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Enabling of Component Identification by High Speed Measuring of Grinding Wheel Topography

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Abstract

The machining process affects quality and function of components. For this reason, it is an important key competence of the manufacturer. Over the past years, counterfeit products have been threatening the user and damaged the reputation of the original manufacturer. On this account, a method of fingerprinting of ground surfaces was developed in the Collaborative Research Center 653 to protect components against plagiarism. However, this method needs the measuring of every single ground surface, which means a huge expenditure of time in the production chain. If it were possible to predict the grinding surface of the grinding tool precisely, occasional measurements of the grinding tool during the setup time would be sufficient to assign the right tool to the component`s surface and the manufacturer behind it. The presented paper is focusing on methods for the determination of the topography of grinding tools. These topographies enable the manufacturer to predict and thus identify the surface of components.

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Keywords: Plagiarism; Laser triangulation; Grinding wheel topography; Surface prediction

1. Motivation

The success of companies is mainly linked with the unique quality of their products. Therefore, plagiarism is one of the biggest problems for manufacturers in mechanical engineering. German manufacturers' estimated sales losses caused by product piracy are about 7.9 billion euros per year [1]. For that reason, the CRC 653 developed a fingerprinting method to identify generally machined surfaces without using conventional marking systems like bar or QR codes [2, 3]. The method uses microscopic, stochastic and thus unique surface areas, which are generated passively in the machining process. In the case of grinding as the last step of most production chains, the identification method is highly promising. Due to the wear behavior of grinding grains, the topography of the tool changes as rapidly as the generated surface does [4]. To keep track of each component, the manufacturer has to measure a surface section of every single component and extract the fingerprint. It is created by the wavelet

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transformation of one or more surface profiles and a subsequent non-maxima suppression of the wavelet image. The detected maxima and minima are called features, and the amount and constellation of features form the fingerprint of the component [5]. The fingerprint and appropriate information are stored in databases of the manufacturer. If customers report a defect or failure, the manufacturer is able to check the originality of the product.

The method has not found an implementation in industry so far. A disadvantage is the need of a 100 percent measuring of products. For a more application-orientated method, an enabling technology is currently under development. This technology will be able to predict ground surfaces by using the complete topography of a grinding tool. The first step to build up a surface prediction model is to investigate the generation of kinematic surfaces by a real tool topography. That means a measuring technology has to be qualified which is able to display the distribution, size and geometry of grains on the grinding wheel topographies. These topographies will be used in a kinematic simulation of the plane grinding process. Inasaki uses a similar approach by measuring a 2 x 2 mm² section of the grinding wheel. Subsequently a grain finding algorithm is applied to identify angles and size of the grains and the component topography is simulated [6]. Another investigation uses triangulated measurement data of a finishing belt to predict to surfaces topography after a honing operation [7]. In this paper, the measuring of grinding tool topographies with a laser triangulation sensor is described. Afterwards, the measured profiles are summarized and compared with the machined surfaces. This comparison serves as a first primitive kinematic simulation in 2D. The future 3D simulation will predict the whole topography and the related fingerprint of the ground surface. This technology enables the manufacturer to identify every ground component by measuring the tool topography.

2. Evaluation of Topography Data

There are numerous instruments to evaluate the micro-geometry of grinding wheels, for example inductive wheel loading sensors, scattered light sensors or reflection sensors. One of the fastest methods uses a laser triangulation sensor and is also applicable for in-process measuring [8]. To qualify the laser triangulation sensor for measuring grinding wheel topographies in shop floor environment, the data is compared with those of conventional surface instruments like tactile devices as well as SEM (scanning electron microscope). For a first application, galvanically bonded cubic boron nitride tools with mean grain diameters of 151 and 252 µm are used. The tool diameter is 30 mm at a width of 8 mm. Consequently, the complete shell surface is 94.25 x 8 mm². These tools are characterized by a high grain protrusion with low bond content and high strength. Therefore, it can be assumed that the summation profile of the tool does not change rapidly during machining. Before the measuring results are compared, the procedure of the different measuring technologies are described.

