Environment. Technology. Resources. Rezekne, Latvia
Proceedings of the 13th International Scientific and Practical Conference. Volume 3, 252-255

Analysis Of Optical Methods For Monitoring The Working Surface State Of The Grinding Wheel

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***Abstract* - The article describes an analysis of non-contact optical methods for monitoring linear wear and the working surface condition of the grinding wheel during dry grinding. The presented methods are based on computer processing of photo and video materials, 3D models surface construction of the grinding wheel, the machine vision and using of the optical equipment. The advantages and disadvantages of this methods were analyzed. As a result of the conducted research, it was concluded that the usable area of the considered methods depends on the circle material, cutting parameters, control objectives, including the requirement for on-line control, and also the available material and technical equipment.**

Keywords - Grinding, tool wear, laser, triangulation, machine vision, light polarization

I. INTRODUCTION

Condition monitoring of a working surface of a grinding wheel has an important role in quality assurance of the machined surface. During grinding process the wheel wears out, becomes salted, and its geometric shape changes. Workable state providing of the grinding wheel surface is an actual task because of shaping treated surface is the result of the interaction of the abrasive tool with the surface of the work piece.

The control can be provided by contact and non-contact methods. All contact methods have a significant drawback. It is the wear of the probe during its interaction with the abrasive grains of the grinding wheel. Therefore, non-contact methods (optical, pneumatic, hydraulic) are becoming more applying. Optical monitoring methods are analyzed in this work, which are based on these basic principles: laser scanning, polarized light using, 3D surface modeling based on static micrographs. At the same time, special software are widely used, such as with statistic analysis using.

II. MATERIALS AND METHODS

Non-contact method of texture analysis for wear determination of a grinding wheel by using machine vision is known [1]. This method consists in obtaining images of the grinding wheel working surface by using a CCD camera (CCD is a charge-coupled device) at different times during the grinding process and their subsequent analysis by existing statistical and fractal methods.

Other non-contact optical method for detection of grinding wheel wear is based on a digital profile grinding machine by using a CCD is also known [2]. A machine vision system with a scheme for visual measurement of the grinding wheel profile has been developed, which consist of a profile grinding machine, a CCD camera GC2441M with a telescoping lens, a controller and a computer processing the received data. To measure the wheel profile photographs of its working surface in different parts are made. It is provided by repeatedly turning the grinding wheel at 45° from the previous position within one full turn. Then received images are transferred to the computer memory, where they are processed by software.

System for active control of surface roughness by measuring the degree of polarization of the reflected radiation is also known [3]. The control method which is

Online ISSN 2256-070X
https://doi.org/10.17770/etr2021vol3.6548

used in this system is an analysis of radiation polarization characteristics, roughness value in the reflected radiation and their relationship. As a result, a model is built (experimental curve), which allows to monitor state of the grinding wheel, focusing on it in real time. The surface roughness control system consists of a radiation source, a workpiece (rough surface), a linear polarizer, an optical image capturing instrument and a data processing device. The optimal angles of incidence and reflection is 45° that was established empirically. Angles of 0° and 90° were also used in the formula to determine the degree of polarization.

Next considered non-contact method for analyzing grinding wheel working surface state by using three-dimensional scanning has been proposed in work [4]. The 3D scanning system includes a Nanovea CHR150 chromatic white light sensor with a specially designed circle positioning scheme. It consists of three tables - horizontal, vertical and rotating, and a motor that drives the grinding wheel. Due to this method, white light passes through a lens with a high degree of chromatic aberration, thus refracting and separating into its constituent colours. The light ray length that hits the interest area of surface is reflected and returned to the lens, while the other rays are scattering. In this case, the reflected ray length is equal to the distance from the lens to the grinding wheel working surface. The 3D scanning system is controlled by using a special LabView software package and the analysis and editing of a grinding wheel surface 3D model is performed by using the Nanovea Mountains 3D Analysis software. This system has a homing subsystem that allows scanning the same area multiple times during multiple grinding tests.

