Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 51 (2020) 1054–1061

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

30th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2021)
15-18 June 2021, Athens, Greece.

Digitization Methods of Grinding Pins for Technological Process Planning

R. Wdowik[a],*, R.M. Chandima Ratnayake[b], M. Żółkoś[a], M. Magdziak[a], G. Valiño[c], B.J. Álvarez[c], J. Misiura[a]

[a]*Faculty of Mechanical Engineering and Aeronautics, Rzeszów University of Technology, 35-959 Rzeszów, Poland.*
[b]*Department of Mechanical and Structural Engineering and Materials Science, University of Stavanger, N4033, Stavanger, Norway.*
[c]*Department of Construction and Manufacturing Engineering, University of Oviedo, Campus of Gijón, 33203 Gijón, Spain.*

* Corresponding author. Tel.: +48 17 743 2536; fax: +48 17 865 1184. *E-mail address:* rwdowik@prz.edu.pl

Abstract

The paper presents different techniques for digitizing grinding pins and discusses the use of digitalized pins and the results of measurements in technological process planning (TPP), focusing on the challenges of the digital era. It describes the potential of different measuring devices, taking into account the digitization of a real tool shape into virtual 2D and 3D models. The following methods for measuring grinding pins are presented in the study: contact and non-contact coordinate measurements – performed on coordinate measuring machines (CMM); optical measurements on microscopes (i.e. focus-variation technique); optical measurements using tool presetters; optical measurements with measuring arm; laser micrometer measurements; and laser triangulation sensor measurements. Moreover, the use of testers which are applied in contour measurements is analyzed. On the basis of the presented methods, taking into account their possibilities and limitations, we discuss how the obtained digital data can be used in the planning of technological processes.

Keywords: grinding; machining; digitalization; digitization; technological process planning

1. Introduction

Grinding pins are grinding tools with small diameters compared to their length, which are applied in different abrasive machining tasks, such as the grinding of holes and external surfaces, rounding of edges, pocketing, grooving, engraving and also in drilling. They are rotating tools which are clamped to the spindles of machine tools by the use of different types of tool holder. Today, computer numerical control (CNC) machine tools are widely exploited by industry, including various types of high cutting velocity (v_c) spindles, suitable for the rotation of small diameter tools, such as grinding pins [1,2]. Grinding pins consist of a metal mandrel and a fixed abrasive layer, with or without a through-hole. The mandrel is intended for clamping the tool, and its shape should be coincident with the tool holder used. The shape of the abrasive layer is usually adapted to the required part feature (i.e. cone, cylinder, disk, etc.). There are two main types of grinding pins – conventional and super-hard. Conventional abrasives (e.g. corundum or silicon carbide) are used in conventional grinding pins, commonly applied for the grinding of steels, cast iron or some brittle materials. Super-hard grinding pins consist of diamond or cubic boron nitride (CBN) grains bonded by different types of binders, such as metal, galvanic, resin, vitrified, and hybrid [3]. Diamond pins are used in the machining of brittle materials (e.g. carbides, ceramics, glass), whereas CBN pins are suitable for grinding of steels. This is mainly due to the well-known diamond chemical affinity for iron which makes it possible for tool producers to manufacture and offer both diamond and CBN pins [4].

10.1016/j.promfg.2020.10.148

2. Digital data in technological process planning

The cutting ability of a grinding tool changes as tool wear progresses during machining, leading to a change in the tool's shape (the result of both grain and bond fracture), the loading of pores between grains, or the dulling of grain-cutting edges resulting from attritious wear [5,6,7,8]. In the case of tool shape change, the tool path should be corrected accordingly, in order to achieve the required accuracy of the machined product. A grinding pin can also be conditioned by different methods, to retrieve the required shape and proper cutting ability of grains. There is an increasing number of grinding tool conditioning processes: mechanical, thermal, chemical and hybrid [9,10]. However, mainly due to their relatively small dimensions and the overall expectations of minimizing production costs, grinding pins can also be used without conditioning by just adapting machining conditions (i.e. tool path or cutting velocity) to the new form/shape of the tool. This is particularly useful in the case of super-hard grinding pins, which are much slower to wear out than conventional ones. In this context, the digitization of grinding pin shapes may be used to plan machining tasks, as well as for CNC toolpath programming and the storage of digital data, etc.

Digitization techniques can be performed on-machine or using separate devices. Digital models of conditioned or brand-new pins are useful for simulating process conditions, taking into account the actual dimensions and shape of the grinding pin. Such models can also be used to modify the CNC programs on the basis of the digitalized tool geometry. The main applications of digital models of pins are divided into four groups:

- Adaptation of pins for specific machining conditions; in this case, a tool path correction, change of machining parameters or clamping conditions are taken into consideration.
- Research activities regarding workpiece or tool characteristics and their influence on process performance (e.g. surface roughness, tool wear analysis, etc.).
- Preparation of conditioning process (e.g. amount of material to remove, or conditioning tool path).
- Storage of digitized tools and their use in digital manufacturing (e.g., in the management of tools, process simulation, product development and presentation).

