ultrasonic machine	08
Implementing partner UNITECH-Maschinen GmbH	09

STUDY ON THE APPLICATION OF ULTRASONIC ASSISTANCE WITH VibroCut *ultrasonic*

As representative examples of the group of hard, brittle materials, ultrasonic-assisted grinding is investigated on components made of quartz glass and aluminium oxide.

To implement ultrasonic assistance, UNITECH-Maschinen GmbH equipped the PRIMINER C500 machining centre with the VibroCut *ultrasonic* system. An ultrasonic vibration is generated in the rotating tool holder and deliberately superimposed on the kinematics of the cutting process. The vibration amplitude is specified by M commands in the NC program and can be set over a wide range. The vibration frequency is found and readjusted automatically by the system. What sets the system apart is its high performance and precision, which are based on an internal sensor for highly dynamic control of the ultrasound.
The test parameters were varied according to the materials to be machined and are summarised in Table 1.

To evaluate the effects of ultrasonic assistance, the passive forces of the grinding process were recorded using a force measuring platform (Kistler) and compared for conventional and ultrasonic-assisted grinding.

To protect the high-precision machine elements, UNITECH modified the drive elements so that, carefully encapsulated, they withstand the aggressive grinding dust.

	Quartz glass	**Aluminium oxide**
Tool	Mounted point – diamond grit electroplated bond	Mounted point – diamond grit electroplated bond
Tool 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
Width of cut 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
Vibration frequency	≈ 18.5 kHz	≈ 18.5 kHz
Vibration amplitude	4 µm / 8 µm / 12 µm	4 µm / 8 µm / 12 µm

Table 1: Parameters of the grinding tests

Technological effects and mechanisms

To investigate the ultrasonic-assisted grinding of **quartz glass**, the component was face-ground on its end face. For the grinding of quartz glass, Figure 2 shows the feed forces for the various feed rates and for the conventional and ultrasonic-assisted drilling process with the vibration amplitude increasing from 4 µm to 12 µm. It can be seen that the feed forces rise with a higher feed rate and that the forces in conventional grinding are at most 4.5 N. With hard, brittle materials, the cutting forces are an important assessment criterion for the grinding process because of the sensitive material, since they determine the efficiency of the material removal process. Excessive forces limit productivity and surface quality and can lead to quality problems such as microcracks or chipping. Figure 2 shows that ultrasonic assistance leads to a significant reduction in the passive force for both feed rates. The forces decrease as the vibration amplitude increases. At a feed rate of 0.2 m/min and a vibration amplitude of 12 µm, ultrasonic assistance lowers the passive force from 4.5 N to 2 N. 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 on a microscopic scale and thus enables controlled material removal. In addition, the rapid movement of the tool leads to altered kinematics and multi-axial loading of the abrasive grains.

