

PROBLEM OF NON-MEASURED POINTS IN SURFACE TEXTURE MEASUREMENTS

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Abstract

This work is focused on the issue of non-measured points – one of the most important problems in surface texture measurements using optical methods. The fundamental aim of this research is to analyse errors of surface texture measurements caused by the presence of non-measured points. This study is divided into two parts. In the first part, circles with non-measured points were artificially created on peak portions of measured surfaces. In the second part – the results of measurement by a Talysurf CCI Lite interferometer were analysed. A measurement area of 3.3×3.3 mm contained 1024×1024 points. The measurements were performed with different intensity of light. Changes of parameters regarding the analysed errors depended on a surface type. The following parameters are susceptible to errors: skewness Ssk , areal material ratio Smr , as well as the following feature parameters: Spd , Sda , Sdv , Sha and Shv . Inaccuracies of measurement in valley parts of two-process textures led usually to larger errors of parameter computations compared with deviations in peak portions.

Keywords: surface texture measurements, optical method, non-measured points, white light interferometer.

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1. Introduction

The manufacturing industry moves towards a higher degree of production acumen. Some properties, like materials' contact, sealing, friction, lubricant retention and wear resistance are related to the surface topography. The designer should decide on the number of surface topography parameters that will meet the functional demands of a product. The knowledge about the relationship between the product's surface texture and its function is still incomplete. The process of measuring the surface topography gives quantitative information about it. The surface texture is very important for many practical applications [1–8]. Many roughness measuring instruments give absolute measurement values of surface heights. The profile measurement is usually quick, simple and easy to interpret. However, most surface interactions are areal in nature. The areal (3D) texture parameters [9] are more reliable than the profile (2D) ones. Therefore the 3D measurement became popular. The assessment of surfaces using profiles has been employed since the early 1930's. The measurement systems basically involved the use of a mechanical stylus. There are a lot of factors affecting an uncertainty in surface geometry measurements using the stylus technique. The uncertainty is influenced by various environment, measuring equipment, measured objects, software, as well as tip shapes and sizes [10]. There are other methods for measuring roughness [11–13]. Some kinds of errors are common for various measuring techniques, for example errors caused by an improper digital filtration. It was found that for multi-process (stratified) surfaces having traces of more than one process, the application of a standardised Gaussian filter led to distortion of roughness

values. Cylinder textures after plateau honing are typical examples of two-process surfaces. Although the fine texture marks fall well within a bandwidth accepted for the cut-off, the scratches do not, since they are too wide. It was recommended that a standard cut-off should be increased to 2.5 mm for this application [14]. A double Gaussian filter (R_k) according to the ISO 13565-2 standard can be also applied [15]. An alternative approach is to use robust Gaussian filters, in which additional weights decreased in the places of valleys or peaks. As a result, textures having deep and wide valleys can be filtered properly [16–19].

The time required to collect real data for areal measurements using stylus instruments can appear excessively long compared with the operating time of the optical techniques [20–23]. This could now become the most important disadvantage of the stylus methods. The optical methods are fast, but they are more sensitive to extraneous effects [24]. Among the optical methods, some of new advanced variants of confocal methods and white light interferometry are the most popular. The confocal optical systems are widely applied in engineering and biology because of very high clarity of obtained images, but when a range is increased the resolution tends to decrease; this factor does not occur when using the interferometric methods. The coherence scanning interferometry extends interferometric techniques to surfaces that are complex in terms of roughness, steps and discontinuities. Additional benefits include an equivalent of autofocus at every point in the field of view [24]. The environment can significantly contribute to measurement errors in the coherence scanning interferometer applications. Sharp edges can cause outliers called spikes in the topographic images [25]. If the light intensity received on a photodetector is too low, the surface height cannot be detected. A part of this image can be corrected using interpolation with an algorithm of determining areas with an ambiguous signal. Non-measured points exist also after the application of confocal optical systems. Non-measured points can result from many different causes, like high steepness of the slopes, surface absorbance or reflectivity. However, it is difficult to find in the accessible technical literature works dealing with the effect of errors caused by non-measured points on the distortion of surface texture parameter values. Nevertheless, this problem is one of the most important ones in the surface metrology. These errors may cause a false quality assessment of machined elements.

The fundamental aim of this research is to analyse errors of surface texture measurement of various machined surfaces caused by the presence of non-measured points. Another aim is to select the surface topography parameters that are the most and the least sensitive to the analysed errors.

