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OPTICAL DETECTION OF GEOMETRICAL AND WEAR FEATURES OF CUTTING TOOLS

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Abstract – In this paper the research results of optical detection of geometrical and wear features of cutting tools are presented. The investigations concentrated on capturing images during the movement of cutting tools by means of CCD- and CMOS cameras by applying different illumination principles. It furthermore focussed on the development of image processing approaches for determining relevant geometrical and wear features on indexable inserts, circular saw blades, and band saws.

The potential for applying the outcomes of this research in the tool industry is shown in the final part of the paper.

Keywords: image processing, cutting tools, wear detection

1. INTRODOCTION

Higher requirements on the quality and performance of cutting tools for applications in the automotive, space and aircraft industries demand increasingly efficient measuring – and inspection systems. In particular, contact-free working measuring methods for inspecting tool geometry and -surface are very important for automatic quality control during the manufacturing process. For example, during the production of saw blades the velocity of the tool lies at 10 m/min. The only applicable solution for capturing high quality images of cutting edge and its macro geometry during motion is by taking the image in a snapshot mode. In order to capture an image of one saw tooth during the continuous motion of the band at a speed of about 10 m/min a very short exposure time is necessary. For reaching a local resolution of less than 10 micrometers during a snapshot, capturing the image demands an exposure time of 60 microseconds. The optical characteristic of the camera lens and image capturing unit requires a very high intensity for sufficiently bright lighting of an object like the saw tooth because of short exposure time. To increase the range of depth focus for getting much sharper images, there is also a need to reduce the aperture, which demands additional light power at the measuring field of the object. At least the time behavior of all active components, like the trigger unit for edge-detection of moved objects, camera and lighting have to be mutually adjusted by a specially developed trigger logic. After the image capturing process the image data will be processed and analyzed for geometry and wear features.

2. GEOMETRICAL AND WEAR FEATURES

Cutting tools are classified according to the following principles:

- Tensile strength of material which has to be processed,
- Type of cutting material and its coating with respect to the tensile strength and the resistance of wear,
- Cutting edge macro- and micro-geometry with respect to the cutting angles and shapes of edges.

Industrial high performance cutting processes demand a very specific selection of cutting tools with respect to their geometry and surface of cutting edge. The applied speed and forces need to be mutually adjusted to the tensile strength of the material which is being processed.

The drawings below (Fig. 1-3) illustrate the basic different shapes and angels of basic cutting tools /4/.

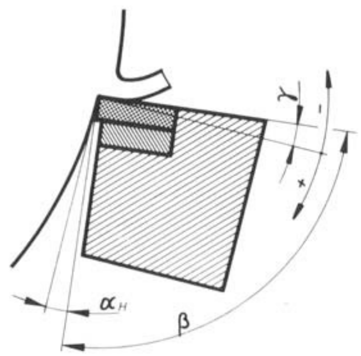

Fig. 1: *Angles at cutting tools:* α *- clearance angle;* β *- sharpening angle;* γ *- rake angle*

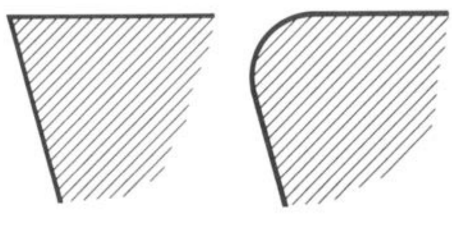

Fig. 2: *Basic shapes of cutting edge profile: Left – very sharp with edge radius less than 5 micrometers; Right – chamfered with edge radius of 20 – 80 micrometers*

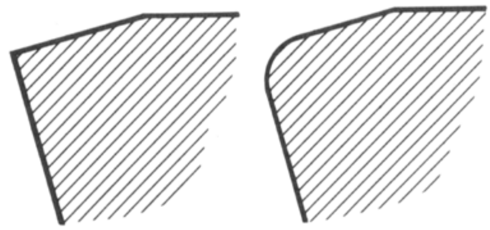

Fig. 3: *Basic shapes of cutting edge: Left - bevelled edge; Right - bevelled and chamfered edge*

The characterization of the behavior of wear on cutting tools needs to be observed to ensure that the cutting process is well done which will result in a high surface quality linked with exact body geometry (Fig. 4-5). During cutting process wear causes deformation of the cutting tool with respect to its micro- and macro-geometry. If the limits of deformation will be exceeded, the cutting process takes much more energy and higher cutting forces, whereby the quality of the cutting result decreases.

