Susceptibility of SPG parameters to the environment conditions and the method of acquisition of cloud of points with optical measuring systems applied

Wpływ warunków otoczenia i sposobu akwizycji chmury punktów z wykorzystaniem optycznych systemów pomiarowych na wartości parametrów SGP

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DOI: https://doi.org/10.17814/mechanik.2017.8-9.108

Digital processing of a point cloud as measured on a concurrently produced surface would offer many opportunities for the operator to plan metrological process and to give more freedom to assess geometric structure (SGP) of the surface. SGP parameters when estimated in specific (non-standard) conditions could be difficult to validate. Non-repeatability of measurement results can often be the reason for escalation of quality problems in today's industry and can arise doubts about reliability of scientific research work. Presented by the authors in the article are the results of studies on how the SGP measurements, when carried out by means of devices based on chromatic confocal microscopy, could be distorted by ambient conditions and by the selected parameter settings. It was ANOVA analysis of variance used to determine effect of interaction of the selected parameters during acquisition and digital processing of the measured cloud of points. Which in practice is related to the repeatability and reproducibility of the parameters values as most frequently used in the assessment of SGP status.

KEYWORDS: surface topography, confocal microscopy, influence of setting parameters on measurement, analysis of variance (ANOVA)

The cloud points recorded without error in the shape of the unevenness and the height of the surface allows for the abandonment of its digital processing, so that the determined values of SGP parameters can be free from the random influence of the operator [1-3]. In addition, the method of determining the SGP parameters becomes much simpler. SGP parameter values recorded without filtration should be reproducible and repeatable for different measurement systems offered on the market by different manufacturers, and at the same time allow for easy classification of the available measuring devices.

In order to identify the effect of ambient conditions and setting parameters on the topography of the surface, an experiment was conducted in which a series of surface scans were performed under controlled conditions using a confocal microscope.

The tests were performed on roughness patterns. The experiment included the variable influence of ambient temperature and the extreme, achievable multi-sensor settings of the Altisurf 520 for SGP tests. The significance of the influence of individual factors on the differentiation of the most commonly used (in industry and science) of SGP amplitudes was analyzed on the basis of ANOVA variance analysis.

In recent years, various optical surface measuring devices have been introduced to the market, the principle of which is based on the effect of phase shift [4] or the confocal effect of chromatic light [5]. There are also devices that use the effect of focusing and reflection on the surface of the measured monochromatic light [6, 7]. The technical documentation, which is appended to this type of equipment, and standards [4, 5] say little about the conditions of acquisition of points on the surface to be measured. In standards [8, 9] only basic rules and recommendations are defined. Probably this is due to the very wide possibilities of using these types of devices and the need to set them each time according to the object being measured. The influence on the coordinates of a registered point cloud can have many factors, depending on the measuring system used, the environment or the operator itself [1-3]. In research conducted in the Topography Research Institute (LTP) of the West Pomeranian University of Technology in Szczecin, the focus was on the selection of conditions for acquisition of cloud points for the surface of objects made of metals.

Based on the obtained results, the significance of the influence of the setting parameters on the variation of the values of the amplitude parameters of the SGP was analyzed using multivariate ANOVA analysis. The experiments were carried out in variable but controlled environmental conditions using Altimet's modern Altiset 520 measuring instrument (Fig. 1) and a C3 sinusoidal sinusoidal slope (according to PN-EN ISO4536-1) Hommel-Etamic No. 3442.

The Altisurf 520 is a multi-sensor device for measuring surface topography. Enables acquisition of data by optical or contact sensors (including reduced pressure on the mapper blade).

The design of the device is based on a table and a gate made of granite. The table moves are carried out in the *XY* plane using motorized motors with a resolution of 0.1 µm. The resolution mechanism used to drive the Z-axis is 0.5 mm. Depending on the sensor used, the device uses interferometer [4] or confocal microscope [5]. In the study, it was decided to use the principle of optical chromatic

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confocal imaging to provide high resolution points collected along the optical axis of the instrument. Thanks to a special arrangement of the aperture in the optical measuring axis, a light beam is focused on the photoelectric transducer and focused on the measured point of the surface. Chromatic confocal sensors can be used to measure objects made of any material of any color, and the sampling frequency can be up to 2 kHz.