Current advances in computer science, increasing precision in reverse engineering and high computing power of modern PCs make it feasible and reliable the practical application of digital models in manufacturing environments.

Investigations concerning grinding tools have been traditionally focused on grinding wheels, mainly regarding tool wear, the influence of grinding parameters on surface roughness, process forces, performance of the process, and accuracy of machined parts. Nevertheless, since tool characteristics determine the safest and producer-recommended machining parameters (i.e. cutting speed, feed, infeed, etc.) [11] it would be of interest to have a digital model of the tool, as it was aforementioned.

On the other hand, few investigations have been dedicated to digitization of tools and, even less, to grinding pins. In recent research, Valiño et al. [12] used a laser micrometer to measure grinding pins and Magdziak and Wdowik [13] performed contact measurements on a CMM and a tool presetter. Alao and Konneh [14] applied a statistical approach for designing and analyzing the surface quality in precision grinding of silicon using grinding pins. Fan et al. [15] proposed an on-line system to measure grinding wheel wear based on an image of a grinding wheel taken on a charge-coupled device (CCD). Grinding wheel topography was studied by Darafon [16], who developed a measurement system for that purpose. In his work, the author divides measurements of grinding wheel topography into contact (e.g. profilometers, CMMs) and non-contact methods which, in turn, may be divided into non-optical (i.e. scanning electron microscopes, acoustic emission sensors) and optical ones (i.e. optical microscopes, auto-focusing systems) [16]. Moreover, Pan, Zhao and Guo [17] studied on-machine measurement of grinding wheels' surface topography by the use of a laser displacement sensor. Sutowski et al. [18] monitored the cylindrical grinding process by the use of a non-contact acoustic emission (AE) system. Also, the wheel loading phenomenon was studied by Adibi et al. through image processing [19].

In conclusion, there is a lack in literature concerning the use of digitized grinding pins and the application of digital data in technological process planning (TPP) although nowadays it is both feasible and very useful, as it was stated before. The following sections present selected methods of grinding pins digitization and the application of obtained data in TPP.

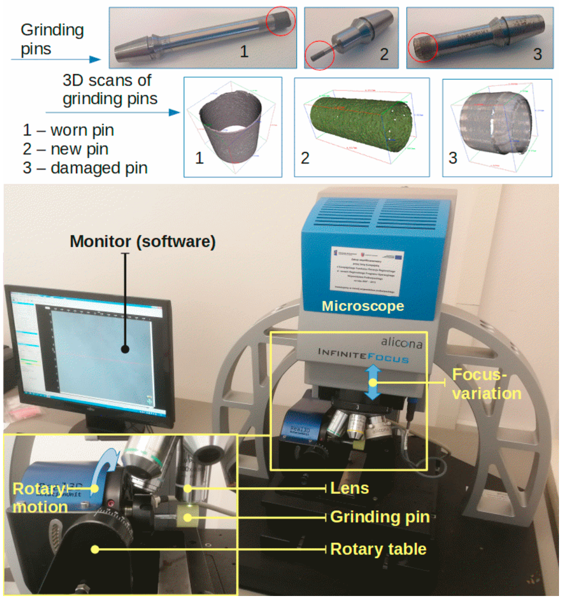


Fig. 1. Verification of grinding pin digitization by the use of focus-variation technique (Alicona's microscope InfiniteFocus Real3D).

3. Exemplary techniques of grinding pin digitization

Various contact and non-contact techniques of grinding pin digitization are presented in this section, and their capabilities and limitations described.

3.1. Application of optical microscopes

This section concerns optical measurements of grinding pins, using the focus-variation (FV) technique, described in ISO 25178 [20], which enables physical objects to be digitalized for further analysis and the application of obtained numerical data. Using an Alicona's InfiniteFocus Real3D microscope, a specimen (grinding pin) located under the attached objective lens was digitized (Fig. 1). Incident light rays are reflected by the specimen surface, pass through the objective lens, are bundled in the optics of the microscope and finally gathered by the sensor behind the beam-splitting mirror [21,22]. In order to detect 3D surface with the full depth of field (DOF), the precision optics are moved vertically, while small regions of the specimen are sharply imaged, due to the small DOF of the microscope optics [21,22]. In the case of a rotating (or rotationally-symmetrical) object, such as a grinding pin, the rotary table is also moved around its axis, providing a complete scanning which is transformed into a 3D model with the software provided by the microscope's producer [21,22,23]. With this software, the following exemplary measurements may be performed on a digitized grinding pin:

- Measurements of external contours of grinding pins, considering different cutting planes (Figs. 2a and 2d),
- Analysis of tool shape by visualization of distance from points on the tool surface to the tool axis (Fig. 2b),
- Measurements of 3D features (Fig. 2c),
- Surface texture measurements (Fig. 3).
- Export, using different file formats and their utilization (measurements performed on digital twins) in PC apps such as CAD, surface analyzers, calculators, etc.

