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EVALUATION OF THE SURFACE TOPOGRAPHY AFTER PRECISION MACHINING

Analysis of the geometric features and determination of the condition of the surfaces machined during an abrasive process is of crucial importance for evaluation of their wear properties. Numerous parameters can be used for assessing topography of technical surfaces. Many of them contain information that is general or poorly correlated with the wear features. The group of parameters used for such purpose should include those that do not cause information redundancy and provide distinct information. Evaluation of the surface geometric structure after precision machining is a difficult process due to the limited scope of unevenness heights that fit within the range of a few micrometers to a few nanometers. In this paper the synthetic indexes of the evaluation of extra smooth surfaces were created, taking into consideration numerous elementary parameters. The value of the synthetic index was determined as the geometric average of the partial indexes which, when compared to the arithmetic average, is more dependent on the data believed to be disadvantageous.

1. INTRODUCTION

Surface topography has always been a subject of interest of engineers, researchers and users. The general influence of the surface characteristics on the utility values of objects has been well known for years now.

It was proved that the geometric structure of the surface exerts significant influence on a variety of processes [1], including abrasion processes, wear of combined roll and slide surfaces, contact endurance and deformations, stress concentration and fatigue endurance, resistance to corrosive influence, suppression of oscillations, connection tightness, contact resistance, contact heat conductivity, magnetic properties, reflection phenomena, absorptions and transmissivity of (light, electromagnetic etc.) waves.

The increasing demands in the field of properties of the elements, as well as minimization of the material wear, elements' mass and size, increase of their load capacity and resistance, as well as growth of the production technology led to the development of numerous measurement methods and a large group of parameters used for evaluation of the stereometric features of surfaces [2],[3],[4].

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The selection of evaluation parameters, which finally form a complementary system, requires the knowledge on numerous problems and availability of decision-supporting systems [5].

Machining precision, achieved for given processes, results from a number of limitations and is considerably lower than the precision that could be obtained using the given method of shaping object surface.

The most important limitations that influence the precision of the produced elements include:

- The limitations resulting from functional, exploitative, reliability-related and aesthetic demands, as well as the recipients' preferences.
- The limitations resulting from the acceptable product price as a whole depending on the quality, prices of competitive products, conditions on the given products' market.
- Technical limitations that influence the selection of requirements concerning the achieved precision, and therefore the choice of technological devices, tools, machining parameters, supervision and control methods.
- The limitations resulting from the features of operations of production of semi-products and the operations that precede the finish machining stage, and many others.

Evaluation of the machining precision that would be achievable in the given production method assuming that all the economic, technical and organizational limitations were non-existent, is not easy. However, a rather simple relation can be stated: the border machining precision depends on the lowest layer thickness of the layer that can be removed as a result of elementary influence of the tool's active elements (single blades, abrasive grains or micro grains) (Fig. 1).