Fig. 1. Altisurf 520 profilometer of modular design for optical and contact measurements

Methodology of research

Five input factors are included in the study, which include typical surface-to-surface scanning parameters, set by the operator (regardless of the measuring method and type of measuring machine), and temperature (fig. 2, Table I). The variability of scan setting parameters in the plan is representative of all available SGP test equipment and is compatible with [5].

The study was divided into two parts, i.e. hot and cold, during which the corresponding experiments carried out according to plan. Each time respectively prepared for laboratory tests, where for approx. 48 h post-cured (cooled) measuring instrument and a standard.

Before performing the appropriate measurements of machine implemented first scan test, followed by a specific sequence of the measurement program. The test measure lasted about 30 minutes and was intended to stabilize the environment after the machine was set and the operator left. Correct measurements were made on a roughness pattern with sinusoidal grooves type C3 Hommel-Etamic No. 3442. The Altisurf 520 measuring instrument is equipped with a CL2 confocal sensor with a measuring range of 0÷400 μm. The area of the scanned surface was 4×4 mm. A series of measurements (16 experiments) were performed in one setting pattern on the machine (without removing it from the machine). All actions taken were designed to prevent additional interference (as a result of unintended operator involvement), which could lead to deterioration in reproducibility and reproducibility of measurement results. Both parts of the experiment plan, it is warm and cold, was made three times alternately.

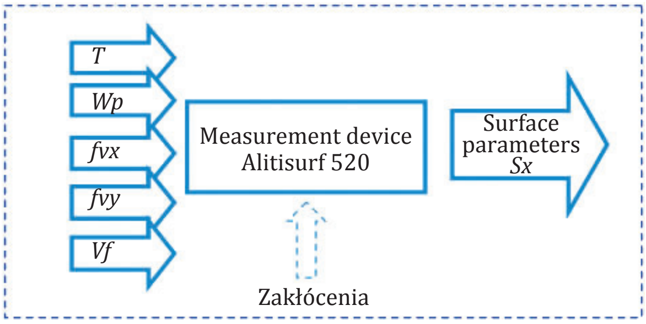

Fig. 2. Complex research object

TABLE I. Description of selected input factors adopted in the experiment plan

Symbol and name of the factor	Description of the factor	Range
T Temperature	Ambient temperature (in the test laboratory is reduced or increased by air conditioners)	16÷26°C
Wp Diode brightness LED	Diode brightness is the amount of light emitted in the direction of the sample. It can be manually adjusted by decreasing or increasing the brightness of the LED (when the amount of light emitted towards the sample decreases, the intensity of light decreases on the sample)	25÷100
fv_x Sampling in *X* axis	The *X* axis sampling rate determines the distance between points in each of the measured profiles	0,6÷6 μm
fv_y Sampling in *Y* axis	The Y axis sampling rate determines the number of profiles measured on the surface	0,6÷6 μm
Vf Measurement speed	The measurement velocity can be varied at each stage, but is automatically limited by the relationship V_f = F · f_{vx}, where *F* (in Hz) is the sampling frequency of the optical sensor used to acquire the measured surface points, or by the maximum permissible velocity on the sensor	120÷1200 μm/s

The results of each scan developed using conventional methods of analysis of surface topography. The procedure included:

- setting a threshold value to remove erroneously collected surface points; Deleted points are set as non-measured values in each case;
- surface leveling (average plane approximated by the least squares method);
- surface roughness filtering (Gaussian filter with cut off cutoff length of 0.8 mm);
- determination of stereometric values of roughness parameters according to ISO 25178 (selected parameters of surface height, functional parameters and surface features) [7].

Scanning the surface at each point of the plan of the experiment was repeated three times. In order to determine the impact of data acquisition conditions, all ANOVA variance analysis was performed in STATISTICA 10 after all experiments were performed.