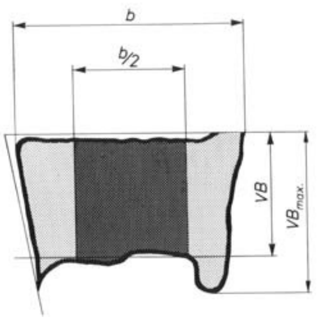

Fig. 4: *Wear on cutting tools and their characterization: VB - Width of wear; VBmax - Maximum width of wear; b - width the wear-area; b/2 - width of extremely deformed area by wear /4/.*

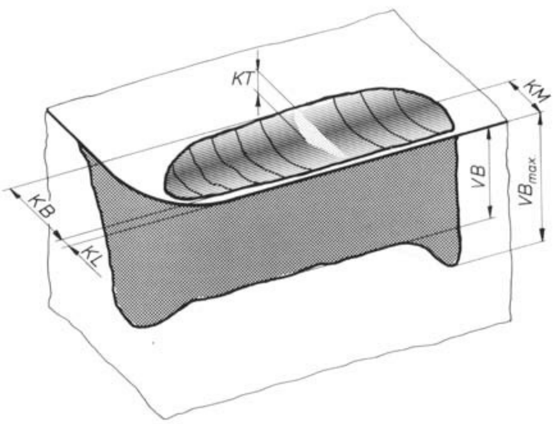

Fig. 5: *Wear on cutting tool edge: VB - width of wear; VBmax - Maximum with of wear; KT - scour depth; KM - Position of scour maximum depth; KB - scour width; KL - scour rip width /4/.*

Circular saws and band saws are a subgroup of cutting tools. Thus, nearly the same deformation of saw tooth occurs during the milling process or during lathe work. Reaching a high level of performance during saw processes will result in very exact saw tooth geometry and a set of mutually adjusted process parameters like cutting speed and forward feed rate. It is very important to ensure the micro- and macro-geometry of saw teeth because wear at saw teeth causes an extreme increase in cutting forces, which could damage the tool and in the worst case the whole machine. For analyzing the behavior of wear, geometrical deformation of saw shape, and the geometry of saw tooth during the cutting process or during the manufacturing, it is necessary to capture exactly anchored snapshots with high quality and contrast /1,2,3/.

3. TEST SETUP FOR IMAGE CAPTURING PROCESS

In order to investigate the image capturing process of moving cutting tools which depends on different illumination principles, a special test setup was realized (Fig. 6). It comprised a mechanical basic design, a programmable motor driven spindle, housing and mechanical components for mounting the cameras, different illumination systems, and a trigger unit.

Fig. 6: *Test setup with circular saw on rotating spindle, lighting, and the trigger unit*

The trigger unit was based on a LASER-beam light barrier which reached a local resolution with a diameter of 50 micrometer and a time response of less than 50 nanoseconds. By means of the unit a very exact trigger signal was generated, which allowed us to eliminate disturbances based on mechanical vibrations during motion. A separate holder for image capturing and a lighting unit were also designed. This mechanical system was not influenced by the vibrations due to the dynamic unbalance of the rotating masses.

4. IMAGE CAPTURE OF TOOLS IN MOVEMENT

The investigations for the image capturing process were carried out mainly on circular saw blades. The velocity of tools was controlled between 0.2 m/s to 8.0 m/s. A camera with a CMOS sensor (1.3 million pixels) and an external trigger input delivered the best results during the tests. Because of the tool velocity an exposure time of about 60 µs and a time resolution of less than 5 µs for the triggering of flash illumination and image capturing were necessary. In order to solve this task a special trigger unit based on the FPGA-digital electronics system was developed in connection with a light barrier. With this system the required delay- and pre trigger intervals were relatively simple to realize. Due to the short exposure time a high light intensity was needed in order to get a good quality of the captured images. On the basis of the achieved test results with different light sources a lighting unit, consisting of multichannel power-LED lights, was developed. By means of the lighting unit it was possible to illuminate the tools from different perspectives. The snapshot image of saw tooth could be captured with an absolute position accuracy of cutting edge of less than 8 micrometers. Furthermore, different lighting modes like bright field, dark field, and transmitted light were realized by activating different channels of power-LED lights. The achieved image quality and image information allows a good detection of saw tooth contour and surface (Fig. 7, 8).