Fig. 1 shows a grinding pin digitization process on the FV microscope. The grinding pins can be measured on different states (new pins, worn pins and damaged ones), and the obtained data analyzed using the microscope's software. The results of such measurements depend on the set-up parameters of the measurement, such as vertical and horizontal resolution, light adjustment, and measuring area.

The main areas of application of FV techniques which are relevant for TPP, are:

- Volume and tool path definition for pins conditioning.
- Tool wear analysis and influence on tool life when producing many parts (if tool changes are required by TPP).
- Surface texture analysis of pins for prediction of surface texture of workpiece.
- Digitization of very small pins for micro-grinding applications.
- Tool-paths correction/programming for very expensive grinding pins which cannot be easily conditioned.
- Product development, regarding grinding pin CAD modelling.
- Data storage and sharing with other software tools.
- Visualization of tools and preparation of digital attachments to the documentation of TPP.
- Preparation of virtual reality and reverse engineering environments, aiming at distance TPP.

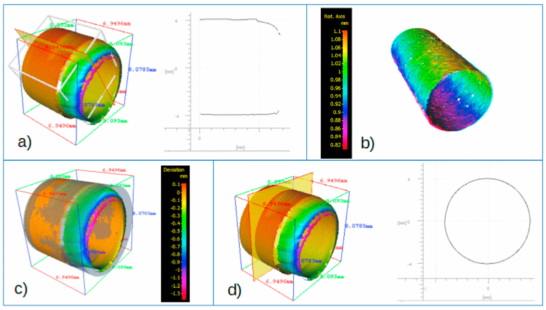


Fig. 2. Exemplary measurements of grinding pins with Alicona's FV microscope: a) outer profile along tool axis, b) distance from pin's point to the axis of rotation, c) 3D form measurement, d) cross section outer profile.

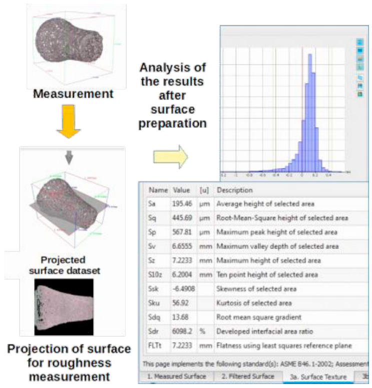


Fig. 3. Surface texture measurement of grinding pin with Alicona's FV microscope.

3.2. Application of tool presetters

Tool presetters are contact or non-contact devices used in measurement of tools clamped to toolholders before their application in CNC machine tools. The results of tool's measurements are sent to CNC machine tool and used as work and tool offsets. Common measured parameters of tools are the length, radius and wear of rotating tools (i.e. end mills, drills, spot drills and shell mills), and the dimensions of turning tools (e.g. X, Z, corner radius and corner wear offsets). The non-contact devices, enabling optical measurements of tools, can also be used for digitizing grinding pins. An example is Mahr MarPreset 2500 TMM tool presetter shown in Fig. 4, which allows the outer profiles of grinding pins to be recorded with the attached camera and a digital model of the tool to be created. The size of a pin's diameter is only limited by the axial movements of the camera and its geometry. The recorded profile can be saved as a DXF file and shared with other CAD software. Although the profile is a 2D image on one plane, multiple measurements of the outer contours may be acquired by the angular positioning of the tool clamping unit, extending knowledge about the geometry of the tool. It can be stated that, due to the rotary movement of the grinding pin in machining, the shape of a worn tool is rotationally symmetrical. Therefore, the profiles measured in different planes are similar. Only in the case of a damaged tool should multiple measurements be performed, in order to obtain more detailed data regarding the geometry. The measurements allow different forms of the pin's wear, such as edge rounding and loss of material on the lateral surface, to be recognized. The data acquisition process is limited because the DXF file contains a cloud of points, and the multiple measurements of the same region of the tool lead to overlapping points, which must be edited in CAD programs.

The main applications of this device in TPP of grinding operations with the use of pins are the following: measurements of pins contours (acquisition of CAD files), editing in CAD and application in NC codes used in CNC machine tools; preparation of digital 3D models of pins on the basis of obtained profiles, CAD modification of the profiles for process simulation; research on the wear, on the basis of the obtained profiles.

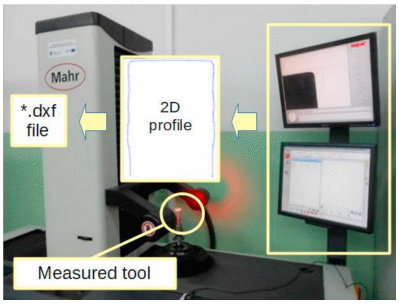


Fig. 4. Measurement on MarPreset 2500 TMM tool presetter [24].

