Process related characteristic-based topography evaluation of wear conditions on grinding wheels

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Abstract

In single and small series production of milling and drilling tools, there are non-productive times at the auxiliary processes, such as sharpening and dressing of the used grinding wheels. These auxiliary processes additionally are influenced by the experience of the machine operator for example regarding the date of initiation. Thus there is no data based approach for the objective initiation of these processes. For this purpose, a process related metrological evaluation of the grinding wheel surface is developed. For the metrological evaluation an optical method based on laser triangulation is used. The measuring system under development is integrated into a machine tool. In addition, characteristic values have been defined which show the wear criteria of the tool and detect their tendency. More over all the data is summarized in a database of wear conditions. The developed method can save tool resources and process time for unnecessary sharpening or dressing.

This work investigates the characteristic-based topography evaluation of grinding wheels and tries to establish correlations between the characteristic values and the tool wear.

1 Introduction

An objective approach to setting up grinding processes based on 3D topography parameters of the grinding wheel does not exist to this day. Furthermore, there is no process-related, metrological evaluation of the grinding wheel surface in order to be able to select the optimal process control variables [5]. To solve this problem, a new measuring system is currently under development at IFW in cooperation with Walter Maschinenbau GmbH and integrated into a tool grinding machine. The measuring system should automatically identify optimal dressing intervals and adapt process parameters in order to ensure permanent tool quality. In addition to the grinding process, a topography measurement of the grinding wheel takes place, whereupon the recorded data of the grinding wheel are processed and checked. In the first step, this results in a recommendation for the operator for the initiation of grinding wheel sharpening or dressing. On this basis, a process adjustment could be implemented.

2 Development of the measuring system

This chapter describes different types of measurement, selection criteria and the final structure of a suitable measuring system for grinding wheel topographies.

manufacturer	Mahr	Alicona	Nanofocus	Confovis	Keyence
device	MarSurf LD 130	InfiniteFocus	µScan	DuoVario	LJ-V7020K
technology	tactile	optical	optical	optical	optical
technique	diamond tip	white light focus variation	confocal point sensor	focus variation, confocal	line scanner, lasertriangulation
measuring time	43.000 s	400 s	27.500 s	2.500 s	1 s
measured surface/ point distance	15 mm x 6 mm, 1 µm x 7,5 µm	15 mm x 6 mm, 1 µm x 7,5 µm	15 mm x 6 mm, 1 µm x 7,5 µm	15 mm x 6 mm, 1 µm x 7,5 µm	15 mm x 6 mm, 1 µm x 7,5 µm

Figure 1: Comparison of different measuring types

In the first step, a distinction is made between the measurement technologies. Topography measurements are usually carried out optically or tactilely. For the process-related topography measurement of grinding wheels 12 different systems were considered. 5 of them will now be compared in the following. Tactile measurements using a diamond tip have a comparably low level of tip wear and tear and a comparably low susceptibility to errors. In addition, the measurement of the surface is only limited by the shape of the tip itself. The tip diameter and the slope act here as hardware filters. Additionally the measuring process take more than two times of a slow optical process. With white light focus variation, on the other hand, recordings can be made just as precisely as with tactile measurements.

These recordings are not automatically filtered by measurement equipment. However, in this type of measurement, as in all optical measurements, has a decisive influence on the edge stability. Optical processes are limited in their ability to record steep flanks of the measured surface because since the emitted light is no longer reflected back to the receiver from a certain flank angle (increasing 60 °). The use of a laser sensor increases the accuracy of the measurement data but also requires more time for the measurement in comparison to a focus variation. Therefore, the measurement time is now listed as a further selection criterion. Due to the hardware and the limited speed of a diamond tip in contact with the surface, the measuring time is the highest for tactile measurements (Figure 1.). Optical measuring systems show gaps in measurement but offer the option of comparably low time-consuming measurements between process steps due to shorter measuring times. A focus variation offers quick measurements (compared to tactile) as well as the combination of focus variation and confocal point sensor. The required accuracy for measuring grinding wheel surfaces is also given here by at least four measured points per grain. It should be noted that when measuring grinding wheels with an average grain diameter of dg = 54 - 126 µm, the accuracy required (54 µm grain leads to a min. pointdistance of 10 µm) is far below the single measuring systems presented here offer. It would therefore be desirable to reduce the measurement accuracy for the benefit of the measurement time. In order to ensure the necessary level of measurement accuracy in combination with an economical measurement time, a laser sensor is used which operates as a line laser. With the line laser sensor the measurement time can be reduced by a factor of one hundred compared with figure 1.