Fig. 7: *Snapshot of saw tooth cutting edges and wear (track speed = 10 m/min, GFE)*

Fig. 8: *Snapshot of saw tooth with cutting edges, captured in transmitted lighting mode (track speed = 10 m/min, GFE)*

The following chapter explains the image analyzing procedure, which could be applied to high quality snapshot on real technical surfaces of cutting edges.

5. IMAGE PROCESSING APPROACHES

The realized development of image processing approaches for the detection of geometrical and wear features of cutting tools is based on analyses of a high number of captured images of tools (indexable inserts, circular saw blades, and saw bands). The images were captured under different illumination conditions by means of the test setup. The conditions of image capturing (e.g. direction) and illumination (transmitted and incident light, direction) were selected depending on the features which were to be detected. For the detection of geometrical features of tools, like clearance and rake angle, transmitted light was used in most cases. In special cases it is also possible to use incident light for the detection of geometrical features. But the obtained accuracy is not as high as for using transmitted light (Fig. 9).

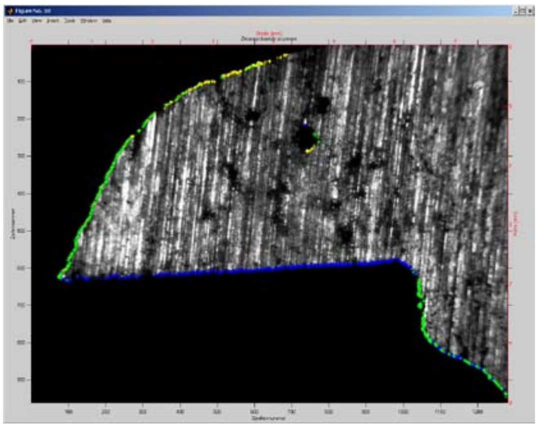

Fig. 9: *Image processing approach detects outer contour of real saw tooth shape*

In order to detect wear features incident light is preferred.

Figure 10 and 11 show a part of a worn cutting edge in incident light. The development of an image processing approach for the determination of width of wear showed that the background should be dark. If the background is bright, the edge transition is not as homogeneous as with a dark background. For the developed image processing approach it is important that the scanning direction is orthogonal to the cutting edge contour of the tool. The measurement uncertainty is significantly lower if the scan direction follows the direction of the sensor line.

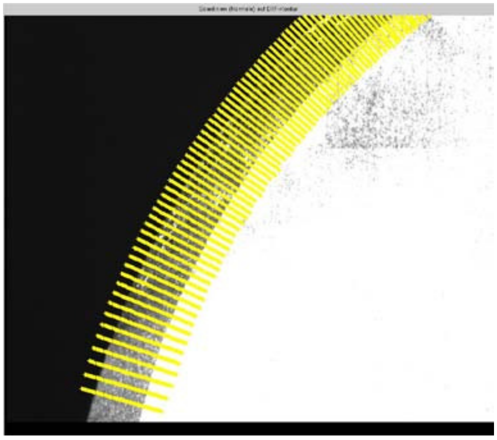

Fig. 9: Normalized scan lines are orthogonally aligned to cutting edge contour

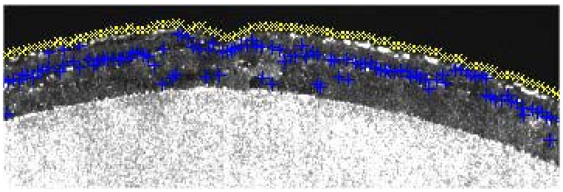

Fig. 11: Scan results of wear marks and their absolute position along the normalized scan lines.

The developed image processing approaches are based on direct relations between neighboring pixels. The grey level differences between the pixels in one line of an image and the pixels of neighboring lines are estimated. In order to increase the spatial resolution, subpixel algorithms can also be used.

Based on the developed image processing approaches in connection with the realized image capturing system for the capturing of snapshots it is now possible to determine relevant geometrical and wear features of different cutting tools.

6. SUMMARY AND OUTLOOK

The achieved investigation results for image capturing of cutting tools during their movement show that with a specially developed flash illumination selected areas of the tools are captured with a high quality. These snapshots allow the determination of relevant geometrical and wear features of cutting tools in a high resolution.

The knowledge gained from the presented investigations provides a basis for applications of the developed image processing approaches in connection with image capturing systems and special flash lights for quality monitoring in the tool industry.

ACKNOWLEDGEMENT

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