The results of the study were obtained by determining the significance of the influence of selected input factors on the stereometric value of the *Sq* parameter, i.e. the mean square distance of the surface points, determined in relation to the reference surface as the standard deviation of the surface unevenness [7]. The *Sq* value is defined as the mean square deviation of the profile of the mapped *Rq* in the 2D system:

$$Sq = \sqrt{\frac{1}{M \cdot N} \sum_{j=1}^{N} \sum_{i=1}^{M} \theta^2(x_i, y_j)}$$

where: $M \cdot N$ – sample size, $\theta(x_i, y_j)$ – residual surface (load capacity).

Elaboration of research results

Table II presents the plan of the experiment and the designated parameter *Sq*, fig. 3 – comparison of the parameters of mean square height (mean square deviation of surface points *Sq*) obtained in individual experiments carried out in accordance with the test plan, and fig. 4 – example views surface obtained for unfiltered point cloud.

For each experiment, the well mapped regular surface pattern, which had previously been leveled. In any case, no unnatural surface structures have been observed due to measurement errors or other undefined (but systematic) effects. Also, the number of unmeasured points were each comparable and was less than 0.1% specify points of the surface.

Basic parameters descriptive statistics for each of the subclass developed using STATISTICA edge 10. Generated average, standard deviations and 95 percent confidence intervals for the average value of the concerned SGP parameter.

Table III shows only the results for the mean square deviation of the surface Sq. Analogous calculations repeated for the remaining parameters analyzed SGP – mean values are presented in Table IV.

Analysis of variance ANOVA

The aim of the study was to evaluate the significance of the influence of individual input parameters for the selected parameter values SGP. Table V presented only results of the analysis of variance for a verified hypothesis for the lack of significance of the effect inputs to the

TABLE II. Experimental plan with actual values of input and output parameters *Sq* (*Sq* - average surface area)

Experimental pattern	Input parameters					Output parameters			Mean, μm	Distance, μm	Standard deviation, μm
	T, °C	*Wp*	fv_x, μm	fv_y, μm	*Vf*, μm/s	Sq_1, μm	Sq_2 μm	Sq_3, μm			
1	16	25	6	6	1200	3,78	3,82	3,77	3,79	0,05	0,026
2	16	100	6	6	120	3,82	4,09	3,79	3,90	0,30	0,165
3	16	100	0,6	6	1200	3,90	3,98	3,81	3,90	0,17	0,085
4	16	25	0,6	6	120	4,05	3,80	3,81	3,89	0,25	0,142
5	16	100	0,6	0,6	120	3,77	3,77	3,81	3,78	0,04	0,023
6	16	25	6	0,6	120	3,79	3,78	3,78	3,78	0,01	0,006
7	16	100	6	0,6	1200	3,78	3,78	3,97	3,84	0,19	0,110
8	16	25	0,6	0,6	1200	3,88	3,80	3,80	3,83	0,08	0,046
9	26	100	6	0,6	120	3,78	3,78	3,78	3,78	0,00	0,000
10	26	100	6	6	1200	3,78	3,76	3,76	3,77	0,02	0,012
11	26	100	0,6	0,6	1200	3,79	3,79	3,80	3,79	0,01	0,006
12	26	25	0,6	6	1200	3,78	3,78	3,79	3,78	0,01	0,006
13	26	25	6	6	120	3,78	3,77	3,78	3,78	0,01	0,006
14	26	100	0,6	6	120	3,79	3,78	3,77	3,78	0,02	0,010
15	26	25	6	0,6	1200	3,81	3,80	3,87	3,83	0,07	0,038
16	26	25	0,6	0,6	120	3,77	3,89	3,74	3,80	0,15	0,079