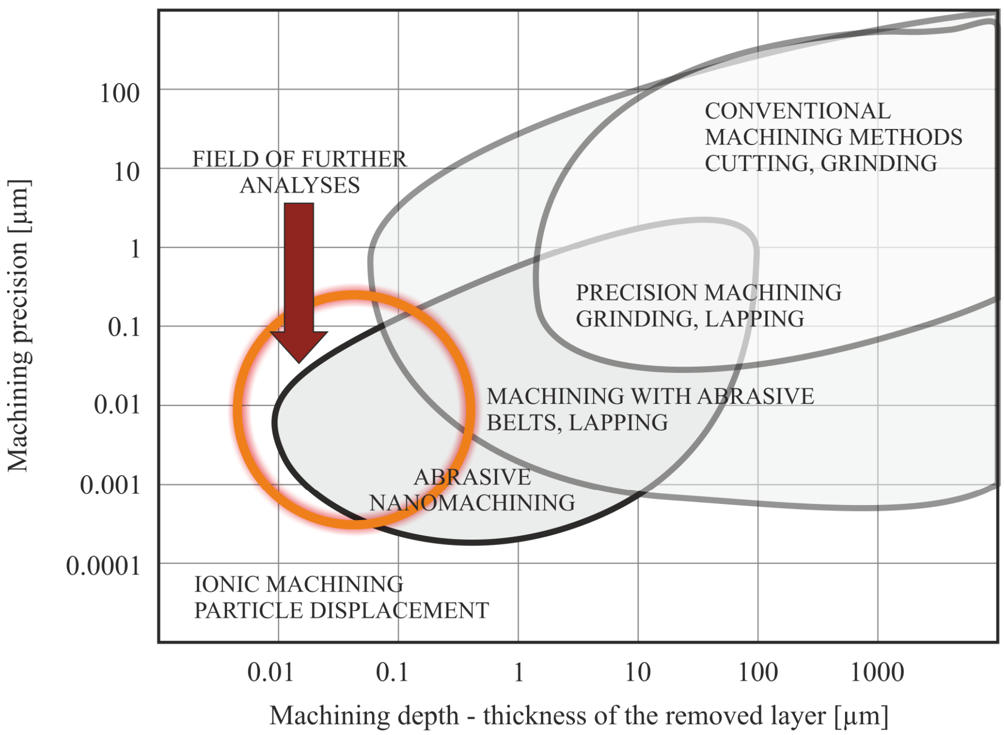


Fig. 1. Area of abrasive nanomachining

In the microcutting processes, especially in precise machining, numerous phenomena and factors gain decisive importance in relation to the process results. They include: discontinuity of the process of creating microchips (in micro- and submicroscale), heat and mechanical deformations of the tools and the machined material, in areas surrounding the grains, depressed in the workpiece surface. Especially the linear and angular dislocations of the abrasive grains under the influence of cutting resistance and randomness of the microcutting process itself are the greater the smaller are the average sections of the cut layers with particular blades.

In abrasive micromachining or precision grinding, the hollow of the blade in the machined material is considerably smaller than the rounding of its nose radii and is comparable to the height of the surface unevenness in the micro–cutting zone.

2. EVALUATION OF SURFACE TOPOGRAPHY

2.1. METHODOLOGY

The problems connected with analysis of the stereometric features and determination of the condition of surfaces machined abrasively is of basic importance [6–8]. What can be now used in evaluation of the machined surface's condition are over three hundred normalized parameters. Some of the parameters, describing the surface's condition in a general manner, are strongly correlated with each other. Characterizing given, detailed surface features, they show high correlation with numerous general parameters and low correlation with other detailed ones.

Evaluation of the surface topography after micro- and nanosmoothing is difficult due to the low measurement range. These are often values ranging from a few micrometers to a few nanometers of the surface unevenness height. With such low amplitude parameter values of the evaluated surface, its other features are starting to gain importance in its correct description more and more often. Evaluation of the microtopography is far more complicated here and can be considered both in relation to the proper selection of evaluation parameters of creation of new surface topography evaluation indexes.

The aim of the realized analysis of the surface characterized by the greatest smoothness, which is covered mainly with flat or flat-like areas, was to develop a methodology of evaluation of such a surface.

A synthetic coefficient, defined as the geometric average of components according to the following formula, was suggested:

$$W_s = \left(\prod_{i=1}^{n} w_i \right)^{1/n} \tag{1}$$

The coefficient consists of four description elements, from w_1 to w_4.

$$w_1 = \frac{\textit{mean radius of islands}}{\textit{mean distance between islands}} = \frac{SPW}{SOW}$$

$$w_2 = \frac{\textit{mean radius of field of the flat summit}}{\textit{mean distance between flat fields}} = \frac{SPPWP}{SOPP}$$

$$w_3 = \frac{\textit{arithmetical mean height of the surface}}{\textit{maximum height of the surface}} = \frac{Sa}{Sz}$$

$$w_4 = \frac{\textit{mean distance between summits}}{\textit{maximum distance between summits}} = \frac{Lwrs}{Lw\max}$$

In order to calculate the values of these partial coefficients, procedures directing their determination were developed. The procedures in question contain calculations of the components, the subsequent steps of calculating the partial coefficients, as well as the supplementary parameters. The methodology is as follows:

- In the first step the surface parameters must be determined, e.g. amplitude parameters, i.e.: *Sa*, *Sq*, *Sz*, *Sp* etc.
- In the next step the level *h*, on which the input surface will be cut. *h* was assumed to be 0,25**Sp*, due to the fact that only a small number of summits cooperates with the surface that is characterized by similar stereometric parameters. The cut is performed to identify the remaining islands as the subsequent surface summits.
- The top part of the surface created as a result of cutting must be changed into a binary image. The numerical operations on binary images are much faster and enable application of the existing functions in specialist applications used for image analysis.
- What is searched for in such a binary image are connected fields, identifying subsequent summits; next, parameters of these fields are determined, i.e. their areas, centers of inertia, distances between the fields, their radii and the average values.
  What is also looked for among the selected fields are such islands that can be qualified as flat in accordance with the assumed definition.

