Measuring Technology for Micro-Tools and -Topographies

Micro-mills and special tools made of carbide or diamond are sometimes only a few tenths of a millimeter in size and have perfectly sharp **CUTTING EDGES** with radii of a few microns. Measuring such geometries at high precision is one of the greatest challenges for non-contact and tactile coordinate measuring technology.

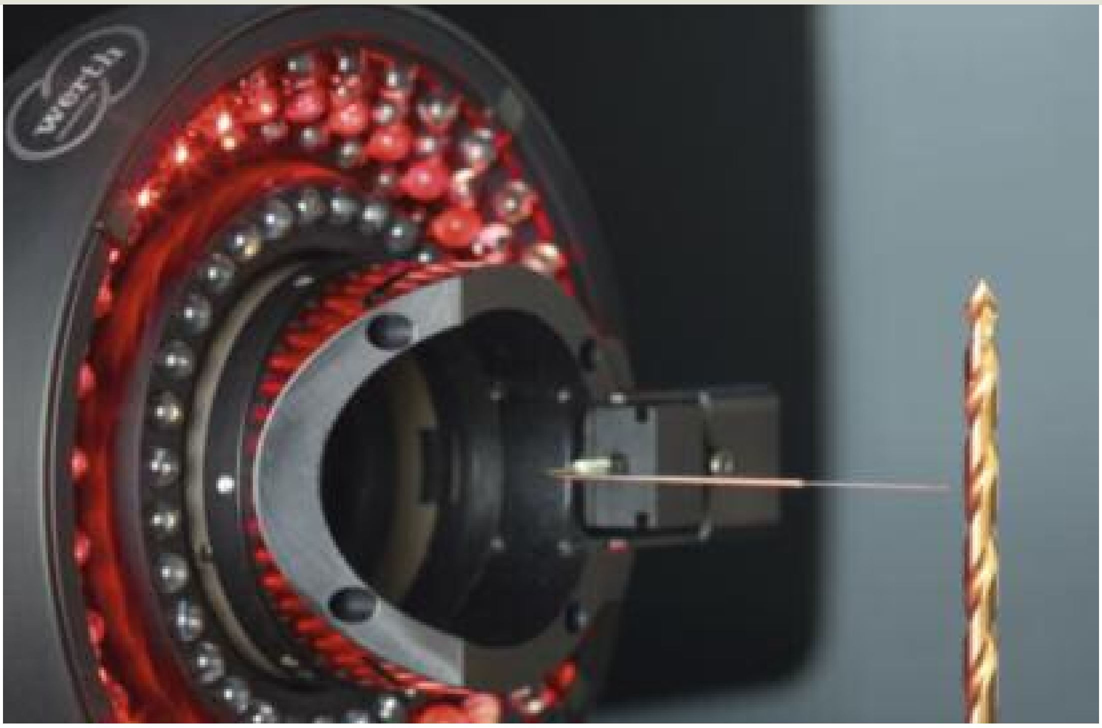

Figure 1. The ›Werth Fiber Probe‹ is particularly well suited for measuring edge roundings

Figure: Werth

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Due to of miniaturization in general, tools made of carbide and diamond also have to be smaller and more precise to be able to produce parts like micro-gears for gear boxes. The drive for more aesthetic designs also leads to ever more complex shapes with small details. A prime example is the production of smartphones.

The surfaces of relatively large tools often have micro-topographies in order to improve cutting performance. For example, machining titanium and carbon fiber reinforced plastic places great demands on tools, often requiring a modification of the micro-topography of the cutting edges.

When measuring tools, measurements can be differentiated into two categories: measurement of the outer contour and measurement of the cross section. Outer contour measurements include, for example, measurements of the diameter, radial runout, radii, corresponding angle, and effective contour, while cross-sectional measurements relate to the rake angle, clearance angle, front rake, and cutting edge geometry **(Figure 1)**.

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Measuring the Outer Contour with Image Processing

Coordinate measuring machines with an image processing sensor are often used for outer contour measurements in order to ensure rapid, reliable measurement of all features. Two different image

Figure 2. Micro-mills with diameters of less than 1 mm

Source: Zecha Hartmetall-Werkzeugfabrikation

processing principles can be distinguished. The software is most often based on what is known as an ›edge finder‹, which detects edges point by point. These systems are sensitive to local interferences, such as dust and grinding patterns. Systems that use contour image processing work differently – they identify the contour formed by the individual points, so that dust and other interferences, can be specifically filtered out. Evaluation of grayscale amplitudes when determining the position (subpixeling) increases positional resolution and thus reduces measurement uncertainty. Such contour image processing allows automatic tracing of contours beyond the field of vision of the sensor.