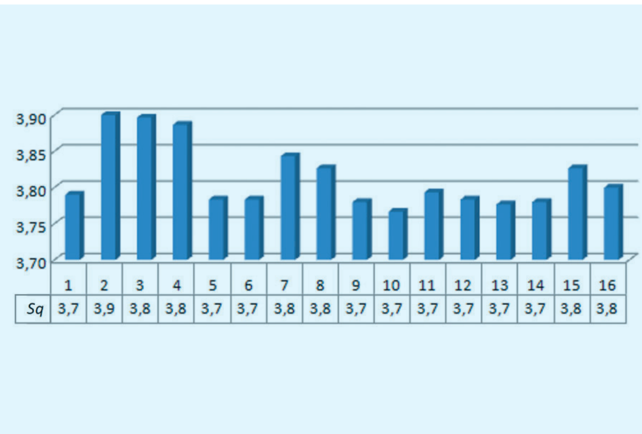

Fig. 3. Summary of *Sq* values for individual test plan systems

TABLE III. Descriptive statistics of the *Sq* value

Effect	Descriptive statistics (*Sq*)						
	Level of factor	Number of observations *N*	*Sq* mean	*Sq* Standard deviation	*Sq* Standard error	*Sq* –95%	*Sq* +95%
Total		48	3,813542	0,072655	0,010487	3,792445	3,834638
T	16	24	3,838750	0,091903	0,018760	3,799943	3,877557
T	26	24	3,788333	0,031851	0,006502	3,774884	3,801783
Wp	25	24	3,809167	0,062479	0,012753	3,782784	3,835549
Wp	100	24	3,817917	0,082724	0,016886	3,782985	3,852848
fv_x	1	24	3,818750	0,072250	0,014748	3,788241	3,849259
fv_x	6	24	3,808333	0,074230	0,015152	3,776989	3,839678
fv_y	1	24	3,804583	0,049955	0,010197	3,783489	3,825677
fv_y	6	24	3,822500	0,090133	0,018398	3,784440	3,860560
Vf	120	24	3,811250	0,084406	0,017229	3,775608	3,846892
Vf	1200	24	3,815833	0,060427	0,012335	3,790317	3,841350

TABLE IV. Mean values of selected SGP parameters

Experimental pattern	*Sa*, μm	*Sz*, μm	*Sq*, μm	*Ssk*	*Sku*	*Sp*, μm	*Sv*, μm
1	3,313	24,867	3,79	0,536	1,97	12,367	12,533
2	3,36	29,867	3,9	0,459	2,09	14,7	15,167
3	3,347	40,3	3,897	0,604	2,217	19,967	20,367
4	3,337	37,433	3,887	0,563	2,13	18,3	19,133
5	3,307	25,067	3,783	0,547	1,967	13,333	11,733
6	3,303	26,533	3,783	0,543	1,97	13,933	12,567
7	3,313	37,8	3,843	0,614	2,153	18,3	19,533
8	3,307	33,533	3,827	0,591	2,09	16,633	17,233
9	3,31	23,1	3,78	0,532	1,953	11,167	11,9
10	3,293	24	3,767	0,54	1,957	12,3	11,7
11	3,283	29,3	3,793	0,625	2,097	15,433	17,133
12	3,283	35,067	3,783	0,618	2,077	17,633	17,433
13	3,307	21,267	3,777	0,535	1,953	10,293	10,967
14	3,303	22,033	3,78	0,535	1,95	11,267	10,733
15	3,297	31,833	3,827	0,6	2,137	15,167	16,667
16	3,297	32,267	3,8	0,606	2,083	15,867	16,4
Variabilit of values, %	102,3	189,5	103,5	136,2	113,7	194,0	189,8

