

MEASUREMENT TECHNIQUES USED FOR ANALYSIS OF THE GEOMETRIC STRUCTURE OF MACHINED SURFACES

Magdalena NIEMCZEWSKA-WÓJCIK¹, Artur WÓJCIK²

¹ Cracow University of Technology, Institute of Production Engineering, Al. Jana Pawła II 37, 31-864 Cracow, Poland, niemczewska@mech.pk.edu.pl or mnw.kipp@gmail.com,

² University of Agriculture in Cracow, Department of Mechanical Engineering and Agrophysics

Abstract:

The quality of machined surfaces, resulting from the manufacturing process and conditioning their functionality, is determined by the surface geometric structure (SGS). There is a close relationship between surface properties, shape, qualitative imaging of the surface topography, technique and technology employed for machining purposes. If a given surface is to have practical applications in engineering, the correct technological process needs to be chosen.

In the paper, various techniques used for measuring of the surface geometric structure were briefly described. The results of the study which were obtained from different measuring devices like Atomic Force Microscopy (AFM), Scanning Electron Microscopy (SEM), Optical Interferometer (WLI), and Optical Microscopy (OM) were presented. Each measuring technique provided different, yet complementary data on the topography of the machined surfaces. Owing to this, a full characterization of the geometric surface structure of the machined surfaces was enabled, including surface properties resulting from the employed technological process.

Based on the taken measurements, the characteristics of chosen devices (measurement techniques) were made with an indication how they can be applied to the analysis of the surface geometric structure (SGS). The devices which are considered to give the best view of examined surfaces and allow a thorough analysis of their irregularities were then indicated.

Keywords: surface metrology, measurement techniques, SGS analysis

1. INTRODUCTION

The surface geometric structure is the result of the machining process of products. The analysis of the SGS is necessary and essential for assessing the surface features. The analysis of the SGP consists of three parts: describing measurement methods (techniques), presenting a surface, and conducting a parametric assessment of the surface.

The basis for the analysis of the topography of a given surface is the selection of appropriate measurement techniques that will enable proper description of this surface and subsequent evaluation of its shape based on obtained images and geometric parameters. There are many

techniques for measuring the surface geometric structure – Fig. 1.

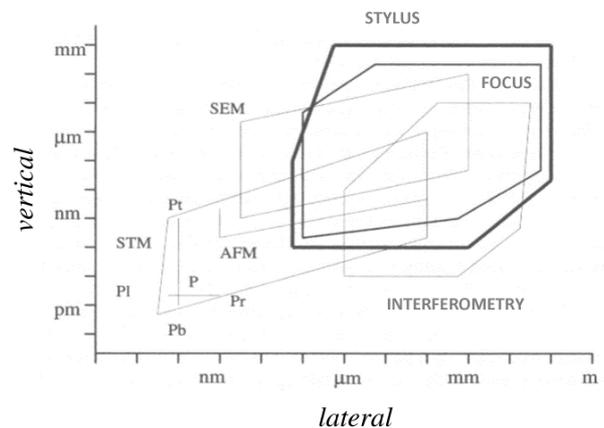


Fig.1: Scope and resolution of the 3D surface measuring methods [1,2]

None of them, however, if used alone, can give complete description of the examined surfaces. It is advisable to employ a variety of techniques to obtain complementary information on the surface topography, which will facilitate interpretation of obtained results [3].

The presentation of a machined surface involves connecting the measured/scanned points so that the obtained image represents the tested surface [4]. There are two ways to present a measured surface: it can be shown with the use of a contour map as well as using an isometric view created with an axonometric projection.

The assessment of a machined surface can be quantitative as well as qualitative. A quantitative assessment requires the determination of the parameters describing the measured surface. This is possible due to the developed hallmarks of the surface geometric structure (3D), which, similarly to the 2-dimensional profile (2D), were divided into functions and parameters; the details were discussed, inter alia, in the following papers [5-8].

A quality assessment is based on the analysis of images which are obtained from surface measurements taken with the use of a variety of devices (measurement techniques).

2. MATERIALS AND METHODS

2.1 Charakterystyka badanych powierzchni

The surfaces of elements made of tool steel (material Type A) and oxide ceramic (material Type B) were studied.

The surfaces of the elements made of tool steel were subject to electric discharge machining (further referred to as EDM). The EDM process was performed using copper electrodes; cosmetic kerosene was used as a dielectric liquid. Pulses were delivered by a generator based on transistor control which allowed to control the energy of single discharges

The surfaces of the elements made of oxide ceramic were subject to an abrasive process (lapping). The diamond micropowder lapping paste was used as an abrasive. During the machining process, the granulation of diamond micropowder was being changed until the desired surface had been achieved.