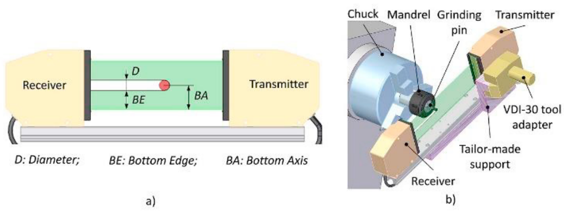


Fig. 5. a) LM measurement parameters; b) set-up of the LM in the CNC lathe.

3.3. Pin measurement with a laser micrometer

A laser micrometer (LM), LS-7000 by Keyence, was considered for non-contact on-machine measurement of grinding pins (Fig. 5a). Its working features are within Table 1. The LM consists of a transmitter of parallel high-intensity light and a receiver, capable of precisely detecting the shadow of an object located between both units. As a result, the dimensions of the object can be displayed and output for further analysis.

Table 1. Basic technical data of Keyence LS-7000 micrometer.

Name (unit)	Value
Measuring range (mm):	0.5 to 65
Measuring accuracy (μm):	± 3
Repeatability (2σ) (μm):	± 0.2
Max. sampling rate (Hz):	2400

The measurement tests of the grinding pin were conducted on a CNC lathe, where the pin was clamped in the lathe chuck (Fig. 5b) and the LM was set up in a lathe turret, and calibrated.

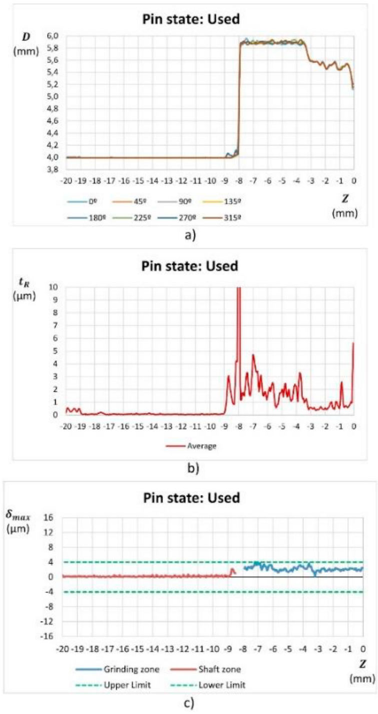


Fig. 6. a) Grinding pin profile; b) average roundness tolerance (t_r); c) maximum deviation (δ_{max}) of the tool axis with respect to the rotation axis.

Two different procedures were used. Firstly, the diameter (D) and bottom edge distance (BE) (Fig. 5a) were measured every 0.05 mm along 20 mm in the negative Z direction, over the whole cutting length and partially along the pin shaft, so that the longitudinal profile could be extracted. Next, the pin was measured repeatedly several times at each Z position, while it was rotating at a constant speed, taking the ranges of D and BE, to analyze roundness and coaxiality between the shaft and the grinding surface. All measurements were registered externally in a PC.

The longitudinal pin profile was represented as the evolution of the pin diameter along the tool length (D in Fig. 6a), the pin roundness at any section (t_r in Fig. 6b) and the coaxiality between the grinding area and the pin shaft (δ_{max} in Fig. 6c).

It can be noticed that the tool wear in the first 3.5 mm of the tool length coincides with the axial depth of cut used in the grinding process with this pin (Fig. 6a). Fig. 6b shows a better roundness in the worn zone, due to the symmetrical distribution of wear around the pin as it rotates during machining. Finally, Fig. 6c shows a fine coaxiality of the shaft zone with the rotation axis, whereas the grinding area does not ($t_{\mathrm{C}} = 8.2$ µm). Since this measurement equipment is intended for continuous production lines, there is only a simple application for exporting measurement parameters through a serial port to an external computer, where all the data are collected into an Excel spreadsheet. Data analysis may be performed by any commercial software.

As a conclusion, the LM was able to perform on-machine macrogeometric measurement of grinding pins to overcome non-productive time, required if the inspection were carried out off-line. Although, in this case, the study was performed in a CNC lathe, it becomes a fast and economical inspection method, easily to be integrated in a CNC grinding machine similar to a laser tool presetter.

3.4. Application of CMMs

The geometry of grinding pins can be reconstructed by using non-contact measuring probes cooperating with coordinate measuring machines (CMMs). CMMs are still very popular measuring systems that are available in the industry. They are used mainly because of their high accuracy [25]. An example of a non-contact measuring probe is the LineScan 2-8 probe. The measurement program for the scanning process, with the use of the abovementioned measuring probe, can be created by means of the Calypso software.