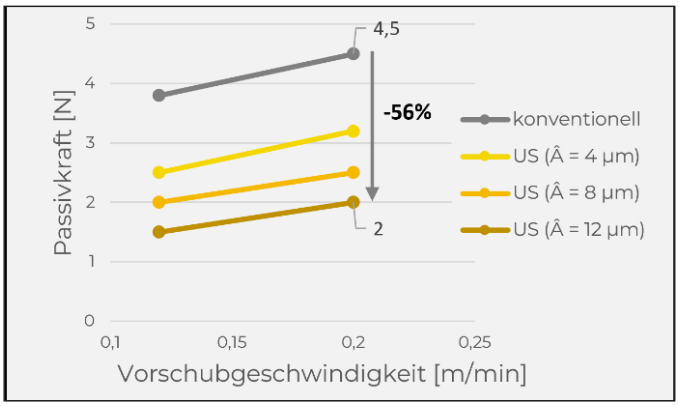


Figure 2: Diagram of passive forces, quartz glass

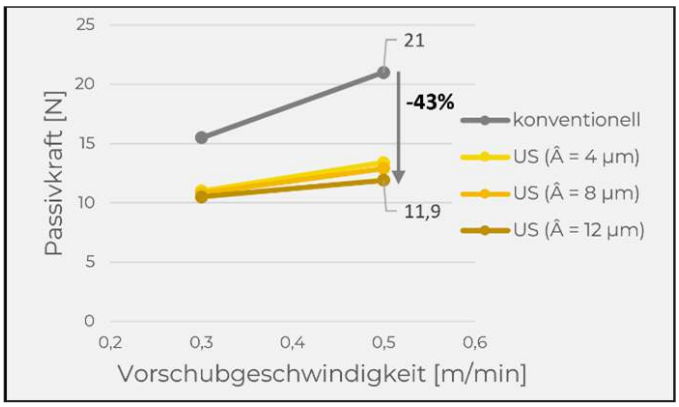


Figure 3: Diagram of passive forces, aluminium oxide

For the second material, **aluminium oxide**, the forces were measured using a comparable procedure. Figure 3 shows the passive force values for grinding the ceramic. Here too, the forces rise with increasing feed rates. For the conventional grinding process and a feed rate of 0.5 m/min, the passive force for aluminium oxide is 21 N. With this material, too, the cutting forces are decisive for the efficiency of the grinding process. Ultrasonic assistance of the grinding process likewise leads here to drastically reduced machining forces. At a feed rate of 0.5 m/min and a vibration amplitude of 12 µm, the passive force is reduced by 43% to 11.9 N. In contrast to quartz glass, the vibration amplitude has less influence here. In this context, the effects of vibration amplitudes between 4 µm and 12 µm are almost identical. Owing to the brittle material behaviour, the ultrasound makes material removal more efficient and more controlled here too, which has a positive effect on the performance of the grinding process.

Results

The results show that ultrasonic assistance has a positive influence on the properties and performance of the grinding process. The ultrasonic tool holders set the grinding tool into high-frequency vibration, which changes both the process kinematics and the mechanisms of action in chip formation. The effects can be summarised as follows:

1. Ultra-fast movement of the abrasive grain

The ultrasound sets the grinding body into extremely fast motion, so that each individual abrasive grain oscillates in the axial direction in addition to its rotary motion. This has a decisive influence on the engagement conditions of the abrasive grains.

2. Efficient material removal

The ultrasound causes “micro-hammering” of the abrasive grains, which breaks up the hard, brittle material at the surface in a defined manner. This makes material removal more efficient and more controlled.

3. Self-cleaning

The ultrasound reduces deposits on the grinding tool and prevents the grinding tool from clogging. The tool thus stays sharp and free-cutting for longer.

4. Sharpening of the grains

The multi-axial, impact-like loading causes the abrasive grains to fracture, forming new sharp cutting edges.



Customer benefits

The drastically reduced machining forces shift the current limits of the grinding process in terms of productivity, process reliability and component quality. Figure 4 summarises the benefits of ultrasonic assistance when grinding hard, brittle materials such as quartz glass or ceramics such as aluminium oxide.



Figure 4: Benefits of ultrasonic-assisted grinding

Efficient and controlled material removal improves component quality in terms of surface roughness and prevents microcracks and chipping. Besides the increase in tool life, it is above all the potential to raise the cutting data, and thus the productivity of the grinding process, that is a key factor in achieving cost savings by using VibroCut ultrasonic.

Cost savings with VibroCut *ultrasonic* when grinding hard, brittle materials

Sample calculation: increased cutting parameters

- Machine hourly rate: 75,- € / h
- Planned operating time: 4,000 h / year (500 shifts per year)
- Grinding share of cycle time: 80%

Higher cutting parameters	Productivity increase	Savings per machine/year
20%	13,3%	€39,900
50%	26,7%	€80,100
100%	40%	€120,000

Figure 5: Sample calculation of the economic benefit of increased cutting data

A sample profitability calculation is shown in Figure 5. In many applications, a return on investment of less than one year is achieved.