2.2 Metodyka badań

The geometric structure of machined surfaces obtained from the machining process (erosive and abrasive one), were tested with the use of the following four research devices (Department of Tribology, Institute for Sustainable Technologies - National Research Institute in Radom): optical microscopy (OM), scanning electron microscopy (SEM), the atomic force microscopy (AFM), and the white light interferometer (WLI).

The optical microscopy (OM) with digital video recording allows to capture images of sample surfaces at different magnifications and directly record consecutive fields of view.

The advantage of the OM is that, compared with other techniques, it allows observation of the large areas of a surface. On the other hand, it fails to show the features of surfaces described by low roughness parameters, or machined surfaces characterized by high technological quality, which may be considered as the disadvantage of the device.

The parameters during research: the lens x20 (magnification x200).

The scanning electron microscopy (SEM) allows, among others, the qualitative analysis of the surface irregularities.

The working principle of the SEM (Fig. 2) is the emission of secondary electrons from a sample, which is excited by the incident electron beam directed onto the tested area. The secondary electrons are formed by collisions of the incident electrons with the sample atoms which release electrons with lower energy [9].

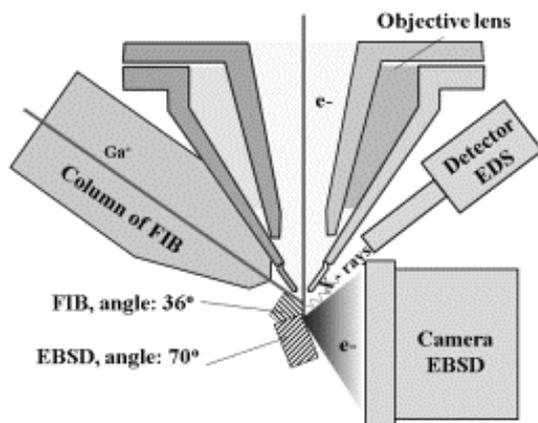


Fig.2: The measurement principle of SEM

The advantage of the SEM is a very good resolution and the quality of obtained images. The disadvantages are the necessity of using a vacuum and a small range in the Z-axis. The parameters during research: non-contact mode, magnification x200 for material Type A and x2000 for material Type B.

The atomic force microscopy (AFM) allows to capture images of surfaces with the resolving power of the nm order, thanks to the use of the interatomic van der Waals forces. The surface is scanned by a sharp tip which is attached to the end of a flexible lever (the cantilever). In this method, the laser beam is reflected off the back of the cantilever and collected by the photodiode detector [4,9]. AFM works in two modes: contact and non-contact.

The operating principle of the AFM (Fig. 3) is based on the measurement of impact forces the cantilever has upon the tested surface while it is being scanned.

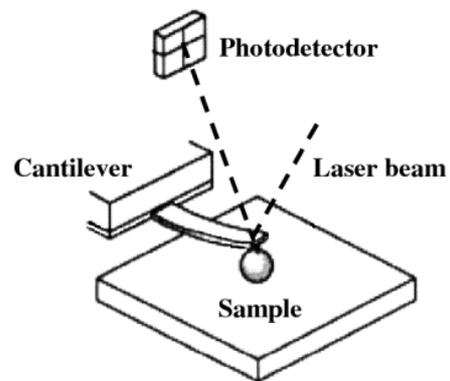


Fig.3: The measurement principle of AFM

The advantage of the AFM is a very good resolution in the z-axis and the high quality of images; whereas its drawback is the small measurement range - the scanning area is no larger than 100x100µm.

The parameters during research: non-contact mode, the scanning area 30x30µm.

The optical interferometer allows to capture the surface geometric structure of an ultra-high vertical resolution, up to 10pm (regardless of the applied magnification) [4].

Its operating principle (Fig. 4) is based on the use of one of the varieties of white light interferometry (WLI), so-called scanning broadband interferometry (SBI).