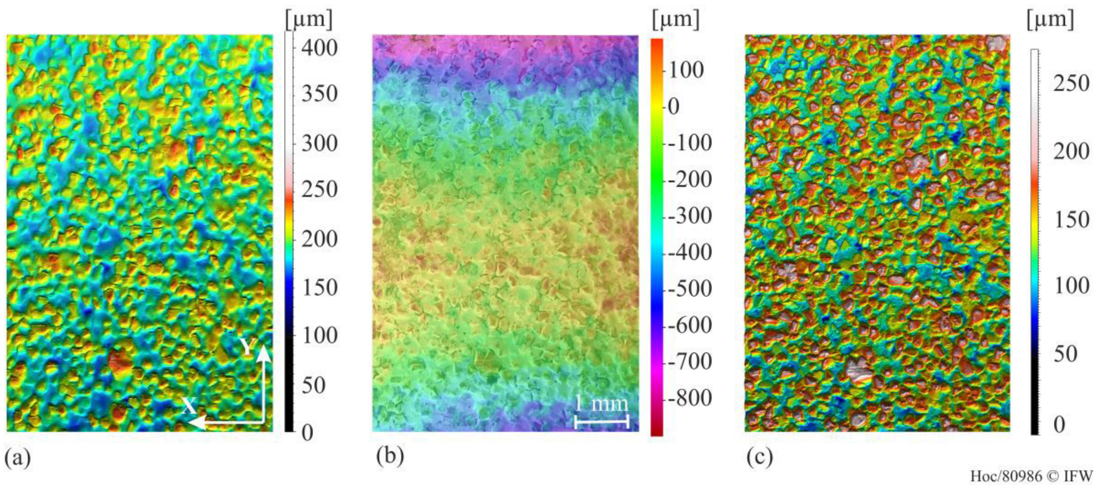

Fig. 1. 7 x 5 mm area of a CBN B252 grinding tool measured with (a) Keyence JL-V7020; (b) Zeiss EVO 60 VP and (c) Mahr LD 130.

The triangulation sensor projects a profile of blue laser light (λ = 405 nm) on the grinding tool. The diffusely reflected light is detected, and a software program generates 800 points for an 8 mm profile. By turning the tool with 9 1/min and measuring with a sampling rate of 2 kHz, the whole tool can be measured in about 6 seconds (Fig.1a). The sampling rate can be increased up to 16 kHz, but the quality then decreases quickly. To generate a 3D surface topography with SEM three pictures are made from different angles. The Mex software of Alicona calculates these pictures to get a high-resolution 3D surface topography (Fig.1b). Last applied measuring principle is the tactile profile method with a Mahr LD 130 profile and contour measuring device. The instrument uses a 4µm probe tip to move over the tool topography and generate a profile with 1800 points. The measuring of 1300 profiles forms a tool topography. In Figure 1, an area of the grinding tool measured with the described instruments and sensor is compared.

The measuring result of the SEM serves as a reference to the real tool topography. Due to the creation of the SEM microgram, there is no 3D topography data set, and the form cannot be removed. It can be seen that the Keyence laser triangulation sensor is able to display every grain in position, geometry and size. There is no shadowing or distorted area in terms of undefined data points. Even the wear state of the grains can be detected. In contrast, Figure 1c shows the results from the tactile device. Every single grain can be described by geometry and size. The resolution at this setting is comparable with the laser sensor, but the disadvantage of the measuring principle is the measuring time. The measuring of the shown selection takes about 9 hours. Besides the quality of the measuring, the time to get a measuring result is of great importance to find acceptance in industry. In this respect, the dynamic laser triangulation sensor has a huge benefit compared to the other two systems (table 1). The grinding tool can be measured directly in the machine tool, and process-specific deviations like runout and inclination of the tool holder can be determined at the same time.

Table 1. Comparison of used measuring instruments

Designation of instrument	Measuring principle	Measuring point distance (X and Y direction) [µm]	Measuring time [s/mm²]
Keyence LJ-V7020	2D laser triangulation	10 x 7	0.008
Zeiss EVO 60 VP	Secondary electron detection	0.04 x 0.04	46
Mahr LD 130	Tactile profile method	10 x 10	537

As a consequence, the laser triangulation sensor is the ideal measuring system to measure grinding wheel topographies in shop floor environment. In the next step, the measured tools are used in a plane grinding process, and the calculated summation profile is compared to the grinding profiles.