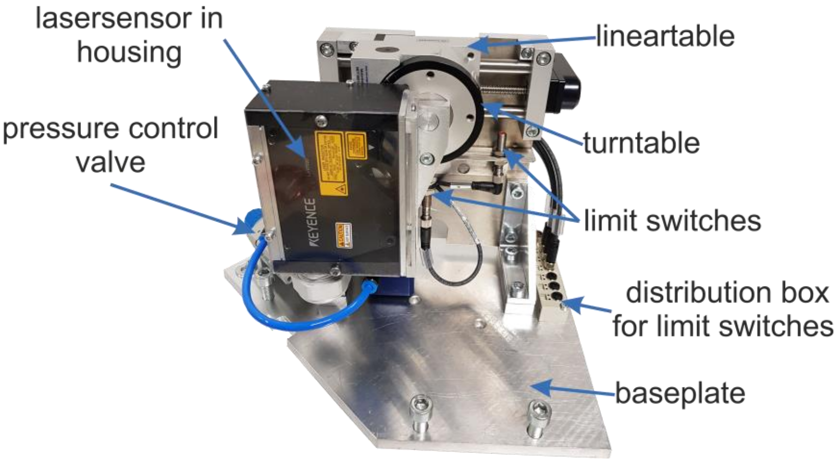

Figure 2: Measuring System (Mount of line laser)

Now the different systems are used to measure the same surface and set the resolution to an equivalent level so that the same point spacing is achieved during the measurements, then the different measurements of the systems can be compared (Figure 1). This figure further shows that a laser sensor is able to measure sections of grinding wheel surfaces close to the process with the same selected accuracy. With a cycle time of several minutes per grinding cycle, the topography measurement must not exceed a duration of 60 seconds within the machine [6, 7], which can only be achieved with the measuring system shown (Figure 2).

The core of the measuring device is a laser triangulation sensor that is embedded in a positioning unit. With the help of this unit, the surface of the grinding wheel can be recorded close to the process. The lower limits for the point spacing in the axial direction of the grinding wheel are 2.5 µm, in the radial direction 0.2 µm and in the circumferential direction 0.5 µm. The sensor in the measuring device can be moved linearly and rotationally by xy. The mobility is necessary to ensure an adaptation to different grinding wheel diameters (60 mm to 130 mm). A linear movement supports the realization of the necessary measuring distance, while the rotary movement enables different angles in relation to the tool surface. Different angles are used for a multiple measurement in case of the unwanted surface reflections leading to mismeasurements. The surface is recorded at an angle of + 15 ° and -15 ° and the corresponding error points are removed by correlating the surfaces. Both axes are referenced using limit switches that are magnetically controlled (position detection ≤ 1 µm). Overpressure in the sensor housing protects the optical components from external influences such as oil mist. The air supply is regulated separately via a control relay. In addition, the compressed air is cleaned of oils and micro particles by xy. The necessary control elements for these processes are located on a separate control platform that can be retrofitted on the machine in a modular manner. The complete measuring system is used in a Walter Helitronic 400L. The measuring device is integrated in the tool changer. The small installation space as well as the risk of contamination by cooling lubricant (KSS) are restrictions that had to be observed for the integration.