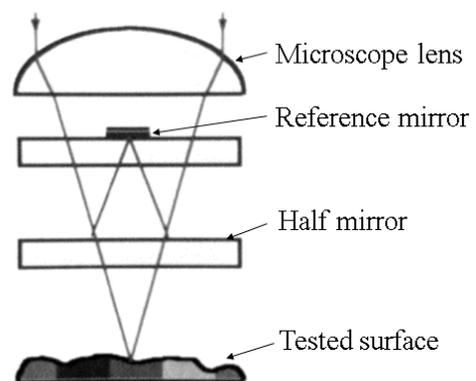


Fig.4: The measurement principle of WLI

The advantage of the *WLI* is a large measuring range as compared with the aforementioned devices, great accuracy of scanning, and a good resolution. The disadvantage, however, is a relatively small measurement area.

The parameters during research: the sensitivity in the Z-axis is 0.01nm, the scanning area 1.65x1.65mm, the Mirau lens x10.

The use of different measurement devices (techniques) allowed to collect additional information on the surface characteristics (including irregularities) formed in the machining process as well as enabling the analysis and interpretation of the results.

For the purpose of a quantitative assessment of the machined surface, the sophisticated metrology software was used (*Talyscan* and *Motic* program).

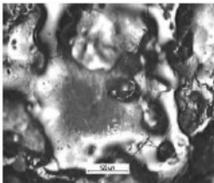
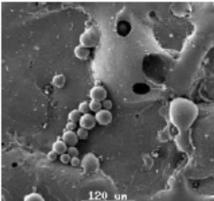
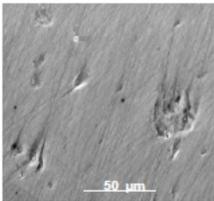
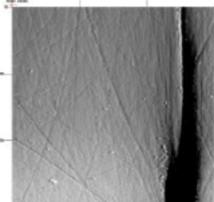
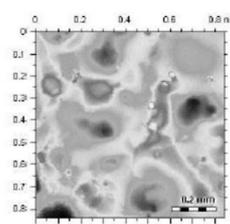
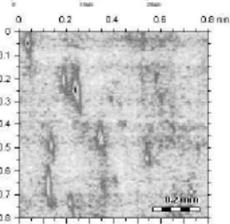
3. RESULTS AND DISCUSSION

The machined surfaces obtained from the manufacturing process were analyzed qualitatively and quantitatively. Selected results were shown in two tables.

Table 1 contains the images obtained with the use of four research devices. The results allow to evaluate the quality of the machined surfaces.

Table 2 presents the parameters describing the condition of the machined surfaces, which allows a quantitative assessment of the machined surfaces

Table 1: Measurement results – pictures

		MATERIAL	
		Type A	Type B
MEASUREMENT DEVICES	OM		No result
	SEM		
	AFM	No result	
	WLI		

In the images displayed in Table 1 the differences between the machined surfaces, which result from the different treatment methods, are shown.

On the surfaces obtained from the electric discharge machining (*Type A*), the various types of surface irregularities can be seen. They take on the form of craters (cupped concave), cavities (empty or filled with the treatment products), remelted areas, burrs (the material elements resembling droplets), a few cracks (surface discontinuities) and spheroids (balls of material).

The surface geometric structure formed in the *EDM* process is the result of mutually overlapping craters (resembling the spherical bowls) and the other earlier mentioned irregularities.

On the surfaces subject to lapping (*Type B*), characteristic scratches left by the abrasive, hard diamond micrograins, can be seen. There are some traces of the previous processing (grinding), resulting from the short time of lapping of the samples. In addition, many crumbled bits were reported on the machined surface, which results from the material properties (high hardness, and thus increased brittleness).

During the research, it turned out that not every type of a machined surface could be measured with the use of any device. To some extent, it has to do with the topography of the machined surfaces (too rough or too smooth) and the limitations of the measuring devices. For this very reason, no measurement results have been obtained from *AFM* for the surface of *Type A* (too high surface roughness) and from *OM* for the surface of *Type B* (too smooth surface, barely visible surface defects).

Table 2: Measurement results – roughness parameters and dimensions

		MATERIAL		
		Type A	Type B	
		<i>Roughness parameters</i>		
METROLOGY SOFTWARE	<i>Talyscan</i>	$S_q = 12.60 \mu\text{m}$	$S_q = 0.0324 \mu\text{m}$	
		$S_z = 65.60 \mu\text{m}$	$S_z = 0.435 \mu\text{m}$	
		$S_r = 79 \mu\text{m}$	$S_r = 0.613 \mu\text{m}$	
		$S_{sk} = 0.12$	$S_{sk} = -3.66$	
		$S_{ku} = 2.67$	$S_{ku} = 35.60$	
		$S_{tr} = 0.966$	$S_{tr} = 0.396$	
		$S_{ds} = 29245 \text{ 1/mm}^2$	$S_{ds} = 2123 \text{ 1/mm}^2$	
	<i>Average dimensions of the surface features [μm]:</i>			
	<i>Motic</i>	(radius)	• Crumbles (diameter): 2.7÷4.8	
		• Craters: 26.5	• Traces of the grinding (length): 50÷150	
	• Cavities: 16	(width): 16÷32		
	• Spheroids: 21			