As tolerances and measurement uncertainty requirements become tighter, a higher optical magnification must be used **(Figure 2)**. High magnification optics, however, offer only a small field of view with a low depth of field. This makes handling more difficult, as the optics need to be positioned very precisely. Due to the small field of view, the measuring speed is lower and it takes longer to capture the entire outer contour.

In order to allow a high measuring speed and a low measurement uncertainty, either several lenses with various magnifications and directions of view are used, or one single optic with variable magnification. For multiple lenses, however, the common measurement range is limited due to the sensor offset. The temperature-dependent drift of the sensor offset leads to additional measurement deviations, so a zoom optic with variable magnification is a significantly better solution.

The patented Werth Zoom enables high reproducibility of different magnifications with motorized movement of the lens components. In addition to the magnification, the working distance can also be varied, so that otherwise inaccessible features can be measured without collision. The Werth Multisensor system allows fully automated changeout of various other sensors, such as conventional probe systems or the patented Werth Fiber Probe, directly in line with the image processing beam path and therefore without sensor offset.

Although telecentric lenses with constant image size allow precise measurements of edge radii and axial undercuts (even outside the focus plane), a zoom optic is much more flexible. It is possible to measure the alignment of a part with low magnification and then perform additional measurements at high magnification **(Figure 3)**. The variable working distance also allows for large tools, such as diamond grinding wheels, to be measured without collision. In conjunction with the variable working distance, the Werth MultiRing, an 8-segment ring light with adjustable lighting angle, provides great flexibility in the imaging of micro-facets and micro-radii.

Rotational tools are measured by capturing several images of the outer contour at different rotational orientations. The images are overlaid in order to represent the effective contour. Effective contour scanning also includes integrated 3D wobble correction in order to correct for errors in the clamping fixture. Very long micro-tools are often not straight and therefore cannot be measured without using wobble correction to position the camera. The high magnification of the zoom optic allows measurement of the effective contour of the smallest details, such as carbide micro-mills of 0.1 mm diameter and 10 µm to 20 µm cutting edge radius **(Figure 4)**.

Outer contour measurement is also very important for turning tools and the corresponding cutting inserts. Substantial benefits in respect to measuring speed and resolution are achieved via raster scanning (Werth patent). Many overlapping images are recorded very rapidly in motion and the images are merged into an overall image. This approach allows for the complete outer contour to be scanned. Large areas ▶

Figure: Zecha

Figure 4. Micro-mill with edge radius 0.02 mm Source: Karnasch Professional Tools

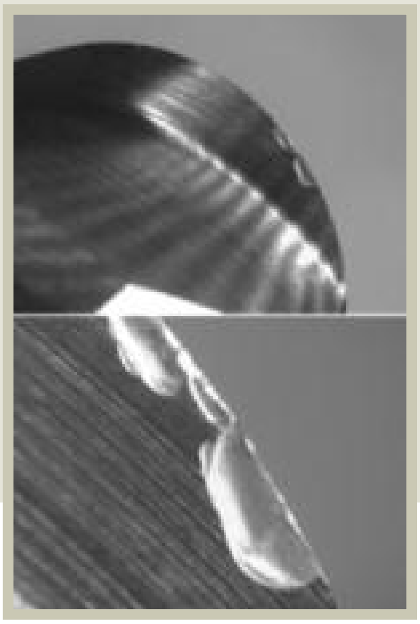

Figure 3. Rapid alignment using the Werth Zoom at a low magnification level (top), high-precision measurement at high magnification (bottom)

can be measured with high structural resolution. The averaging across several images involved in this strategy also leads to improved measurement uncertainty. The dimensions can be determined in the overall image as easily as measuring ›in the image‹. Saved images can also be analyzed offline, for example in order to measure additional features at a later time. With raster scanning it is not necessary to position the sensor at each individual feature, therefore the measurement time is greatly reduced, especially when many dimensions are measured. The Werth QuickInspect MT uses raster scanning to measure cutting inserts on the shop floor with high precision and measuring speed.