A further key benefit of ultrasonic assistance is increased process reliability. The efficient and gentle machining achieved with ultrasound is particularly helpful for complex, cost-intensive components, as it reduces the risk of process disruptions and quality-relevant deviations and thus avoids costly and time-consuming scrap. This applies in particular to unmanned machining over several shifts.

Further information

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

The VibroCut ultrasonic system stands for the most powerful and most precise ultrasound on the market. Its enormous performance achieves large vibration amplitudes and sets even larger grinding tools vibrating. An integrated sensor measures the ultrasonic vibration directly. Highly dynamic control thus ensures reproducible vibration characteristics and takes the precision of the ultrasound to a new dimension.

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



VibroCut *ultrasonic* performance data			
Vibration frequency	f_{Vib}	=	16 ... 50 kHz
Vibration amplitude	Â	=	0,1 ... 80 µm
Power	P_{Wmax}	=	100 ... 1,000 W

Figure 6: Ultrasonic tool holder for VibroCut ultrasonic

Please feel free to contact us directly or find out more on our website:

VIBROCUT

VibroCut GmbH
Annaberger Str. 240
09125 Chemnitz
info@vibrocut.de
www.vibrocut.de

The PRIMINER CNC milling machine in use with VibroCut *ultrasonic*

The PRIMINER C500-5X is a 5-axis machining centre distinguished by outstanding precision and flexibility. Weighing 9.5 tonnes, it is ideally designed for the complex machining of workpieces in five axes and enables the production of high-precision components from various materials such as steel, aluminium and plastics. Its versatility makes it well suited to many applications, from prototypes to series production.

With its technical data, the C500-5X provides optimum support for the VibroCut *ultrasonic* equipment. It meets very well the demands that grinding and drilling hard, brittle materials with ultrasonic-assisted drilling processes place on the machine.



Technical data		C500-5X
Table		
Max. workpiece diameter	mm	700
Table size	mm	Ø 500 x 400
T-slot (width x number x pitch)	mm	14 ×80 ×5
Max. load	kg	300
Travel		
X/Y/Z travel	mm	700 / 550 / 500
A/C travel	deg	+30° ~ -120° / 360°
Spindle nose to table	mm	120 - 620
Spindle		
Spindle taper	-	SK40/BBT40/CAT40
Spindle motor power	kW	9 / 22
Spindle motor torque	Nm	63 / 135
Spindle speed	rpm	12000
Feed		
Rapid traverse X/Y/Z	m/min	48
Rotational speed A/C	rpm	50/60
Cutting feed rate	mm/min	1-12000

Technical data		C500-5X
Tool changer		
Number of tools	pcs	40
Max. tool length	mm	300
Max. tool diameter	mm	Ø 80 / Ø 125
Max. tool weight	kg	8
Accuracy (VDI 3441, full travel) Positioning accuracy (without linear scales)	mm	0,008 (X/Y/Z)
Repeatability (without linear scales)	mm	0,006 (X/Y/Z)
Positioning accuracy (with linear scales)	mm	0,006 (X/Y/Z)
Repeatability (with linear scales)	mm	0,004 (X/Y/Z)
Dimensions and weight		
Dimensions	mm	3976×4965×3050
Weight	kg	7000

Please feel free to contact us directly or find out more on our website:

PRIMINER

PRIMINER
Werkzeugmaschinen GmbH
Tungendorfer Str. 10
24536 Neumünster
info@priminer.de
www.priminer.de

UNITECH-Maschinen GmbH — renowned partner in mechanical engineering

UNITECH-Maschinen GmbH is one of the established companies in the mechanical engineering sector in the Chemnitz region. Its activities range from design, manufacturing and sales through to full service for many types of machine tool. Developing complete solutions, technological consulting and user training are also part of its range of services.