In order to gather information and conduct a quantitative assessment of the machined surfaces, two types of sophisticated metrology software were used. From the data presented in Table 2 and the images shown in Table 1, it can be inferred that the surfaces have a different geometric structure.

The roughness parameters of the machined surface measured with the use of the *WLI* were obtained with the Talyscan v.6.1. program.

On the surface measured using the *WLI*, we cannot see the surface irregularities which emerged on the surface when it was measured with the scanning electron microscopy *SEM*. Taking measurements of these irregularities (features) was possible due to the Motic v.2.0. program.

Both white light interferometry *WLI* and scanning electron microscopy *SEM*, providing complementary information on the samples, allowed to make a comprehensive analysis of the machined surface

SEM gives a real image of the measured surface with all its irregularities, which allows a qualitative assessment of the machined surfaces; whereas a quantitative assessment of these surfaces is enabled by the use of *WLI* and the sophisticated metrology software.

4. CONCLUSIONS

This paper offers a short overview of selected measurement devices (techniques) useful in the analysis of machined surfaces. Some capabilities of metrology software facilitating the analysis and assessment of *SGS* were shown as well. It should be noted that:

- Optical Microscopy (OM): allows a measurement of the surfaces characterized by large roughness; furthermore, it shows huge surface areas, thus exposing more defects, including wear products deposited on these surfaces (see the another work of the authors [10]);
- Scanning Electron Microscopy (SEM): allows measuring and imaging of the surface microstructure; if sophisticated metrology software is used for the analysis purposes, surface irregularities can be measured easily - small defects which failed to be captured with the use of *AFM* and *WLI* (see the another work of the authors [11]).
- Atomic Force Microscopy (AFM): it allows to show small surface areas, providing high-quality images; it enables viewing details of a machined surface within the measured areas (see the another works of the

authors [11,12]).

- Optical Interferometer (WLI): allows to measure all types of surfaces; enables an accurate quantitative assessment of the measured surfaces using specialized software; defects taking the form of cavities, hills or wear products deposited on machined surfaces are possible to be measured with a high accuracy (see the another works of the authors [11,12]).

REFERENCES

- [1] P. Pawlus, "Surface Topography – Measurement, Analysis, Influence", Publishing House of Rzeszow University of Technology, Rzeszów, 2006.
- [2] K.J. Stout, L. Blunt, "Three Dimensional Surface Topography", Penton Press, London, 2000.
- [3] T. Mathia, P. Pawlus, M. Wieczorowski, "Recent Trends In Surface Metrology", *Wear* 271/3-4, pp. 494-508, 2011.
- [4] M. Wieczorowski, "Surface topography analysis", Publishing House of Poznan University of Technology, Poznan, 2009.
- [5] T.R. Thomas, "Rough Surfaces", Imperial Collage Press, London, 1999.
- [6] PN – 87/M – 04250: The surface layer. Terminology.
- [7] PN – 87/M – 04251: Surface Geometric Structure. Surface Roughness. Numerical values of the parameters, 1987.
- [8] PN – 87/M – 04256: Surface Geometric Structure. Surface Roughness. Terminology, 1987.
- [9] Cz. Łukianowicz, "Principles of surface roughness measurements by light scattering methods", Publishing House of Koszalin University of Technology, Koszalin, 2001.
- [10] M. Niemczewska-Wójcik, "The microscopic analysis of material`s surfaces for use in medicine", *Tribology - Friction, Wear, Lubrication* vol. 3, pp. 205-213, 2008.
- [11] M. Niemczewska-Wójcik, J. Gawlik, J. Śladek, "The measurement and analysis of surface geometric structure of ceramic femoral heads", *Scanning*, doi: 10.1002/sca.21106 (in press).
- [12] M. Niemczewska-Wójcik, A. Mańkowska-Snopczyńska, W. Piekoszewski, "The investigation of wear tracks with the use of noncontact measurement methods", *Archives of Civil and Mechanical Engineering*, vol. 13 (2),pp. 158–167, 2013.