2. Materials and methods

This study is divided into two parts. In the first part, circles with non-measured points were artificially created on peak parts of different measured surfaces, with the same measured areas and sampling intervals in perpendicular directions. The measuring area was 3.3×3.3 mm, the sampling interval in perpendicular directions was 5 μm . Ten samples with simulated errors were studied. A ratio of *non-measured* points (NM) was in each case 0.73%.

In the second part of this study the results of measurements by a Talysurf CCI Lite interferometer (produced by Taylor Hobson Ltd) with a 0.01 nm vertical resolution were analysed. A Nikon 5 \times /0.13 TI objective was used for all the measurements. The measuring area of 3.3×3.3 mm contained 1024×1024 measured points. The measurements were performed at a different intensity of light. The results of measurement with the smallest number of non-measured points were the reference (best) data. Fifteen surfaces (one- and two-process, isotropic and anisotropic, random and deterministic) were measured and analysed.

In both parts, TalyMap Gold version 6.1 software, copyright by Digital Surf, was used for filling in non-measured points. They were replaced by a smooth shape calculated from the neighbour points.

Before computations of parameters, flat surfaces were levelled using a least square plane, whereas curved forms of surfaces were removed using polynomials.

3. Study of surfaces with artificially created non-measured points

The aim of this part of research was to analyse the effect of surface type on the errors, because the NM ratio and shape of breaks were the same.

Ten surfaces were analysed; four of them were subjected to a detailed study. Fig. 1 shows examples of the analysed textures. The arrows indicate places where non-measured points are present after filling in. They indicate the effect of non-measured points on surface views. One can see that the corrected part of image is clearly visible on the surface after milling, as shown in Fig 1a, because the circle with non-measured points was located in a surface peak part. The modified circles on honed (Fig. 1b) and polished surfaces (Fig. 1d) are also visible. An anisotropic character of these textures is the most probably reason of visibility of the improved surface parts, because the corrected details are isotropic. However, it is difficult to find a circle with filled in non-measured points on the lapped surface with isolated oil pockets, created by the abrasive jet machining (Fig. 1c). The presence of dimples and an isotropic character of the peak surface part after lapping are the most probable reasons of a small visibility of the error.

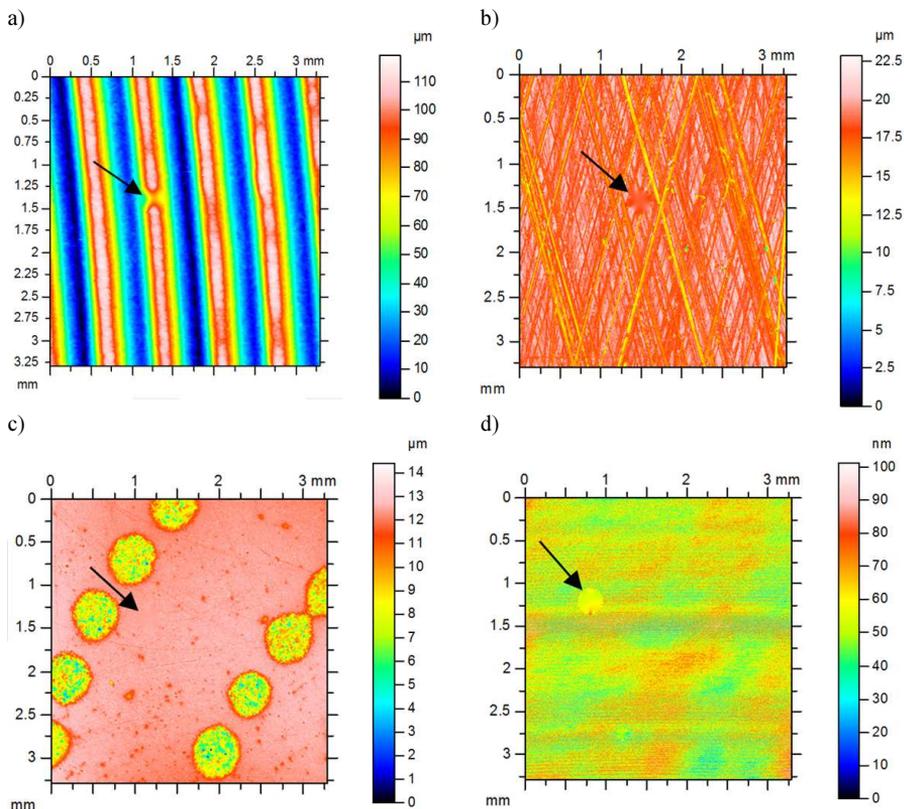


Fig. 1. Contour plots of surface points after milling (a); honing (b); texturing by the abrasive jet machining after initial lapping (c) and polishing (d) after filling in non-measured points.