Calculation of the partial coefficients was begun by determination of a few supplementary parameters, which the following items depend on:

- Lwh – the number of islands on height *h*,
- $Pwih$ – the area of islands on height *h*,
- Lsh – the number of flat islands (for the assumed criteria),
- $Psih$ – the area of flat islands,
- Lwi – the average distance between the islands.

Using the above mentioned supplementary parameters two dependencies were developed in which the following elements are compared:

a) the number of flat summits in relation to all summits on the given cutting level – $U_1^{'}$ (2),

b) the sum of areas of islands defined as flat in relation to the sum of all the considered areas – $U_1^{''}$ (3).

$$U_1' = \frac{Lsh}{Lwh} \tag{2}$$

$$U_1'' = \frac{\sum Psih}{\sum Pwih} \tag{3}$$

First, the following are determined respectively: the average radius of the islands, and the average distance between the islands. Next, the first partial coefficient is calculated – the relation of the average radius of the islands to the average distance between them, described with dependence (4).

$$w_1 = \frac{Rw}{Lws} \tag{4}$$

When proceeding to analysis of the flat summits it should be remembered that in order to determine them or rather choose from among all the islands the following methodology was followed:

- Each island was separated from the binary image, thus creating a board of objects, consisting of identified islands in the original surface image,
- Each object had its views developed in two directions: *X* and *Y* (Fig. 2),
- A derivative, for which the condition described with dependence (5) was checked, was calculated for each of the developed views.

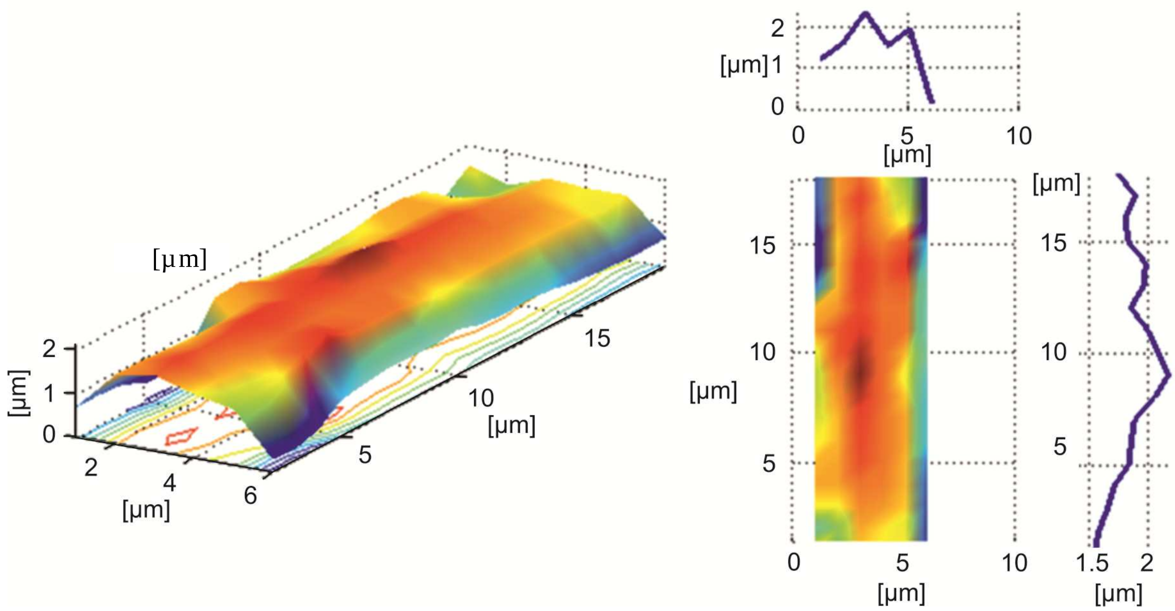


Fig. 2. Determination of the parameters of a single island

$$-\varepsilon < \frac{d^2 z}{dxdy} < +\varepsilon \tag{5}$$

Value ε was adopted as a pre-determined percentile of the value of *Sp* summit. If the given summit fulfilled the condition assuming that values of the derivative of the summit height (calculated for the data on the developed views of this summit in both directions) fit by 80% in $\pm\varepsilon$, the summit was declared flat.

Having decided which of the analyzed islands were flat summits, the following parameters were calculated: the field of flat summits *Psih*, their average radius *Rws*, and the distance between them *Lws*.