Many setting parameters of the LineScan measuring probe have an influence on the final accuracy of non-contact coordinate measurements, e.g. exposure time, laser power, scanning speed, nominal points, measuring field, qualified surface points (QSP) and gridded scan lines (QSL). For example, the settings concerning laser power depend on the types of reconstructed or measured surfaces. In the case of white surfaces, low laser power is sufficient. For all other surfaces, high laser power is recommended [26]. In the case of the LineScan 2-8 probe, the measuring range is equal to 8 mm. Such a measuring range can be applied during measurements of grinding pins without the need to change the positions of the measuring probe in the Z axis of a CMM, because of the simple geometry of the considered digitalized object. QSPs are calculated on the basis of the raw scan lines (RSL). QSPs are compressed points evaluated using averaging.

Moreover, the Calypso software has many settings which influence the final results of measurements conducted by using the LineScan probe. The user of a CMM has the opportunity to: perform the best-fit process of measured data to nominal data; filter or eliminate measurement points; use the region filter; conduct triangulation and check the accuracy of a measured product by comparing the results of measurements to the CAD model of an investigated object.

In the case of scanning grinding pins, performing the filtration and the elimination of measurement points, as well as creating a triangulated surface, may be very useful when preparing models of considered objects. The region filter enables erroneously scanned points, resulting from using fixtures, optical reflections or other negative influences, to be removed [26]. The *eliminate points* function also helps the user of a CMM to delete wrongly measured points, which may be located on surfaces of other objects not belonging to an investigated grinding pin. Moreover, the operator of a CMM can reduce the number of scanned points and/or decrease the overlapping of points by performing the filtration process.

The advantages of using the LineScan measuring probe are as follows: high speed of measurements, high point density and wear resistance. On the other hand, the main disadvantages are: shadowing effects, surface dependence and limited geometrical evaluation by using the Calypso software [26].

In order to verify the usefulness of the LineScan measuring probe in the case of the reconstruction process of the selected grinding pin, coordinate measurements of the chosen object were taken by using the CMM ACCURA II (Fig. 7). Moreover, Fig. 7 shows the grinding pin, which was measured by using the non-contact method, based on laser triangulation. The results of the scanning process of the grinding pin are illustrated in Fig. 8.

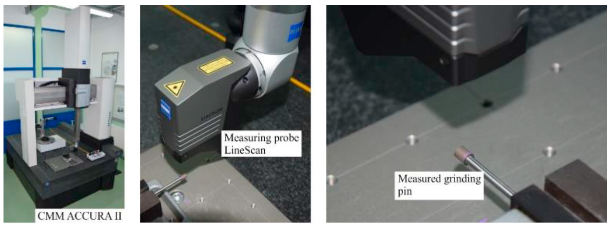
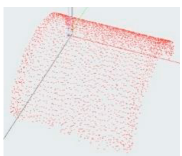


Fig. 7. The measured grinding pin and the applied measuring system.



458.531283	-1034.133571	-599.869296
458.531466	-1034.108831	-599.803415
458.508853	-1034.043574	-599.649110
458.557806	-1033.949418	-599.465646
458.555360	-1033.853972	-599.304536
458.554872	-1033.740234	-599.138112
458.499771	-1033.620778	-598.984027
458.552868	-1033.494805	-598.841629
458.500531	-1033.343595	-598.692930
458.523072	-1033.287891	-598.644475
458.499894	-1033.034046	-598.445092
458.552726	-1032.868783	-598.337689
458.552881	-1032.701696	-598.244238
458.499758	-1032.519472	-598.158601
458.552964	-1032.327527	-598.082967
458.552631	-1032.128858	-598.020808
458.552640	-1031.937714	-597.974614

Fig. 8. Results of the measurement process of the selected grinding pin.

Coordinate measurements were taken in the manual mode by using WBScan measurement software. However, the scanning process of the considered grinding pin can be conducted in the automatic mode.

3.5. Application of a laser triangulation sensor on a CMM

Based on laser triangulation on a CMM, another non-contact measuring probe was used to digitize two grinding pins of identical type, one of which was in a new state, whereas the other was worn after the machining process. In this case, the sensor was a laser scanner by Hexagon, model HP-L-10.6T, mounted on a motorized indexable head, PH10MQ, by the same manufacturer, allowing the probe to inspect features from different angles. The CMM was a DEA Global Image. The digitizing process was controlled by means of the software, PC-Dmis CAD++, with the Laser Interface utility. Table 2 shows the main characteristics of the laser probe.

Table 2. Basic technical data of the HP-L-10.6T triangulation laser probe.

Name (unit)	Value
Laser type:	690 nm (type 2, visible red)
Depth of field (mm) / Stand-off (mm):	±30 / 170
Accuracy (ISO 10360-8:2013):	
PForm.Sph.D95%:Tr:ODS (MPL) (μm):	34 (probing dispersion value)
PForm.Sph.1x25:Tr:ODS (MPE) (μm):	22 (probing form error)
Warm-up time (min):	20
Data rate (pts/s):	30,000
Dimensions (L × W × H) (mm)	134 × 72 × 60 (98)
Weight (g)	379

The grinding pins digitization was performed by means of an automatic routine generated from the CAD model with PC-Dmis CAD++. For a complete 3D representation of the pins, five orthogonal orientations of the probe were considered. Next, the grinding pins were clamped vertically in a vise allocated on the CMM table, and an inspection procedure was performed with a contact probe, in order to align the pins with respect to the CAD model. The next step was to set up the laser probe and performing the qualification tests on a calibrated sphere under the five orientations planned and after waiting for the required laser warming-up period of 20 minutes (Fig. 9a). Once calibrated, scanning of the pins was conducted under the five probe orientations, covering the whole surface (Fig. 9b). Each pin was represented by merging the five point clouds, which were filtered to remove spurious points and to meet a uniform distribution of points at overlapping areas (Fig. 10a). The main filters available are based on controlling the distance among neighboring points and keeping the incident laser angle below a reasonable limit.