3. Experimental Setup

3.1. In-process measuring of the grinding tool topography

For a future prediction of the ground surface, it is necessary to measure the grinding tool topography before and after grinding to understand the wear behavior. As shown in Figure 2, the Keyence sensor is fixed to a holding plate which is clamped in the machine vise of the machine tool. To get a uniform reflection signal and to increase the trigger speed, the grinding tools are covered with a white detection spray (usually for penetration tests). After starting the measurement, a batch of 13330 profiles is stored. During these 6 seconds, the tool makes an entire rotation. The setting parameters are listed in table 2.

Table 2. Setup for laser triangulation sensor.

Setting parameters	Measuring distance	Amount of profiles	Points per profile	Sampling rate	Trigger speed
Value	± 2.6 mm	13330	800	2 kHz	30 µs

The measurement is repeated three times before and after the grinding experiments. The result of scanning is a XY matrix with 10.6 million Z values. This matrix is imported into Matlab to calculate the summation profile, which is created by the maximum Z values of a Y column in X direction.

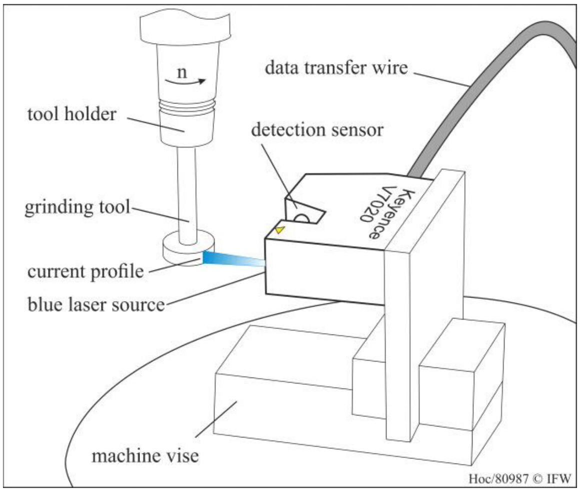

Fig. 2. In-process-measuring setup

3.2. Peripheral surface grinding experiments

For the grinding experiments, a Röders RFM 600 DS machine tool is used. It is a five-axis high-precision milling machine with rotary tilting table. The rectangular-shaped workpieces (50 x 50 x 20 mm³) are made of SAE 1045 with a Rockwell hardness (cone) of 24. The upper side of the three workpieces is wet ground in six and polished in two further steps until a reflecting surface below Ra = 0.1 µm is reached. Only in this way, it is ensured that the influence of the grinding tool on the surface generation can be evaluated. In the next step, the specimens are clamped in the machine vise and adjusted with a digital 3D measuring probe. Before starting the grinding experiment, the tool diameter is measured by a machine-integrated laser beam at working speed and a height of 0.5 mm. Afterwards, the depth of cut for the first cutting path is determined iteratively by decreasing the distance between tool and workpiece until first scratches are visible. Surprisingly, the first visible scratches are reached in a theoretical distance of 0.1 mm. A reason can be the laser beam measurement of the tool diameter. The measurement does not detect every outstanding grain during the high-speed rotation. For the following four paths on the specimen, the depth of cut is increased until the entire tool width is ground. After grinding, the three specimens are measured with an optical laser microscope to determine the real depth of cut. It is assumed that the distance between the polished surface and the deepest scratch is the depth of cut of the path. All paths are ground with a cutting speed of 30 m/s at a feed rate of 1000 mm/min.

4. Correlation between Grinding Tool and Surface

After the grinding experiments and the measuring of the used tools and the workpiece topography, the profiles have to be compared. This comparison serve as a 2D kinematic matching between tool and workpiece. At first, the focus is on the wear behavior of the grains. Therefore the measured and programmed depths of cut values are correlated in table 3 (programmed ones in brackets).

Table 3. Measured and programmed depths of cut a_e.