Relative changes of the surface topography parameters defined according to the ISO 25178 standard due to disturbances were studied.

Although the error caused a change of the milled surface view (see Fig. 1a), the relative absolute changes of parameter values were not higher than 2%. A different tendency of changes of values for various height parameters was found: for statistical parameters Sa (arithmetic mean height) and Sq (root mean square height) as well as Spk (reduced summit height) and Sv (maximum valley height) they decreased, whereas for Sk (core roughness depth) and Sp (maximum peak height) parameters the changes increased. They were not higher than 0.7%. Due to a decrease of the Spk parameter as well as $Sr1$ ratio (upper bearing area) values, the $Sa1$ parameter value decreased; its changes were comparatively large (about 1.9%). The values of both skewness Ssk and kurtosis Sku increased. As a consequence of reduced statistical height parameter values, the values of hybrid parameters Sdq (root mean square slope) and Sdr (developed interfacial area ratio) decreased. The material volume Vm increased; its changes were the biggest of all the analysed parameters (about 2%). Among the feature parameters, Spd (peak density) and Sda (mean hill area) values increased. The spatial parameters were stable. Generally, it was found that the values of parameters related to a peak surface part ($Sa1$ and Vm) changed in the greatest degree.

It is interesting that – from the cylinder liner surface parameters – the closed dale volume Sdv value decreased the most (about 4%) (Fig. 1b). The maximum relative change of other parameter values was 1.7%. From the amplitude parameters only the value of Sq decreased, whereas Spk increased. Similarly to the milled surface, the Ssk and Sku parameter values increased, whereas those of Sdq and Sdr decreased. The functional parameter values from V family changed; those of Vm increased, whereas Vmc (core material volume) and Vvc (core void volume) decreased. The feature parameter values Spd and Sdv (mean dale volume) decreased while that of Sda increased. Generally, the same tendency of parameter value changes for the milled and honed surfaces was found.

The parameter values of textured surfaces shown in Fig. 1c changed marginally due to the presence of non-measured points. The maximum change of parameter values was 1% (Spd and Sdv values decreased). The values of the following parameters decreased: Spk , $Sa1$, Sdr , Vvc and Sda , whereas Sxp (extreme peak height) – increased.

The relative errors of parameters for the polished surface shown in Fig. 1d were comparatively large. Those for Sdv decreased by about 8%, for $Sr1$ increased by 2.4% and – consequently – for $Sa1$ increased by 3.5%, whereas for Ssk and Sda decreased by 3 and 1.6%, respectively. Changes for other parameters were smaller than 1%; for the following parameters they decreased: Sk , $Sr2$ (lower bearing area), Sp , Sa , Std (texture direction), Sdq , Sdr , Vvc and Spd , whereas for the following parameters they increased: Spk , $Sa2$ (oil capacity), Sku and Vm .

Generally, after analysis of parameter value changes for all ten tested surfaces it was found that deviations of the skewness Ssk and kurtosis Sku values occurred (up to 3%). The values of statistical amplitude parameters Sa and Sq typically decreased, whereas those of the parameters describing total height Sz , Sp and Sv were more stable. As a result of the amplitude reduction, the values of hybrid parameters also decreased. Since non-measured points were located in the peak regions of analysed surfaces, the values of parameters connected with a peak part: $Sr1$, Spk , sometimes Sk and consequently $Sa1$ typically changed (up to 4%); in most cases the peak density Spd value marginally decreased. The spatial parameters were usually stable; the main directionality described by Str , changed only for the anisotropic one-directional texture (Fig. 1d). Large changes of the feature parameters: Sdv and Sda deserve attention. Changes of parameter values depend on a surface type. For example, maximum changes of parameter values shown in Fig. 1c was 1%; it is difficult to find filled-in non-measured points on this graph.

