WHITEPAPER

Ultrasonic-assisted deep hole drilling of nickel-based alloys

Nickel-based alloys, such as those known under the brand names Inconel, Monel, Hasteloy or Nimonic, are high-performance materials that are used in demanding applications. They are characterized by exceptional corrosion resistance, high strength and stability even at extreme temperatures. These properties make them the ideal material for high-temperature applications. Nickel-based materials are therefore primarily used in aerospace technology, energy technology and in the chemical and petrochemical industries. In components such as engine components, combustion chambers and turbine blades, nickel-based alloys make an important contribution to increasing the efficiency and service life of modern high-performance systems.

However, their complex composition and pronounced temperature resistance place high demands on machining and, in particular, on machining production, so that nickel-based alloys are among the materials that are difficult to machine. Deep hole drilling of these materials poses a considerable technological challenge due to their specific properties. The high strength and toughness, low thermal conductivity and pronounced tendency to work hardening lead to increased tool wear, unstable machining processes and, particularly in the case of deep holes, insufficient chip removal. In addition, the strong heat development during machining can lead to dimensional deviations, thermal damage to the edge zone and even damage to the tool. As a result, conventional deep hole drilling processes quickly reach their limits, especially when high quality and process reliability are required.

The use of ultrasonic assistance is an innovative approach to overcoming existing process limits when machining difficult-to-cut materials such as nickel-based alloys. By superimposing the feed movement with ultrasound, the material properties are modified, the chip formation mechanisms are changed and friction is reduced. This leads to a reduction in cutting forces and improved chip removal, resulting not only in a significant increase in tool life, but also in improved component quality and greater process stability. Ultrasound enables more economical, precise and process-stable machining for cutting and, in particular, deep hole drilling of difficult-to-cut high-performance materials.

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

This article examines the ultrasonic-assisted deep hole drilling of Monel K-500 (2.4375) as an example for the group of nickel-based alloys.

A machine tool, designed as a deep hole drilling machine, was equipped with the VibroCut ultrasonic system to realize the ultrasonic assistance. An ultrasonic movement is generated in the rotating tool holder and the kinematics of the deep drilling process are superimposed with this movement in the feed direction. 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 and guarantees constant properties.

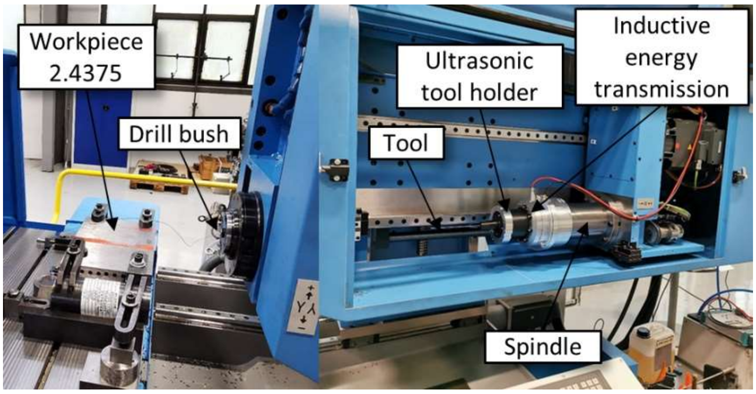
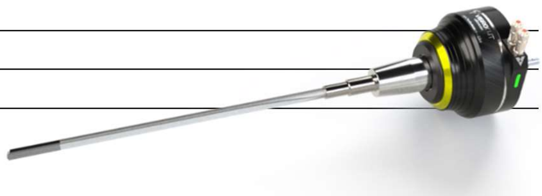


Figure 1: Processing situation

The test parameters for conventional and ultrasonic-assisted deep hole drilling of the nickel-based alloy Monel K-500 are summarized in Table 1.

Table 1: Parameters of the deep hole drillings

	Material Monel K-500
Tool	Single-lip drill bit, solid carbide with steel sleeve
Tool diameter	Ø6 mm
Drill depth	135 mm
Revolution n	2,700 U/min
Cutting speed v_c	50 m/min
Feed rate	0.011 mm
Feed velocity v_f	30 mm/min
Coolant pressure	Oil 100 bar
Ultrasonic frequency	≈ 19.5 kHz
Amplitude $\hat{A}_{pp}$	4.5 µm



In order to analyze the tool wear, the tool condition was measured between the bores using a tool microscope. An acceleration sensor was used to assess the process stability.

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Technological effects and mechanisms of action

The series of tests on tool wear in the nickel-based alloy 2.4375 was carried out at a cutting speed of 51 m/min and a feed rate of 30 mm/min. A reduced amplitude of 4.5 µm was used for ultrasonic assistance. The respective test series were interrupted as soon as a critical wear condition of the tool was reached. This was the case after three holes in conventional deep hole drilling and after nine holes in ultrasonic-assisted deep hole drilling.