The surface topography of the grinding wheel is measured directly in the machine room. The grinding wheel is positioned by an executed NC program near to the sensor, which is swivelled into the machine room by means of the tool changer until it has reached the measuring distance of 30 mm. During the measurement the grinding wheel rotates and the sensor records the surface within a few seconds. For example, the measurement of a grinding wheel with a diameter of 100 mm and a width of 10 mm takes 21 seconds over its entire circumference. The measuring performance is currently 100 mm²/s. After the measurement, the grinding wheel topography is evaluated. A C-Sharp-based graphical user interface is used to coordinate the axis movements and the measurement of the integrated sensor. With the boundary conditions depicted, a process-related measurement can now be guaranteed when carrying out wear tests with grinding wheels.

3 Wear conditions and experimental procedure

This chapter describes the experimental procedure that was carried out. Metal, ceramic and synthetic resin bonded grinding wheels were examined. The grain size investigated was between 54 and 126 µm. The examined diamond grains did not show any special features or characteristics and thus represent the standard grain body for the experiments. For the experimental procedure flat grinding was chosen as an analogy experiment. This is intended to generate different types of wear [8]. Grain wear begins in the crystal layers and is microscopic. Typical wear mechanisms of diamond grains are splintering or abrasive wear of the grain edges. Those edges that protrude the highest from the bond and thus reach deepest into the work piece during processing experience the highest load. The thermos-mechanical load wears them out and dulls them. One consequence of this is an increase in the cutting edges in contact with the material and a reduction of the effective grinding wheel roughness. In addition, there is an increasing heating of the work piece due to increased friction and grinding forces. The effects are thermal structural damage, tensile residual stresses and cracks in the surface of the work piece. Furthermore, due to defects such as lattice boundaries or impurities within an abrasive grain, micro cracks can arise. The cracks lead to the splintering of grain parts. In addition, sharp temperature changes act on the near-surface crystal layers of the abrasive grains due to the grinding process. This causes oxidation and diffusion processes, which lower the abrasion resistance of the grain and create a pressure-softening layer. The blunting of the cutting grain increases the friction surface in contact and thus the effective cutting forces. This leads to increased overloading and breaking of bonds [1, 4].

Another possible mechanism is the clogging of the chip spaces. The spaces between the grains are clogged by removed material chips in combination with the cooling lubricant. As a result, the cutting edges are partially covered and cannot penetrate the material of the unmachined work piece. Distinguishing features for this are metallic shiny areas in the form of points that can spread over the majority of the grinding wheel work surface. The result is an increase in process force and greater heating of bare, smooth areas than with unclogged grinding wheels. This causes damage to the work pieces through grinding cracks and structural changes [8].

In order to generate the now defined and described wear conditions, the surface grinding tests were carried out by varying the cutting speed v_c, the feed speed v_f and the infeed a_e. The material removal rate was continuously adjusted by keeping a constant mesh width (Table 1).

Table1: Process parameters

Bond	Metal, synthetic resin, ceramic
Cutting speed v_c [m/s]	10, 15, 20, 25
Feed speed v_f [mm/min]	120, 180, 240, 300
Infeed a_e [mm]	1, 1.5, 2, 2.5
Operation width a_p [mm]	5

In addition, a limit force was defined for carrying out the tests, which resulted from machine data and grinding wheel data. This force of 500 N must not be exceeded. Otherwise there is a risk of damage to the tool or the machine. In addition, this provides an indicator of when the tests must be terminated and the maximum permissible wear condition of the tools has been reached. In summary, 192 experiments were run in triplicate, which results in a total of 576 experiments.

During these tests, the topography measurement using the developed line laser measuring system was carried out between each state of the grinding wheel. The sequence of these measurements provides for the recording of the grinding wheel topography in the form of a point cloud first. These point cloud data are fed to a process model that is differentiating between cases. Based on the recorded point cloud data in combination with a knowledge based database, a decision is then made as to whether a process adjustment, a topography adjustment or no adjustment is necessary (Figure 3).