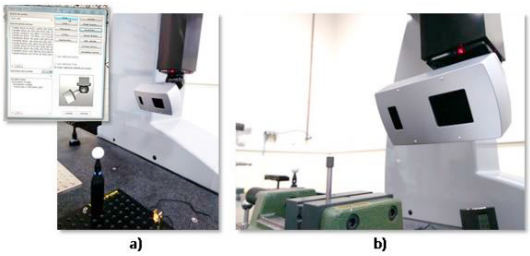


Fig. 9. a) Qualification of the laser probe; b) digitizing of a grinding pin.

After post-processing the point clouds (Fig. 10a), the PC-Dmis functions enable to perform the metrological analysis. Among the main inspection activities, the following stand out:

- Longitudinal profile extraction by performing a section with a plane containing the symmetry axis. This can be performed for different orientations of the cutting plane, so it is possible to compare the profile to the CAD model at different orientations around the grinding pins (Fig. 10b).
- Cross sections, perpendicular to the symmetry axis, at different locations from a reference plane (Fig. 10c). This profile enables information regarding tolerances of circular features (i.e. roundness or radial runout), as well as the evolution of tool diameter along its length, to be extracted. The latter can be useful for implementing tool compensation on the CNC grinding machine.
- CAD analysis, to determine 3D deviations of the point clouds with respect to the model (Fig. 10d). This is very useful for realizing the volumetric evolution of tool wear.

The digitized point clouds can be exported to formats such as XYZ (text), IGES or PSL (PolyWorks) to be processed by other software packages. The inspection reports can also be exported to Excel or XLM formats. Input information to PC-Dmis can also be in CAD formats (STL, STEP, IGES, Parasolid, Catia, etc.), as well as data from TXT or Excel. All this allows the information to be adapted from/to TPP tools.

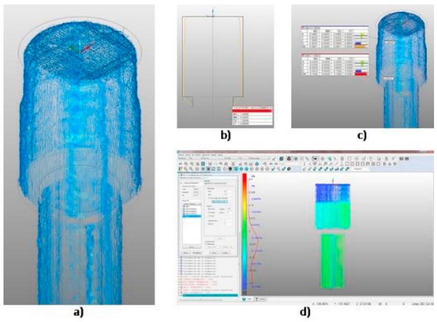


Fig. 10. a) 3D points of the worn grinding pin; b) longitudinal profile; c) dimensional and tolerance analysis of two cross sections; d) distribution of 3D deviations of the digitized points with respect to the CAD model.

Fig. 11. Application of measuring arm: a) measuring arm, b) digitized grinding pins, c) software settings.

3.6. Application of measuring arms

Measuring arms can be applied in contact and non-contact measurements of objects. This technique is very useful for measurements that are performed in different places. In the case of grinding pins, the use of non-contact measurement is possible. The measuring range of the arm plays an important role in data acquisition. Fig. 11 presents the measuring arm, Metris MCA II 2400 M7. The scanning process is enabled by the laser head and is run manually (an operator scans an object, holding the head). The main technical data of the used device are presented in Table 3. The preliminary measurements revealed that it is possible to obtain only part of the lateral surface of grinding pins (Fig. 11). The measuring range of the device is supposed to be the main reason for this limitation. The obtained surfaces may be exported by the use of the export function and several formats, such as: *.3ds, *.aac, *.cta, *.dxf, *.ibl, *.iges, *.stl, etc. This device can be used in the TPP of grinding, mainly for the on-machine inspection of tools, taking into account the measuring range limits.

Table 3. Basic technical data of the Metris MCA II 2400 M7 Articulated Arm with MMD100 Laser Scanner [27].

Name (unit)	Value
Measuring range (m):	2.4
Point repeatability (mm):	0.031
Volumetric accuracy (mm):	0.042
Arm weight (kg)	11.9
Laser Scanner	
Stripe width (mm)	100
Measuring range (mm)	100
Stand-off distance (mm)	150
Min. point resolution (mm)	0.065
Sensor weight (approx) (g)	400

Table 4. Basic technical data of the Nikon iNEXIV VMA-2520 benchtop video measuring system [28].