Measuring the Cross Section with Multisensor Systems

Measurements of the cross section provide many parameters that are critical to tool performance (including the flute shape, roughness, rake angle, edge preparation, and undercut). Most tool measuring machines measure only sections that are orthogonal to the tool axis. Sections orthogonal to the cutting edge are often also interesting, however, because they follow the line of chip formation and removal. Various non-contact methods are used for measurements (focus variation method, laser distance sensors, and chromatic focus sensors). They often provide good results, but reach their limits with highly reflective or transparent materials, such as diamond.

Focus variation methods are dependent on surface contrast due to their measurement principle, so that measurements of highly reflective surfaces (polished or coated carbide tools) and transparent materials (diamond tools) are difficult or impossible. Due to the low contrast, local reflections can be measured erroneously as surface structures and falsify results.

The patented Werth Laser Probe (WLP) uses the aperture angle of the telecentric zoom objective as a triangulation angle according to the Foucault principle, to determine the distance from the tool surface. This sensor can also measure low-contrast surfaces. The WLP is integrated in the beam path of the optic without sensor offset, so the common measurement range is not limited. By using the image processing sensor to observe the laser spot, operation is made easier. In conjunction with a high-resolution telecentric lens, the smallest details can be measured using the WLP, such as groove parameters on micro-drills.

This Chromatic Focus Point (CFP) sensor, also a non-contact sensor, uses a special optic to exploit the effect that the spectrum of white light is focused at different distances and has a greater measurement range than the WLP. This means that rapid scanning of the groove profile is possible within the measurement range without time-consuming adjustment along the optical axis. The CFP is largely independent of the surface and is also suitable for measuring highly reflective or transparent tools.

Despite all the advantages of non-contact sensors, in many cases additional tactile measurements are necessary. Small or sensitive tools made of carbide or diamond, however, often cannot be measured using conventional probe systems. The smallest conventional styli for industrial use have probe spheres of about 0.3 mm diameter, so they are too large for many applications. Smaller spheres would require a thinner stylus shaft, which increases the risk of breakage to an unacceptable level. The probing force of conventional styli is approximately 100 mN, so the cutting edges could be damaged in some cases.

A perfect solution is available with the Werth Fiber Probe (WFP). The WFP is available in a 2D and a 3D version and has been proven in industrial applications for over 15 years. It consists of a glass fiber with an illuminated probe sphere on the end. The sphere diameter can range from 20 µm to about 200 µm. The fiber probe is mounted using the Werth Multisensor System interface, directly in front of the image processing sensor. The probe sphere is then located in the focal plane of the objective. The deflection of the sphere after contact with the workpiece surface is captured optically. As with conventional measuring

Figures: Werth (3, 6), Karnasch (4), Schnyder (5)

Figure 5. Micro-hobs with modulus of less than 0.05 mm Source: Schnyder

probes, controlled scanning is also possible using the WFP with automatic tracking of the workpiece surface. The micro-stylus achieves a very low probing uncertainty of less than 0.25 µm when used with suitable machines. The very low probing force of about 1 mN enables reliable measurements without damage.

The WFP can also be used to measure reflective and transparent surfaces, so it is particularly well suited for measuring edge rounding on carbide and diamond tools. Radii of less than 5 µm can be measured reliably. The sharpness of a perfect edge (radius 0 µm) can also be measured using the fiber probe. Another application is the measurement of relief profiles on micro hobs, cutting wheels, and skiving cutters **(Figure 5)**.

Advancing in New Dimensions

Flexible image processing sensors such as the Werth Zoom with effective contour scanning and raster scanning are available for outer contour measurements. The integration of a laser distance sensor and the patented fiber probe results in a powerful multisensor coordinate measuring machine that can be used to measure any desired features. The laser distance sensor is used to perform cross-section measurements, such as the rake angle and clearance angle and the flute shape. The WFP can also be used to measure edge rounding and undercuts.

Until recently, complete three-dimensional measurement was not sufficiently precise for the toolmaking industry. The Werth Chromatic Focus Line (CFL), a line sensor for measuring high-precision carbide and diamond tools, has been recently introduced. Using the new sensor, the entire external 3D geometry, including micro-topography of the edges, can be captured very quickly with low measurement uncertainty **(Figure 6)**. ■ MI110478

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Figure 6. Result of a CFL measurement on a micro-drill tip: STL with high detail resolution