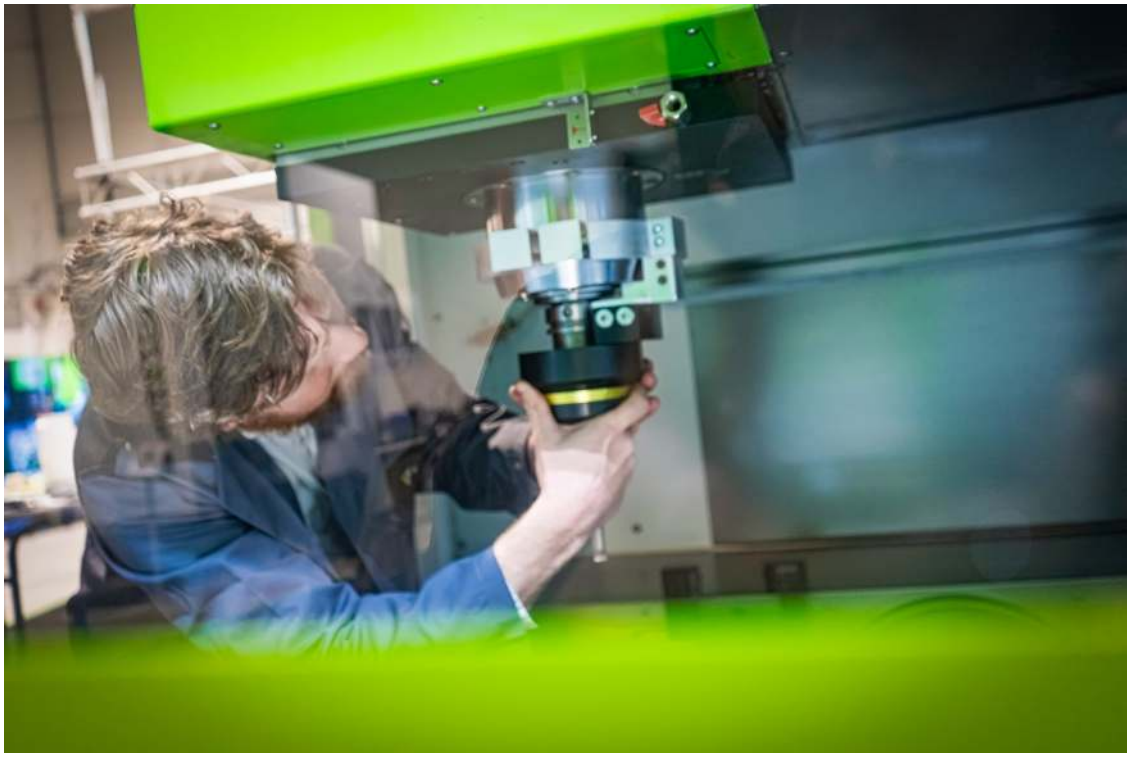
The proximity to VibroCut GmbH and the sale of Priminer machines gave rise to an excellent cooperation.

The integration partner of VibroCut GmbH for the machining of hard, brittle materials is UNITECH-Maschinen GmbH. An expert in technology-oriented modifications to machine tools and an experienced service partner, UNITECH has modified the high-precision 5-axis PRIMINER C500 machining centre into the most powerful ultrasonic grinding machine in its class.

The VibroCut ultrasonic grinding tool, together with operator guidance and process monitoring, was fully integrated into the machine. The machine itself was protected against the aggressive machining dust, among other things by elaborate encapsulation, with the aim of long-lasting quality.

The machining medium is separated from the dust and fed to the machining process in a targeted manner. Where required, the machine can be supplemented with fire protection measures if potentially explosive media are used.

To safeguard unmanned machining over several shifts, process and quality monitoring are integrated.



Technology integration by UNITECH-Maschinen GmbH and Dr Oliver Georgi of VibroCut GmbH

Please feel free to contact us directly or find out more on our website:

UNITECH

UNITECH-Maschinen GmbH
Clemens-Winkler-Straße 6
09116 Chemnitz
www.unitech-maschinen.de