Grinding wheel description	B252-1	B252-2	B151-1
1. path	50 (0) µm	9 (0) µm	55 (0) µm
2. path	58 (20) µm	12.5 (20) µm	71 (10) µm
3. path	65 (40) µm	32 (40) µm	38 (20) µm
4. path	95 (80) µm	49 (80) µm	39 (30) µm
5. path	73 (120) µm	46 (120) µm	83.5 (100) µm

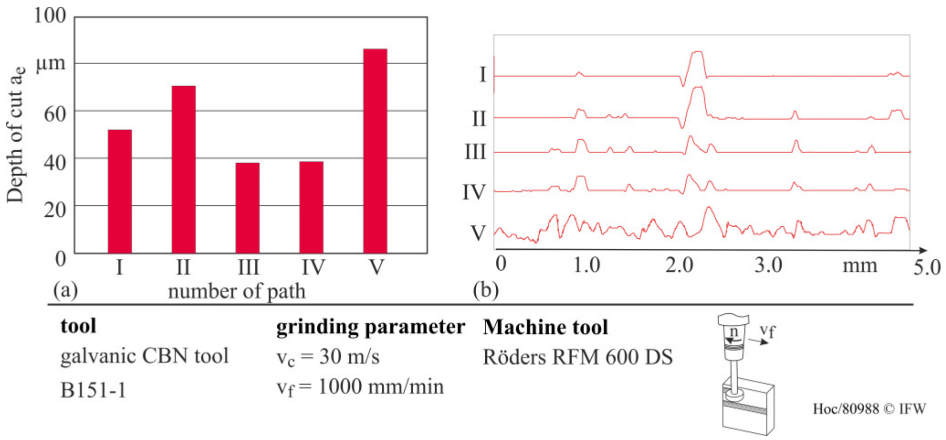

Fig. 3. Measured depths of cut and corresponding workpiece profiles

It can be seen that the iteratively determined depth of cut of the first path is different for the three tools. This is caused by single grains with outstanding height. These grains generate one deep scratch in the workpiece surface. It can also be seen that the measured depths of cut do not correspond with the programmed ones. The reasons are occasional outbreaks of grains. Outbreaks and other tool wear can be observed on the workpiece (Fig. 3) and also on the tool topography, as it is shown in Figure 4 with the example of tool B151-1. Figure 3a shows the measured values for the depth of cut of the five cutting paths. From the first to the second path, the depth increases, as it is assumed. In path III, the depth of cut is nearly halved. The reason is an outbreaking grain tip. Despite programmed infeed of 10 µm, the depth of cut in path IV increases by 1µm only (Fig. 3). The reason might be a deviation in flatness of the specimen. In path V, the depth of cut increases again with smaller outbreaks in tool topography and generates a completely ground surface without polished parts. All the changing processes can be described by the measured 3D topography like in Figure 4. The Figure shows the summation profile of the tool B151-1 before and after machining the five paths.