These parameters allow for determination of the second partial coefficient, analogically to the previous one, i.e. the ratio of the average flat summit's radius *Rws* to the average distance between these summits *Lws* (6).

$$w_2 = \frac{Rws}{Lws} \tag{6}$$

The next partial coefficient is the ratio of two known surface amplitude parameters: *Sa* and *Sz* (7).

$$w_3 = \frac{Sa}{Sz} \tag{7}$$

The last partial coefficient that refers to the summit dispersal on the surface is the ratio of the average distance between the summits and the maximal distance (8).

$$w_4 = \frac{Lwi}{Lw\max} \tag{8}$$

Having calculated all the partial coefficients the synthetic, dimensionless coefficient was determined on basis of the previously stated ratio (1).

When analyzing the components of the obtained coefficient it should be noticed that only one of them uses the existing description of its input parameters (*Sa* and *Sz*). The remaining ones are new. This results from the fact that the standard parameters (authors mean the normalized parameters) often do not reflect the character of the surface. This is the case with analyzing surfaces with low or very low unevenness' values.

3. EVALUATION OF THE SURFACE

3.1. OBJECTS OF ANALYSIS

Samples made from various exploitative materials were subject to research. The materials included, among others, steel, zirconium ceramics, aluminum and brass. Moreover, the samples were machined with various abrasive machining types, i.e. through grinding, smoothing and polishing. For each material 70 measurements were made.

3.2. MEASUREMENT SYSTEM

Talysurf CCI 6000 measurement system by Taylor Hobson company was used for the measurements of the surface topography. It is one of the most advanced non-contact optical systems that offers the possibility of spatial evaluation of the surface topography. The general view of the system used in the Laboratory of Micro- and Nanoengineering at the Department of Precise Mechanics at Koszalin University of Technology is presented in Fig. 3.

Fig. 3. The general view of the Talysurf CCI 6000 measurement system by Taylor Hobson company

The measurement method was based on an algorithm that the producer calls coherence correlation interferometry, CCI. The registered image of the interferential lines is processed by the computer with a Xeon processor. On basis of the processed data, a precise spatial map of the measured surface is created in high resolution. The device enables obtaining vertical resolution up to 10pm (0,1 Å), with the measurement range (in axis Z) to 10mm (dependent on the device configuration). Regardless of the applied magnification such a map may contain over 1 million of measurement points (1024 × 1024 points).

Due to its high flexibility, the Talysurf CCI 6000 measurement system can be used in a wide variety of fields, including material engineering (analysis of polymeric materials), mechanics (measurements of the topography of precisely machined smooth and supersmooth surface), electronics (measurements of backings of semiconductor systems, analysis of MEMS, MOEMS structures), microoptics (microlenses, diffractive optics), biomedicine (implants, endoprosthesis).

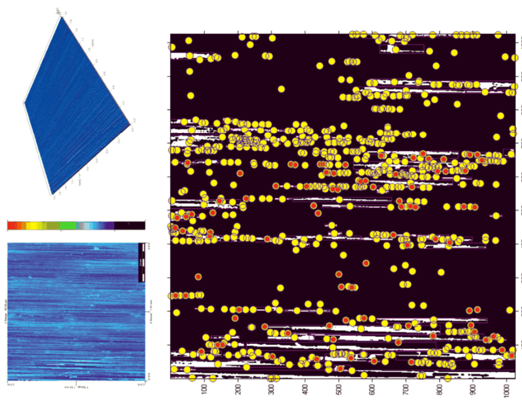
3.3. SURFACE ANALYSIS

Samples made from various exploitative material were subject to research. The materials included, among others, steel, zirconium ceramics, aluminum and brass. Moreover, the samples were machined with various abrasive machining types, i.e. through grinding, smoothing and polishing.

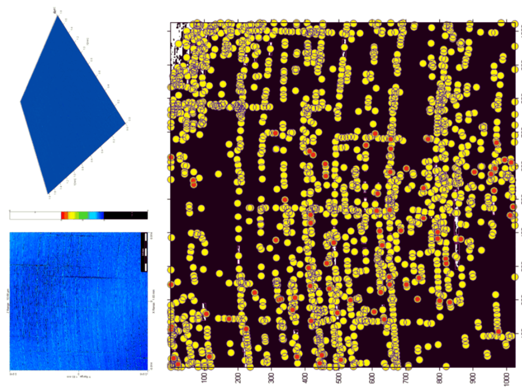
Table 1. Comparison of parameters and coefficients for surface after grinding