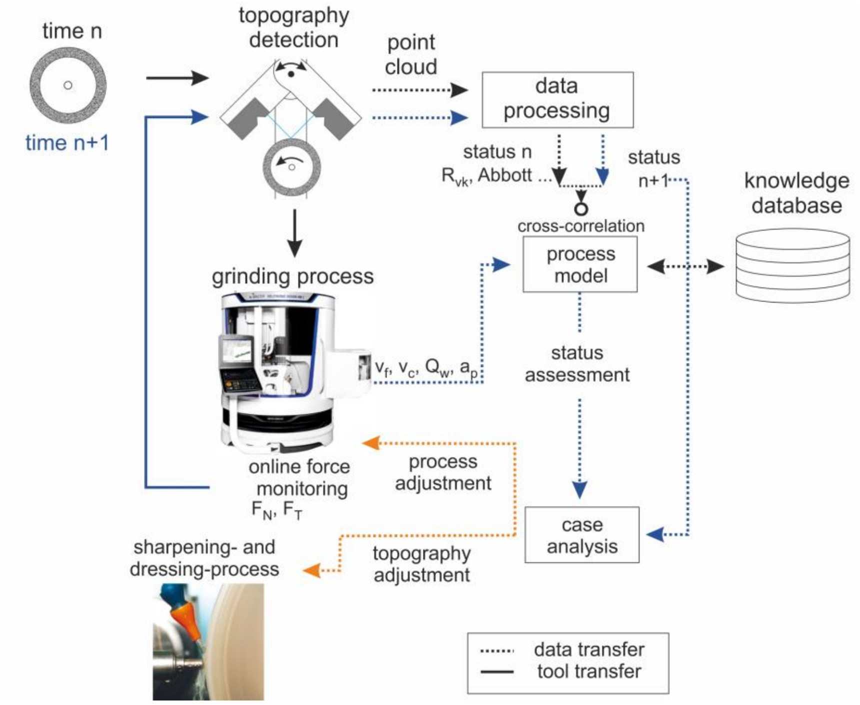

Figure 3: Experimental measurement procedure

4 Results and discussion

This chapter aims to classify and present the test results. The measurement results that are recorded in an exemplary measurement are shown in the form of topographies in Figure 4. A section of a grinding wheel with a metallic bond and an average diamond grain size of $D_g = 54$ µm is considered. The same surface is recorded again after the grinding wheel has been used in the machine for a comparison. On the basis of the measured data and their analysis, surface parameters can be calculated in accordance with DIN ISO 25178 [2]. These are used for decision making of the knowledge based process model. To corroborate the measurement results, no intervention in the process between measurement two and three was made for the test measurement. The recommended action of the process model would have been a dressing step after a machining volume of V_w = 6,800 mm³, with a total infeed of 118 µm.