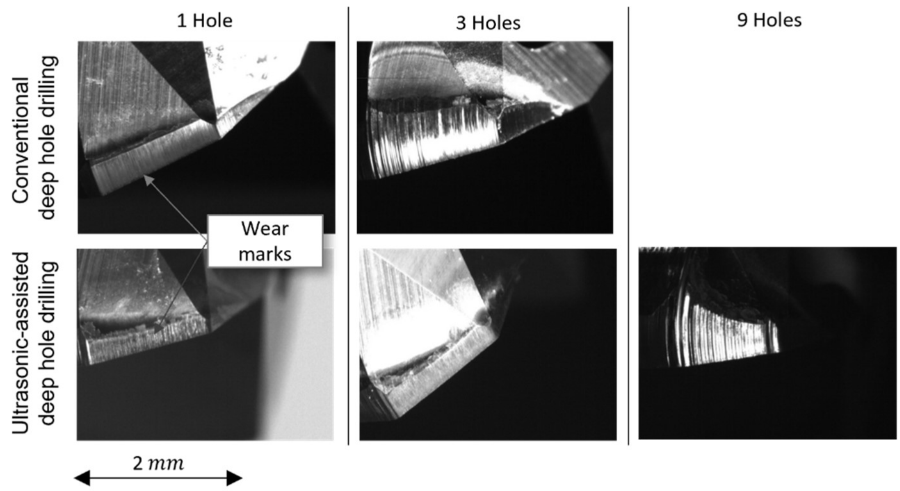

Figure 2: Tool condition of conventional and ultrasonic-assisted deep hole drilling

The tool condition was recorded after each hole using an optical microscope. Figure 2 shows a comparison of the tools for conventional and ultrasonic-assisted deep hole drilling. Strong signs of wear can be seen on the flank face of the main cutting edge after just one drill hole. In comparison, the width of the wear marks is significantly reduced with ultrasonic assistance.

The single-lip drill used in conventional deep hole drilling shows extreme wear marks after just three holes, which is why the test series was aborted at this point. In addition, the drilling process became more unstable with increasing tool wear. Chip jamming and strong acoustically perceptible tool vibrations occurred. Tool wear is significantly reduced during ultrasonic-assisted deep hole drilling, which is why the series of tests was continued up to hole nine to ensure a comparable wear condition. During the machining tests, it was found that ultrasonic assistance led to a significant reduction in chip jamming and tool vibration or noise. Figure 3 summarizes the development of the width of wear marks for conventional and ultrasonic-assisted deep hole drilling. The course of both the maximum width of the wear mark “max” and the average width of the wear mark “mean” shows the significant reduction in tool wear due to ultrasonic assistance. After three holes, the mean width of the wear mark is 708 µm for conventional deep hole drilling and 304 µm for ultrasonic-assisted deep hole drilling, which corresponds to a reduction of 57 %. The maximum width of the wear mark decreases by 56 % from 903 µm for the

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conventional process to 368 µm with ultrasonic assistance. The results show that ultrasonic assistance enables a much longer tool life and a significantly more stable deep hole drilling process.

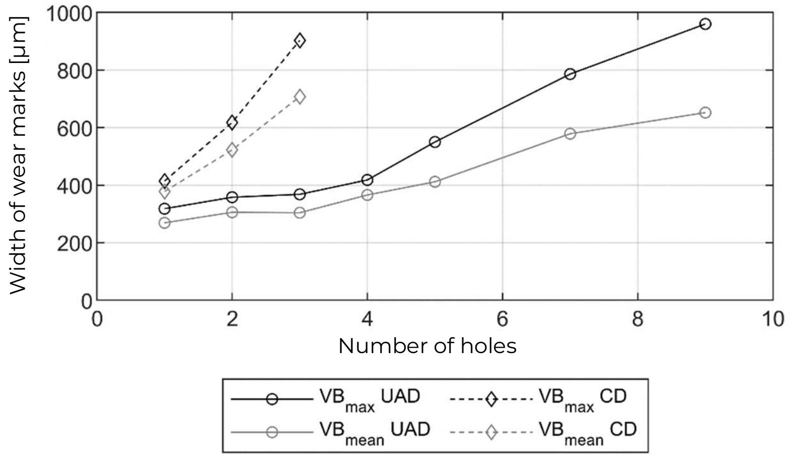

Figure 3: Width of wear mark over the number of holes

The results show that ultrasonic assistance has a positive influence on the properties and performance of deep hole drilling in nickel-based alloys, and particularly Monel K-500. The ultrasonic tool holders set the deep hole drilling tool in a high-frequency movement, which changes the process kinematics as well as the material behavior, the mechanisms of action during chip formation and tribological contacts. The effects and impacts can be summarized as follows:

1. **Reduction of cutting forces due to material effects**

Ultrasound leads to a change in material properties and thus directly to reduced cutting forces in both the feed and cutting direction.

2. **Improved chip removal**

The ultrasound reduces friction in tribological contacts. As a result, the friction between the chip and tool shank is significantly reduced, which prevents chip jamming and improves chip removal from the deep hole drilling.

3. **Reduced tool wear**

Reduced cutting forces and lower friction have a positive effect on the wear progress of the tool. Significantly longer tool life can be achieved, particularly with difficult-to-cut materials.

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Customer benefits

The reduced machining forces, improved chip removal and reduced tool wear have a positive effect on the limits of the deep drilling process in terms of productivity, process reliability and quality. Figure 4 summarizes the advantages of ultrasonic assistance in deep hole drilling of nickel-based alloys.