ORIGINAL SURFACE / BINARY IMAGE

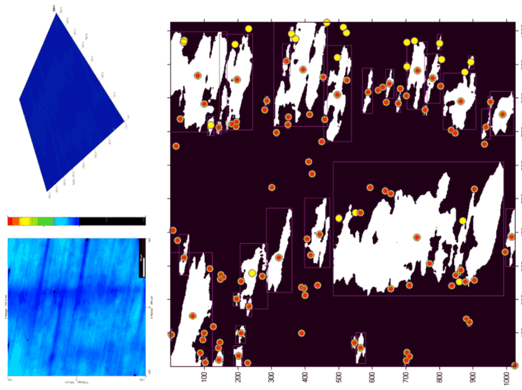
GRINDING



SMOOTHING



POLISHING



PARAMETERS

Parameter	GRINDING	SMOOTHING	POLISHING
Sa	0.25 µm	0.017 µm	0.003 µm
Sq	0.61 µm	0.042 µm	0.007 µm
Sp	7.19 µm	1.15 µm	0.396 µm
Sv	6.43 µm	1.53 µm	0.402 µm
Sz	13.62 µm	2.67 µm	0.798 µm
Ssk	0.80 µm	0.49 µm	-4.205 µm
Sku	15.53 µm	36.59 µm	169.034 µm
Lwh	676	1591	124
$Pwih$	416.4 µm^2	84.6 µm^2	6627 µm^2
Lsh	87	78	101
$Psih$	150.9 µm^2	44.07 µm^2	4369 µm^2
Rw	7.13 µm	4.5 µm	24.02 µm
Lwi	356.22 µm	526.7 µm	1755.6 µm
Rws	11.8 µm	8.59 µm	47.72 µm
Lws	529.25 µm	534.85 µm	587.63 µm
w_1	w_1=0.02	w_1=0.0085	w_1=0.0415
w_2	w_2=0.0223	w_2=0.0161	w_2=0.0812
w_3	w_3=0.0191	w_3=0.0063	w_3=0.0037
w_4	w_4=0.0205	w_4=0.02884	w_4=0.03297
W_s	W_s=0.0364	W_s=0.0223	W_s=0.0452

A series of tests with special interest in surfaces of high smoothness was realized on basis of the developed methodology. A group of surfaces after various abrasive machining was created. First, the group underwent parametric analysis using the TalyMap 5.1 software, Platinum version. The next step was analyzing the surface topography using the evaluation coefficients developed by the authors. What can be seen below are some results selected from a large set of data, analyses for the previously mentioned samples.

Having analyzed both the partial coefficients, as well as the end synthetic index included, inter alia, in the hereby work, it must be noticed that they are highly dependent on the cut level *h*, on which the analysis will be made. This is obviously not a flaw. It is merely a cue hinting that this depth should be selected in such a way so as to take into consideration e.g. destination of the analyzed part and the character of the work it performs. The authors suggest that the h oscillated from 0,1 to 0,3 of the *Sp* summit parameter value. Moreover, what should also be kept in mind is the proper selection of value ε, as the proper classification of the given summit as a flat one or not depends on it.

4. SUMMARY AND CONCLUSION

This coefficient can be successfully used in evaluation of the surfaces that are characterized by high surface finish. The following parameters are often selected for classification of surfaces from the group of amplitude parameters: *Sz*, *Ssk* and *Sku*. Crucial conclusions result from the ratios of *Sz:Sa* and *Sz:Sp*. Parameters *Ssk* and *Sku* show low correlation with the following parameters in this group.

Parameter *Sz* indirectly informs about the unevenness height and it is not sensitive to the influence of single random summits and pits. It also shows definite correlation resulting from the character of the layout of surface ordinates with parameters *Sa* and *Sq*. The ratios *Sz:Sa* and *Sz:Sp* are a good measure of the unevenness slenderness.

However, the most important parameters should result from the relation between given 2D parameters (e.g. distribution of summits) in mutually perpendicular directions as the shape and layout of the areas of probable contact that are being shaped are highly important. Selecting one set of parameters for all purposes is not justified.

Depending on the conditions of the planned exploitation and, to some degree, also on the features of the surface shaping process, a group of parameters should be created that will maximize the informational usefulness, meet the condition of complementarity, include information on dispersion and changeability of the geometric parameters and also fulfill the condition of relation between parameter values and the given surface features and will also enable determination of possible process corrections.

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