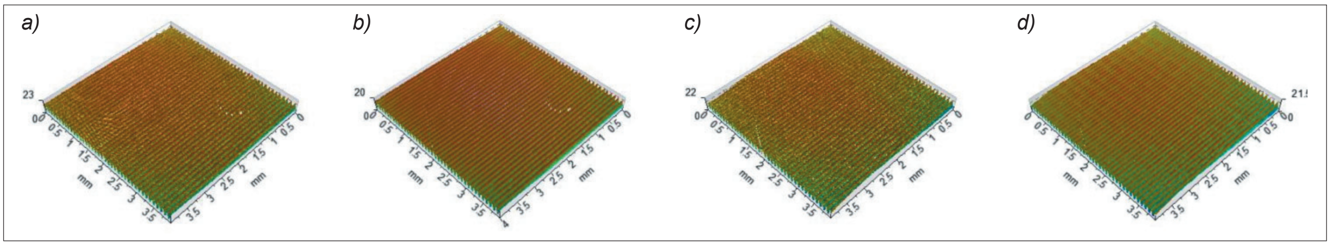

Fig. 4. Surface views for the experiments obtained from the test plan: a) No. 1, b) No. 13, c) No. 2, d) No. 14

r_{ms} deviation of the coordinate points of the surface *Sq*. A similar calculation is repeated for the other parameters analyzed SGP. Materiality of the impact factors for other input parameters SGP (*Sa, S., Ssk, sku, Sp* and *Sv*) are given in Table VI.

For all analyzed input parameters, the significance level of the test p = 0.05 was assumed. In the case of an amplitude parameter *Sq* showed only a significant effect of temperature (Table V).

TABLE V. Variance analysis results sheet for *Sq*

	Sum of squares between groups *SS*	Degrees of freedom	Average squares between groups *MS*	Test value *F*	Probability level *p*
Free term	698,0688	1	698,0688	138 774,0	0,000000
T	0,0305	1	0,0305	6,1	0,017983
Wp	0,0009	1	0,0009	0,2	0,671293
fv_x	0,0013	1	0,0013	0,3	0,613574
fv_y	0,0039	1	0,0039	0,8	0,386502
Vf	0,0003	1	0,0003	0,1	0,823951
Błąd	0,2113	42	0,0050		

Table VI presents the result of the analysis of interaction between input parameters on the mean square deviation of the coordinates of the surface points *Sq*.

With respect to the other input parameters, there was no reason to reject the null hypothesis.

From the analysis performed emerges an interesting conclusion that all main effects is an important input parameter temperature (Table VII).

TABLE VI. One-dimensional significance tests for Sq

	Sum of squares between groups *SS*	Degrees of freedom	Average squares between groups *MS*	Test value *F*	Probability level *p*
Free term	698,0688	1	698,0688	143 071,3	0,000000
T	0,0305	1	0,0305	6,3	0,017725
Wp	0,0009	1	0,0009	0,2	0,667247
fv_x	0,0013	1	0,0013	0,3	0,608994
fv_y	0,0039	1	0,0039	0,8	0,380883
Vf	0,0003	1	0,0003	0,1	0,821637
$T \cdot Wp$	0,0078	1	0,0078	1,6	0,216610
$T \cdot fv_x$	0,0009	1	0,0009	0,2	0,667247
$Wp \cdot fv_x$	0,0046	1	0,0046	0,9	0,338738
$T \cdot fv_y$	0,0204	1	0,0204	4,2	0,049079
$Wp \cdot fv_y$	0,0039	1	0,0039	0,8	0,380883
$fv_x \cdot fv_y$	0,0039	1	0,0039	0,8	0,380883
$T \cdot Vf$	0,0002	1	0,0002	0,0	0,853640
$Wp \cdot Vf$	0,0011	1	0,0011	0,2	0,637827
$fv_x \cdot Vf$	0,0008	1	0,0008	0,2	0,697211
$fv_y \cdot Vf$	0,0117	1	0,0117	2,4	0,131031
Błąd	0,1561	32	0,0049		

In order to refine the statistical analysis, an additional analysis was made taking into account interactions of the input parameters. Interactions main effects were tested by ANOVA factorial designs.

Based on the results listed in Table VI, it can be concluded that the parameter *Sq* strongly affected by the ambient temperature only the temperature and the interaction in conjunction with sampling-adjusted by the operator in the *Y*-axis (fv_y).