Name (unit)	Value
Stroke X x Y x Z (mm):	250 x 200 x 200
Minimum readout (µm):	0.1
XY MPEE1 (µm):	2+8L/1000
XY MPEE2 (µm):	3+8L/1000
Z MPEE1 (µm)	3+L/50
Camera:	1/3-in. 3CCD color
Working distance (mm):	73.5
Magnification:	0.35 to 3.5x - optical 12 to 120x - on screen
FOV size (mm):	13.3 x 10 to 1.33 x 1
Video resolution (pixels):	640 x 480
Touch probe:	Renishaw® TP20
Maximum workpiece weight (kg):	15

3.7. Application of optical microscopes

Microscopy plays a crucial role in different measurement tasks. The camera recording application enables automation of the measurement process. Table 4 presents technical data of the Nikon iNEXIV VMA-2520 benchtop video measuring system, which was used for the experiments. The microscope is presented in Fig. 12. It can be observed that the outer profile of a tool is recorded after the definition of the measuring area and the parameters of the measurement process. The obtained outer contours can be exported to a CAD environment for analysis. The following export options may be used: CSV format file, NC format file, DMIS format file and DXF files.

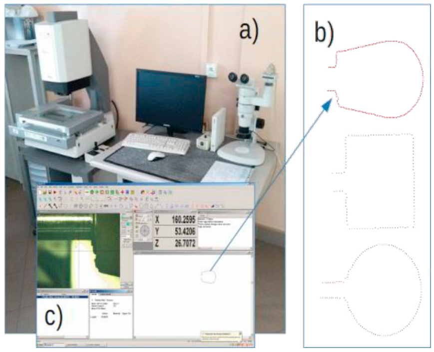


Fig. 12. Application of optical microscopes: a) Nikon iNEXIV VMA-2520, b) digital models of various grinding pins, c) microscope's software.

3.8. Application of devices used in measurements of contours

This contact measurement technique enables the geometry of contours, as regards various objects, to be obtained. A study was made of whether the Mahr MarSurf XC 20 device is suitable for measurements of grinding pin contours. The basic technical data of this device are presented in Table 5. The device and exemplary contours obtained in the experiment are presented in Fig. 13.

Table 5. Basic technical data of the Mahr MarSurf XC 20 with PCV 200 contour measuring station [29].

Name (unit)	Value
Traversing lengths (mm):	0.2 ÷ 200
Measuring range in Z (mm):	50
Resolution in Z, relative to a stylus tip (µm):	0.38
Resolution in Z, relative to a measuring system (µm):	0.04
Tip radius (µm):	25
Contacting speed in Z (mm/s):	0.1 ÷ 1
Probe arm length (mm):	350
Positioning speed in X (mm/s):	0.2 ÷ 8
Positioning speed in Z (mm/s):	0.2 ÷ 10
Guide deviation over 200 mm (µm):	< 1
Measuring speed (mm/s):	0.2 ÷ 4
Measuring force (mN):	1 ÷ 120

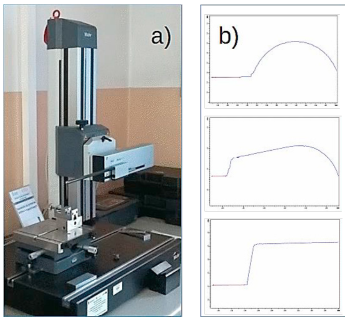


Fig. 13. Device used in measurements of contours: a) Mahr MarSurf XC 20 with PCV 200 contour measuring station, b) exemplary contours obtained.

4. Conclusion

Grinding is the process which is used for both rough and finishing operations. Grinding pins may be controlled by the use of various contact and non-contact methods. This paper presented some selected methods of grinding pin digitization. It can be stated that pins' digital twins can be used in both industrial environments and academic research. Industrial enterprises may find them useful in TPP.

Both contact and non-contact methods allow the digital models of grinding pins to be obtained. The focus-variation technique is useful in the digitization of grinding pins, although the measurement time is long. CMM measurements allow the geometry of pins to be obtained, in both contact and non-contact procedures, but they also need the existence of a CMM in the manufacturing environments. Laser micrometers, if used as on-machine measurement technique, can lead to the automation of different procedures (e.g. wear can be measured without unclamping the tool from the machine tool). Tool presetters may also be utilized, and it is possible for the geometry of tools to be recorded and modified for different applications. The presented microscopic investigation also revealed the usefulness of such measuring techniques in data acquisition. The contours of tools may be recorded using this technique.

It should also be stated that the point clouds resulting from a 3D digitizing process will be similar, regardless of the technique used. Only the quality of the point clouds will be dependent on the precision of each technique. The dimensional analysis of a point cloud can be performed with different software applications (i.e., Alicona's software, Geomagic, or even in Matlab), so the information for process planning depends more on the software capabilities than on the digitizing technology itself.