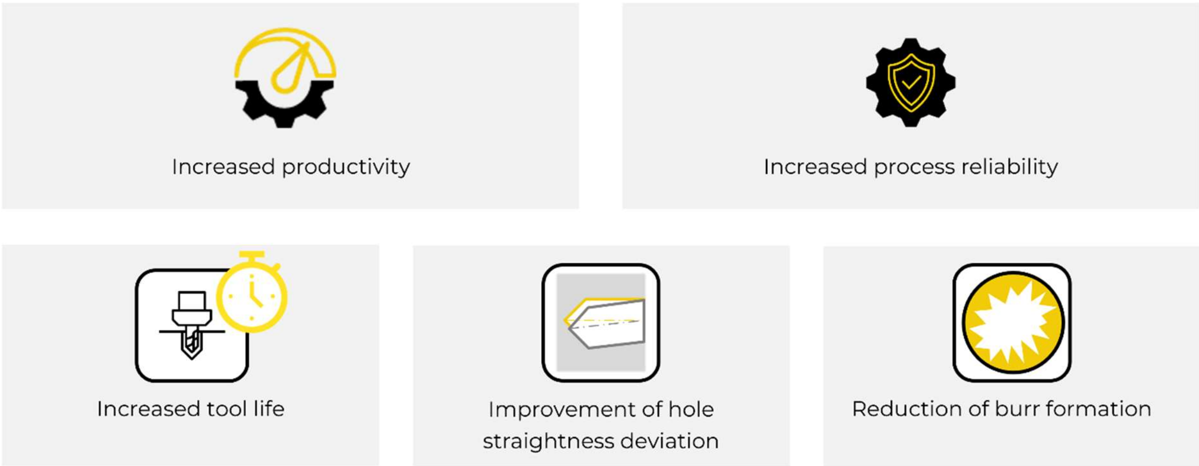

Figure 4: Advantages of ultrasonic-assisted drilling and deep hole drilling

In particular, the hole straightness deviation of drilling and deep hole drilling is improved by the ultrasonic-induced force reduction, which is a decisive factor in many industrial applications with high quality requirements or challenging L/D ratios. In addition, tool wear is significantly reduced. The increase in tool life reduces tool costs, which are often very high when machining difficult-to-cut materials.

Furthermore, the deep hole drilling process is much more stable in the demanding material, which is why process reliability can be significantly increased. For example, the reduced machining force and improved chip removal reduce the probability of spontaneous tool breakage. This is a decisive factor in industrial component production, particularly for cost-intensive components made from nickel-based alloys. In certain applications, the use of ultrasonic assistance is what makes deep hole drilling even possible.

In summary, ultrasound for machining and in particular deep hole drilling of difficult-to-machine high-performance materials enables more economical, precise and process-stable machining. For companies in the aerospace, energy, chemical and petrochemical industries, this offers an innovative technology to meet the challenges of deep hole drilling of nickel-based alloys.

Further information

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

The ultrasonic system **VibroCut *ultrasonic*** represents the strongest and most precise ultrasound available on the market. Due to its enormous power, high amplitudes are achieved and even larger deep drilling tools are set in motion. An integrated sensor measures the ultrasonic movement directly. Highly dynamic control ensures reproducible properties 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_{Wmax}	=	100 ... 1,000 W

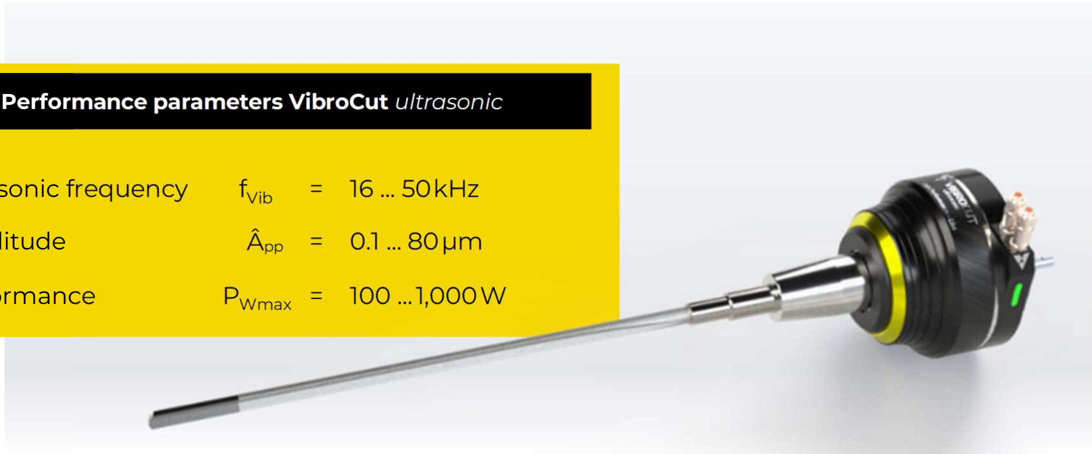

Figure 5: Ultrasonic tool holder for VibroCut ultrasonic

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 change.

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