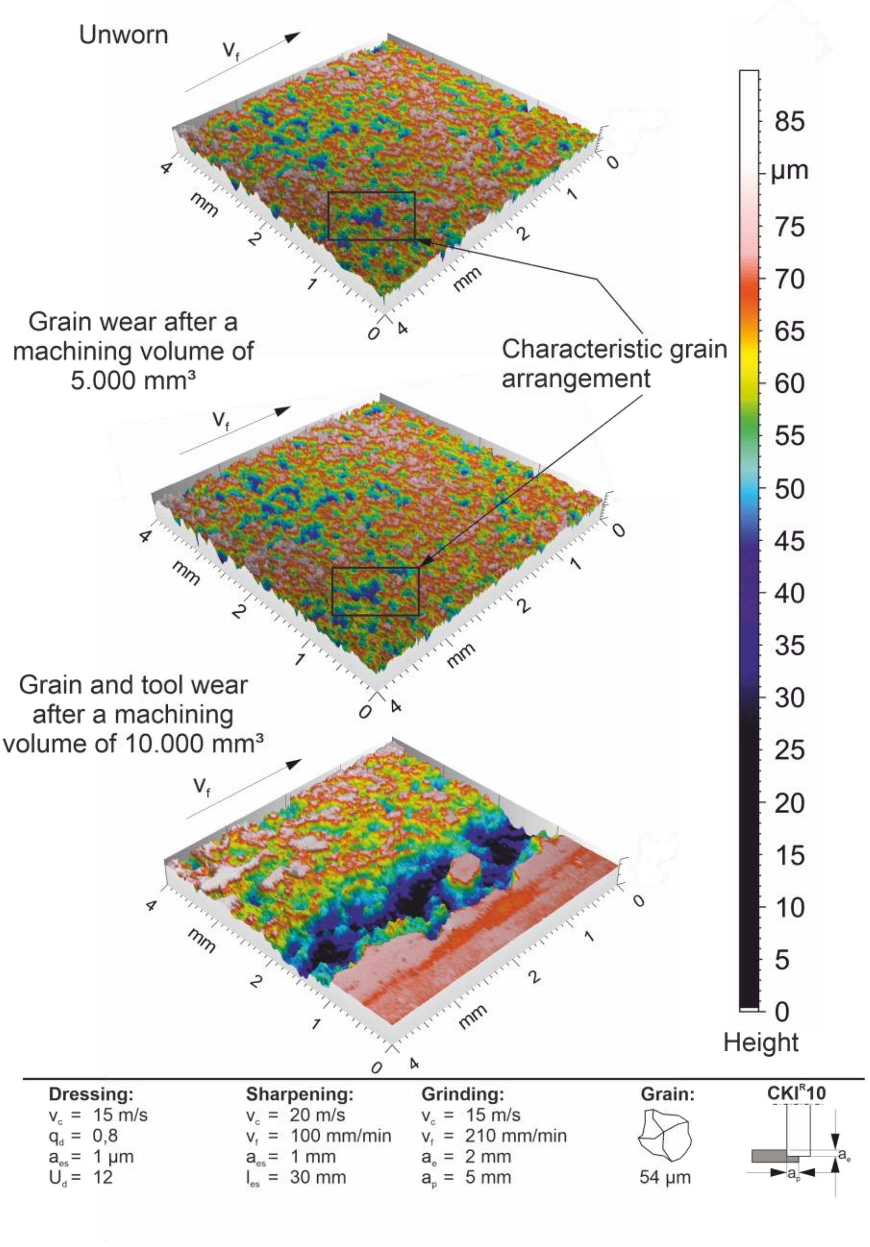

Figure 4: Developement of measured grinding wheel topographies

After a machining volume of V_w = 5,000 mm³ (carbide CKI®10), however, increasing wear of the grains can already be observed. The grain protusion has decreased. The beginning of clogging within the valleys can also be seen. This is shown by the accumulation of material in the valleys. With a further increase to V_w = 10,000 mm³, a macroscopic clogging forms on the grinding wheel surface (Figure 4, bottom). Grain wear and clogging correlate with the functional topography and height parameters of the grinding wheel surface. A significant drop can be seen explicitly for all peak values until the accumulation of material overlays the tool structure. An increase was recorded for the valley values.

For the objective classification of these results, however, the objective parameters of a topography evaluation are required. These characteristic values can be classified in 5 categories (height, function, feature, volume and hybrid). Of all the parameters considered, a total of 13 3D parameters can be identified as proportional to the grinding wheel wear on the basis of the tests carried out (Table 2). In order to assess a recommended method, an equation is required that reflects the respective state of wear of the grinding wheel. This is done using the following formula:

$$\boldsymbol{Z(x) = 0,6 * \sum_{i=1}^{n} \left(\frac{N_i(x) - G_i}{G_i} * y_i * (\pm 1) \right) + 0,4 * \sum_{i=1}^{n} \left(\frac{M_i(x) - G_i}{G_i} \ * y_i * (\pm 1) \right)}$$

$$, \boldsymbol{i \ \wedge j \ \epsilon} \ \mathbb{N}, \qquad \boldsymbol{-1 < Z(x) < 1}$$