Also known optical method for monitoring of the grinding wheel surface state, in which the wheel is repeatedly photographed by an electron microscope [5]. 3D model of the grinding wheel working surface is created from array of photographs. During the experiment, images of the interest area of the grinding wheel surface are recorded by using a Supereyes B008 digital microscope. Photographs are collected and processed by using the special software Helicon Focus Professional; as a result, the 3D model is formed. Then the grinding wheel has been processing a carbide workpiece for 15 minutes, after that it is photographed again and new 3D model with changes is created. Then the two models are compared by using the same computer program.

Similar to the previous method is a method for analysis the 3D parameters of the diamond grinding wheels working surface by using laser scanning [6]. A significant difference of this method is the using of a laser scanning device instead of a digital microscope. Laser scanning allows obtaining a 3D model of the analyzed surface without using an array of photographs and its subsequent processing. The laser processes the grinding wheel scanned profile, transfers it in digital form to a computer and allows simultaneously showing to nine parameters of the working surface. The result of the analysis is a digital volumetric surface relief, indices of the standard deviation of the profile, the height from the top of the grains to the centreline, the average step of irregularities, deviation from the standard, the height of irregularities by ten points, and the value of the relative reference surface area, showing the contact area of the grinding wheel with the surface of the processed workpiece.

Also, a method of colorimetric computer analysis of the working surface parameters and defects of a superhard material is proposed in work [6]. In the course of analysis by a metallographic microscope, images of the grinding wheel surface are obtained in polarized light rays. The authors have developed the corresponding software in the Borland Delphi 5.0, based on the Pascal programming language. It allows determining grain wear by using the obtained photographs as a percentage of the total number of pixels in the image. Varying the tint components of the photographs in the RGB color system allows selecting the required colors in the image, calculating their exact number in pixels to determine the surface quality of the grinding wheel.

A predictive model for grinding surfaces based on the topography of a wheel for modeling grinding is presented in work [7]. The measurement is carried out by a laser triangulation sensor mounted on the machine. The obtained result is imported into the software for modeling of the processing. Measuring of the grinding tool surface by using laser triangulation allows describing the wear behaviour with high accuracy.

The use of focus variation microscopy to assess active surfaces is considered in article [8]. The principle of the method is that the light reflected from the surface returns to the optical system of the microscope and through the ray splitter to the active area of the photometric detector. In which an image containing information about color, brightness, contrast, length and width are forming. The signal processing unit searches only those parts of the image on which the light ray has been focused, then these parts are reconstructed and finalized. To create a 3D model, surface microtopography is required, for which scans are carried out along the Z axis. This method is used for measuring and analyzing the active surfaces of abrasive tools of various types. Focus variation microscopy is a promising measuring method with greater potential for development, especially with its hardware implementation.

Also known method on-machine measurement of the grinding wheels 3D surface topography using a laser displacement sensor [9]. The coarse diamond grinding wheel is attached to the vertical spindle; the laser sensor is attached to the work table. To ensure an accurate measurement, the laser ray should be aligned with the centre axis of the spindle. After the laser ray is reflected through the controller, the point height is determined. The laser sensor moves downward along the spindle axis with low speed, thus scanning the entire circumference of the grinding wheel surface along a spiral path. The results obtained are processed in the Matlab. This method allows to approximately revealing the shape of each grain. The model determines the following three parameters: active grain volume, active grain-containing amount, and active grain. Knowing these parameters, it is possible to estimate the real characteristics of the grinding wheel.

Creation of a triangulation model of the grinding wheels working surface relief consists in creating a set of photographs of a working surface fragment with different height orientation of the depth field [10]. Then happens layer-by-layer photography with a step-by-step shift of the digital microscope optical system. After that the set of photographs is processed in the Helicon Focus Professional application, as a result of which an OBJ-model of a fragment of the grinding wheel working surface is obtained. Using the MechLab application, the OBJ-models are converted into an STL-model, and then into a DBF-image (triangulation model). Topological analysis consists in the determination of the Euler-Poincare characteristic, the kind of surface, the analysis of the adjacency of faces and edges. With the help of the triangulation model integral characteristics (linear, angular, surface and volumetric) can be determined.

III. RESULTS AND DISCUSSION

The advantages and disadvantages of the considered methods are summarized in Table 1.