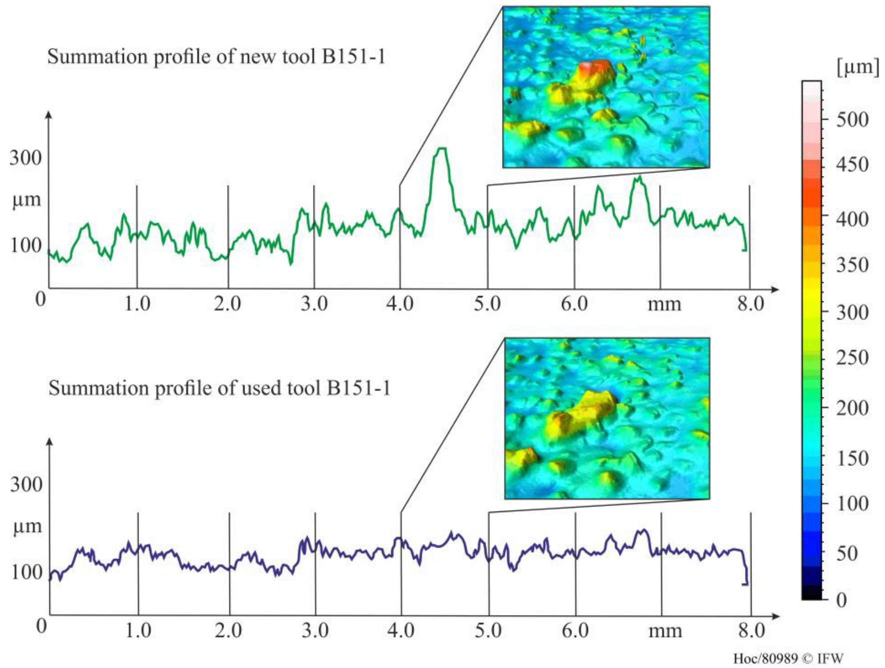

Fig. 4. Summation profiles of tool B151-1

The detailed section displays the area around an outstanding grain in 3D. In this view the wear behavior can be described. For the following comparison of the summation profile, it is assumed that because of the high rotation speed of about 19,000 1/min and the medium feed rate of 1000 mm/min, every grain has to pass the same workpiece area several times and creates a uniform scratch in contact. That means that the summation profile is a direct reproduction of the workpiece profile and can be used as a primitive 2D kinematic simulation. Figure 5 validates this theory with the example of the tool B252-2. The Figure shows the summation profile of the new tool, the five cutting paths and the summation profile of the used tool below.

Before a comparison is made and the summation profile is generated, the whole topography has to be filtered by an outlier filter. Without filtering, the summation profile consists of high, sharp peaks which do not display the real topography. It can be seen that the marked peaks of the summation profile create a similar imprint on the workpiece topography. There are some other peaks which do not have a correlation to the scratch in the polished surface. A reason for this could be left artefacts from measuring. At present, it is not possible to check all grains for artefacts after filtering. But in total the imprint of the summation profile correlates with the ground surface, so it can be determined that the grinding wheel topography and the generated summation profile can be used for a 2D kinematic prediction of ground surfaces.

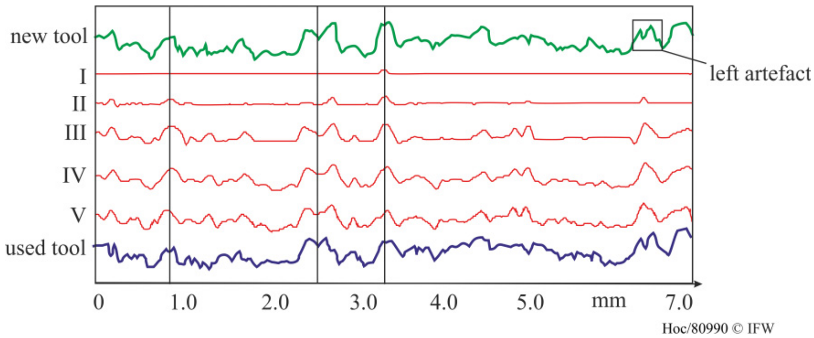

Fig. 5. Comparison of summation profiles of tool B252-2 and the workpiece profiles

5. Conclusion and Outlook

In conclusion, the presented method is able to describe changing processes on the tool topography and on the workpiece in detail. For a future 3D surface prediction, it is necessary to learn more about the wear behavior of galvanically bonded tools to create a wear model. Furthermore a method to check the tool topography for artefacts has to be developed, and the summation profiles have to be compared with ground profiles of a material which does not cause grain wear like Obomodulan®. So the change of the summation profile can be eliminated. Then, the comparison of profiles has to be quantified with a difference profile and describing values. If the tool topography can be predicted in the machining process, it will also be possible to predict the generation of a workpiece topography with only one scan at the beginning of machining. As already mentioned at the beginning, the predicted surfaces will be calculated with the fingerprinting method. So the manufacturer can identify every ground product by measuring the tool topography once or in discrete periods. The next step will be the investigation of tools with smaller grains to identify the limits of the laser triangulation technology. Furthermore, the possibility of an online monitoring during machining has to be checked.

It is for sure that the measuring accuracy and speed will still be increasing in the future. The simulation of grinding processes becomes more and more realistic, so that grain modeling with octahedrons, ellipsoids, etc., as proposed by [9, 10, 11, 12, 13], is no longer state of the art.

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