Acknowledgements

The concept of the content of this paper and the part of the research regarding the literature analysis, description of selected devices were performed within the project, "Science internship for the investigations of digitalization in manufacturing", in the Bekker Programme, financed by The Polish National Agency for Academic Exchange (www.nawa.gov.pl). The abovementioned project was carried out at the University of Stavanger in Norway.

References

[1] Abele E, Altintas Y, Brecher C. Machine tool spindle units. CIRP Annals 2010;59:781–802.
[2] Cao H, Zhang X, Chen X. The concept and progress of intelligent spindles: A review. International Journal of Machine Tools and Manufacture 2017;112:21–52.
[3] Kopac J, Krajnik P. High-performance grinding—A review. Journal of Materials Processing Technology 2006;175:278–284.
[4] http://www.inter-diament.com.pl/ (accessed 17.06.2020).
[5] Hwang TW, Evans CJ, Whitenton EP, Malkin S. High Speed Grinding of Silicon Nitride With Electroplated Diamond Wheels, Part 1: Wear and Wheel Life. J. Manuf. Sci. Eng 1999;122:32–41.
[6] Hwang TW, Evans CJ, Malkin S. High Speed Grinding of Silicon Nitride With Electroplated Diamond Wheels, Part 2: Wheel Topography and Grinding Mechanisms. J. Manuf. Sci. Eng 1999;122:42–50.
[7] Liao TW, Li K, McSpadden SB, O'Rourke LJ. Wear of diamond wheels in creep-feed grinding of ceramic materials I. Mechanisms. Wear 1997;211:94–103.
[8] Liao TW, Li K, McSpadden SB. Wear mechanisms of diamond abrasives during transition and steady stages in creep-feed grinding of structural ceramics. Wear 2000;242:28–37.
[9] Wegener K, Hoffmeister H-W, Karpuschewski B, Kuster F, Hahmann W-C, Rabiey M. Conditioning and monitoring of grinding wheels. CIRP Annals 2011;60:757–777.
[10] Żyłka Ł, Babiarz R. Dressing process in the grinding of aerospace blade root. J Mech Sci Technol 2017;31:4411–4417.
[11] http://www.comegui.com/wp-content/uploads/pdf/INTERNAL%20GRINDING.pdf (accessed 17.06.2020).
[12] Valiño G, Wdowik R, Misiura J, Zapico P. Non-contact measurement of grinding pins by means of a 2D laser micrometer. Procedia Manufacturing 2017;13:534–541.
[13] Magdziak M, Wdowik R. Contact and Non-contact Measurements of Grinding Pins. MATEC Web of Conferences 2015;35:02004.
[14] Alao A-R, Konneh M. An experimental study on precision grinding of silicon using diamond grinding pins. International Journal of Materials Engineering Innovation 2011;2:325–345.
[15] Fan K-C, Lee M-Z, Mou J-I. On-Line Non-Contact System for Grinding Wheel Wear Measurement. Int J Adv Manuf Technol 2002;19:14–22.
[16] Darafon A. Measuring and Modeling of Grinding Wheel Topography. Dalhousie University, Halifax, Nova Scotia 2003.
[17] Pan Y, Zhao Q, Guo B. On-machine measurement of the grinding wheels' 3D surface topography using a laser displacement sensor. 7th International Symposium on Advanced Optical Manufacturing and Testing Technologies: Advanced Optical Manufacturing Technologies. Harbin 2014.
[18] Sutowski P, Nadolny K, Kaplonek W. Monitoring of cylindrical grinding processes by use of a non-contact AE system. Int. J. Precis. Eng. Manuf. 2012;13:1737–1743.
[19] Adibi H, Rezaei SM, Sarhan AAD. Grinding Wheel Loading Evaluation Using Digital Image Processing. J. Manuf. Sci. Eng 2014;136:011012.
[20] ISO 25178-606:2015 Geometrical product specification (GPS) -- Surface texture: Areal -- Part 606: Nominal characteristics of non-contact (focus variation) instruments.
[21] Danzl R, Helmli F, Scherer S. Application of Contemporary Non-Destructive Testing in Engineering. 10th Int. Conf. Slovenian Society for Non-Destructive Testing. Ljubljana 2009.
[22] Alicona Imaging GmbH, IFM Manual G4 3.5.1.5 2011;
[23] https://www.alicona.com/en/focus-variation/ (accessed 17.06.2020).
[24] Wdowik R. Analysis of ultrasonic assisted grinding of alumina and zirconia based ceramic materials. Rzeszów University of Technology, Rzeszów 2015.
[25] Li Y, Gu P. Free-form surface inspection techniques state of the art review. Computer-Aided Design 2004;36:1395–1417.
[26] Zeiss C. Documentation of the LineScan measuring probe.
[27] http://www.metris3d.hu/termekeink.html (accessed 17.06.2020).
[28] https://www.nikonmetrology.com/en-gb/product/inexiv-vma-2520 (accessed 17.06.2020).
[29] https://hammondcompany.com/wp-content/uploads/2017/09/marSurfXC2.pdf (accessed 17.06.2020).