TABLE 1. OPTICAL METHODS FOR MONITORING THE WORKING SURFACE STATE OF THE GRINDING WHEEL

Name of the method	Authors	Advantages	Disadvantages
Texture analysis by using machine vision [1]	N. Arunachalam, B. Ramamoorthy	Obtaining reliable values with minimal errors.	Impossibility of obtaining data in real time, and when rotating manually.
Grinding wheel wear detection based on profile grinding using a CCD camera [2]	F.Fana, L.M.Xub, Z.Zhangc, .J.Chaod, C.Fane, L.Shif	High measurement accuracy comparable to the data obtained during the verification of the experimental results with a profilometer.	Impossibility to analyze in real time; the process is not automated - manual rotation of the wheel to the desired angle is required to provide CCD camera access from the required angle.
System for active control based on measuring the degree of polarization of the reflected radiation [3]	Ziyatdinov R.R., Shabaev A.A., Valiakhmetov R.R	The ability of using method in real time; automation of changing cutting conditions; high reliability.	Indirectly monitoring - reaching a certain degree of polarization indicates a degradation of surface quality and wear.
Analysis of the grinding wheel working surface state by using three-dimensional scanning [4]	A. Darafon	Automated, has a high speed of data collection; suitable for testing wheels made of various materials; varying data sampling intervals, image resolution, spot size.	Impossibility to receive data in real time; removing the grinding wheel from the machine is required.
Evaluation of the working surface relief development of diamond wheels on a metal bond [5]	V. L. Dobroskok, Ya. N. Garashchenko, A. N. Shpilka	The ability to obtain a large amount of statistical data; visual representation of the state of the wheel working surface as 3D models, graphs and histograms.	Impossibility to receive data in real time; large number of images is required to create 3D models.
Analysis of 3D parameters of the diamond wheels surface by using laser scanning [6]	A. I. Grabchenko, V. A. Fedorovich	Reducing the time for obtaining a 3D surface model; increased accuracy; the possibility of analysis various grinding materials; universal using.	Impossibility to receive data in real time and with a rotating grinding wheel.
Colorimetric computer analysis of parameters and defects of the superhard working surface [6]	A. I. Grabchenko V. A. Fedorovich	High accuracy of results; applicability to the analysis of the surface condition of grinding wheels made of various materials.	Impossibility to receive data in real time, because each photo is saved manually and processed separately.
Wheel topography method [7]	R. Hockauf, V. Böß, T. Grove B. Denkena	Measuring of the grinding tool surface using laser triangulation allows high accuracy describing of the wear.	Impossibility to receive data in real time.
Focus variation microscopy to assess active surfaces of the grinding wheel [8]	W. Kapłonek, K. Nadolny, G. M. Królczyk	High measurement efficiency, resolution, reproducibility, speed; simple control; software with a number of useful features.	Restrictions at large angles of inclination; measurement errors or their absence (appearance of unmeasured points).
Topography of the wheel by using a laser displacement sensor [9]	Y. Pan, Q. Zhao, B.Guo	The possibility of using the method to analysis a rotating wheel while machine processing; applicability to universal surface grinding machines.	Possibility of inaccuracy during measuring the grain shape of the grinding wheel.
Triangulation model of the wheel working surface relief [10]	V. L. Dobroskok, A. N. Shpilka, V. B. Kotlyarov	The ability to obtain adequate 3D models by analyzing the geometric characteristics of the shadows.	The measurement results depend on the resolution of the matrix and the optical system, and the software features.

IV. CONCLUSIONS

Each of the considered methods has its own field of application, depending on the resolution, measurement accuracy, degree of automation, and the possibility of obtaining data in real time.

Based on the analysis of existing methods, it can be concluded that the most promising direction of optical control of the grinding wheels surface state is the use of laser sensors for creating 3D models of the working surfaces by using the triangulation method.

The authors are conducting research on the use of high-resolution webcams in three main direction:

1) analysis of the colour scale of microphotographs of the grinding wheel surfaces and the workpiece and their statistical processing (the goal is to determine the moments of occurrence of burns and the dynamics of salting);

2) determination of the amount and size of sludge particles on the grinding wheel surface based on pattern recognition (the goal is to determine the optimal dressing time);

3) analysis of the correlation between the degree of salting (according to microphotographs) and the amount of radial wear during grinding of various materials (according to the indications of pneumatic-electric-contact transducers [11]).

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