TABLE VII. Summary of the significance of the influence of selected input factors on the output values of SGP parameters

	Sa	*Sz*	*Sq*	*Ssk*	*Sku*	*Sp*	*Sv*
T	■	■	■	■		■	■
Wp							
fv_x		■		■	■	■	■
fv_y							
Vf		■		■	■	■	■
$T{\cdot}Wp$		■			■	■	■
$T{\cdot}fv_x$							
$T{\cdot}fv_y$		■	■	■	■	■	■
$T{\cdot}Vf$							
$Wp{\cdot}fv_x$		■				■	■
$Wp{\cdot}fv_y$							
$Wp{\cdot}Vf$		■				■	■
$fv_x{\cdot}fv_y$		■				■	■
$fv_x{\cdot}Vf$							
$fv_y{\cdot}Vf$					■		■

Analogous calculations were repeated for the remaining SGP parameters analyzed. Due to the very large number of results in Table VII significant effect of the test agent shown graphically – using the mark ■.

Conclusions

The experiments and the statistical processing and analysis of data with ANOVA variance analysis allowed to formulate the following conclusions.

It appears that the operator, assuming a certain temperature in the laboratory during the scan, can significantly affect the majority of the SGP parameters tested (Table VII). The temperature in the magnitude of the applied sample Y-axis may result in a significant change in the values of most of the SGP recorded parameters. Differences caused by the operator unconsciously during surface scanning range from several to several dozen percent of the amplitude values of the SGP parameters.

The Altisurf 520 multisensor machine was used for this study. Some observations and observations also appear to be true for the measurements made with contact instruments, but detailed comparative studies were not performed in LTP. In the research literature on the accuracy of optical measurement systems is the lack of similar studies. Accordingly, appropriate tests should also be carried out for other measuring devices that differ in structure and material. Expanding the research into a set of different SGP measurement devices should lead to the formulation of detailed guidelines – how to perform surface area acquisition for specific groups of materials with the properties in question so that the results are reproducible and reproducible.

One of the more commonly studied parameters of the SGP, Sa parameter (arithmetic mean deviation of surface unevenness from the reference plane), proved to be the least sensitive to the setting conditions of the measuring machine. In addition to the identified effect of the temperature *T* was found lack of interaction between the different adjusting parameters.

In turn, very sensitive to the operator's settings were the parameters related to the maximum height of the points of the *Sz* surface and the maximum height of the *Sp* and *Sv* surfaces. The differences in these parameters in the various experiments of the test plan range from a dozen to even 200%. In addition to the aforementioned effects of temperature, the influence of sampling in the *X* and *Y* directions and the combined effect of the intensity of the light emitted from the source directed at the surface to be measured is noticeable. Technical documentation often includes the parameters *Sz, Sp* and *Sv*, and the operator can unconsciously contribute to significant scatter (loss of repeatability and reproducibility) of the collected measured values. A suitable method of filtering (digital processing) of registered point clouds may be a solution. Each time it is necessary to indicate its course and conditions of acquisition of points on the surface of the studied object.

To avoid the need for filtration, it is best to use parameters whose values are determined in terms of averaged baseline values, i.e. relatively stable values of *Sa* and *Sq*.

The influence of the main effects on the values of the ordinate parameters of the ordinate surfaces was also determined, i.e. on the *Ssk* inclination and *Sku* kurtosis. The operator, selecting the density of the sampling points of the profile, and the distance of the lines and velocity during the scanning of the surface, can result in differences ranging from several dozen to several dozen percent of the parameter values. These differences are significant enough that, in specific cases, can lead to an incorrect assessment of the nature of the surface or plane with sharp tips.

The significant influence of temperature on all parameters of SGP should be explained. changes resulting from extensibility of the pattern. Modern testing equipment SGP do not have the function of temperature compensation of the measured object, in which they are equipped with coordinate measuring machines. At present, it is also very difficult to compensate for the temperature of small inequalities of the measured surface (small lengths) on the basis of the known values of the coefficients of expansion – in the case of the measured object the compensation value was on the border of micro- and nanometers. Should also compensate for changes in the dimensions and geometry of the measuring devices due to temperature. These changes are often difficult to avoid (even with today's inverter air conditioning systems), especially when the scan time reaches 30 hours.

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