The wear factor Z (x) is calculated using the respective variables N_i and M_i. The variables N_i (x) and M_i (x) each represent the individual parameters of the peak and valley area and give the values for the respective cutting volume x again. The values are subtracted with the limit value G_i and then divided by this. If the limit value is above the starting value of N_i (0), the individual term of the parameter is multiplied by -1 in order to avoid compensation for the wear factor. The individual terms are each assigned their specific weighting y_i and added up. Due to the greater importance of the peak area according to the resulting roughness of the work pieces, it is weighted with 60% and accordingly the groove area with 40%. The wear factor Z (x) thus assumes a value between -1 and 1 for each cutting volume x. The wear factor Z (x) reflects the respective state of wear of the grinding wheel surface.

There are two ways to determine the limit value G. The first approach describes the derivation of the limit value, which is based on the percentage decrease or increase of a parameter N_i or M_i. To do this, it is first calculated by how many percent a parameter has changed compared to its initial state. The percentage value determined is then transferred to the initial value N_i (0) or M_i (0).

The second approach describes the derivation of the limit value, which is based on the absolute decrease or increase of a parameter N_i or M_i. For this purpose, the values of the variables N_i (x) or M_i (x) are considered in the worn condition and defined as new limit values. The determination of whether a grinding wheel is worn is linked to the following two conditions:

- The specified wear factor Z (x) is exceeded [Z (x) < 0.1, combined knowledge of 30 machine operators]
- A parameter N_i (x) exceeds its limit value

However, the second condition only applies to parameters whose weighting y_i is greater than 30% in total. Thus the parameters are included with less weight in the wear factor.

Table 2: 2D and 3D parameter description [2]

Catagories	2D formula sign	3D formula sign	Description	Peak / valley area (N_i /M_i)	Weighting y_i [%]
Functional	R_{pk}	S_{pk}	Reduced center height	N_2	25
	R_{vk}	S_{vk}	Reduced groove depth	M_1	40
	M_{r1}/M_{r2}	S_{mr1}/S_{mr2}	Surface material proportion	N_3 / M_2	14 / 30
	-	S_{xp}	Extreme value of the peak height	N_1	30
Characteristic	-	S_{pc}	Mean value of the tip curvature	N_6	5
	-	S_{pd}	Peak density	N_7	4
	-	S_{ha}/S_{hv}	Area / volume of a closed hill	N_5 / N_8	4
	-	S_{da}/S_{dv}	Area / volume of a closed valley	M_4 / M_5	6 / 4
Volume	-	V_{mp}	Peak material volume	N_4	14
	-	V_{vv}	Volume of valleys	M_3	20

The optical measurement basically proves to be effective. It is possible to achieve usable measurements within a few seconds and, in conjunction with the wear factor Z (x), to quantify the state of wear. However, the usability of the measurements depends on the measured object. Precise recordings of the synthetic resin-bonded and metallic grinding wheel were achieved, while the ceramic grinding wheel resulted in increased measurement inaccuracies due to the pores. These measurement inaccuracies are compensated for by means of suitable filtering. For the continuation of the work, an increased focus is therefore placed on the type of filtering. There are several ways in which the measured data can be filtered. The type of filtering has a fundamental influence on the surface parameters, which in turn determine the process recommenddations.

5 Conclusion

The developed and presented measuring system enables process-related and efficient topography measurements on grinding wheels, which could not be implemented before. Based on this an the wear factor Z (x), an objective and data-supported adaptation of the processes is possible, so that a reproducible and resource-saving process design is implemented. Thus, the often subjective and uneconomical experience of the individual machine operator can be replaced. In addition, in the future, a self-learning algorithm will be linked to the model for weighting the parameter changes over the process duration. In order to implement the entire process, the process flow is also optimized and resource conservation is demonstrated.

Acknowledgement

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