4. Study of surfaces measured in different conditions

It was found that improper measurement conditions might cause serious inaccuracies in the parameter calculations. High errors of parameter computations occurred even for very small ratios of *non-measured* points (NM). Fig. 2 presents an example. Non-measured points of a small ratio (0.0268%) located in a valley surface part caused a considerable increase of roughness height in this part (the *Sv* value increased by more than 20%). In addition, the spatial parameter values changed; the autocorrelation length *Sal* increased by more than 20%, whereas the texture parameter *Str* by more than 15%. The peak density decreased by about 25%, whereas the values of feature parameters: *Sda*, *Sha* (mean hill area), *Sdv* and *Shv* (mean hill volume) increased by more than 25%. These changes are large, therefore analysis of the surface distortion due to the presence of non-measured points deserves attention. However, the changes of parameter values characterizing the material ratio curve, from the *Sk* family: *Sk*, *Spk*, *Svk* (reduced valley depth), *Sr1* and *Sr2* were smaller than 5%. An increase of the NM ratio from 0.00935 to 0.0268% caused non-visible changes of the contour plot; therefore it was presented in Fig. 1 only for the reference surface.

From the analysis of several measured surfaces it was found that – due to a growth of relative light intensity from the initial small value - the NM ratio decreased, reached the smallest value and then increased.

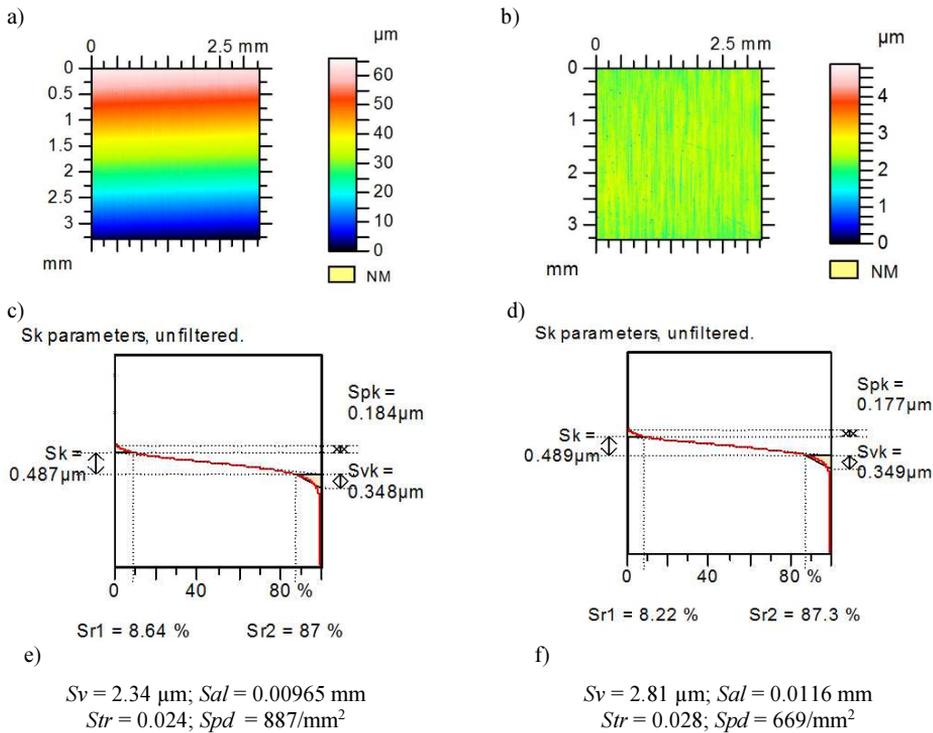


Fig. 2. Contour plots of the polished surface before (a) and after form removal (b) with material ratio curves (c, d) and selected parameters (e, f); graphs a, b, c, e correspond to NM ratio 0.00935%, but d and f – 0.0268%.

Too small a light intensity caused the presence of non-measured points in a valley region, whereas too high intensity – in a peak surface part. An increase of light intensity caused typically a growth of height, hybrid and functional (*V* family) parameter values as well as of oil

capacity, however for very high NM ratios (larger than 40%) different tendencies of parameter changes were also possible. The spatial parameter Sal value mainly decreased due to an increase of light intensity. Its changes were higher for the anisotropic surface compared with the isotropic or mixed ones. The variability of Sdq parameter is smaller than that of Sdr . A similar finding was found in other research reports [22, 23] and in the first part of the present study.

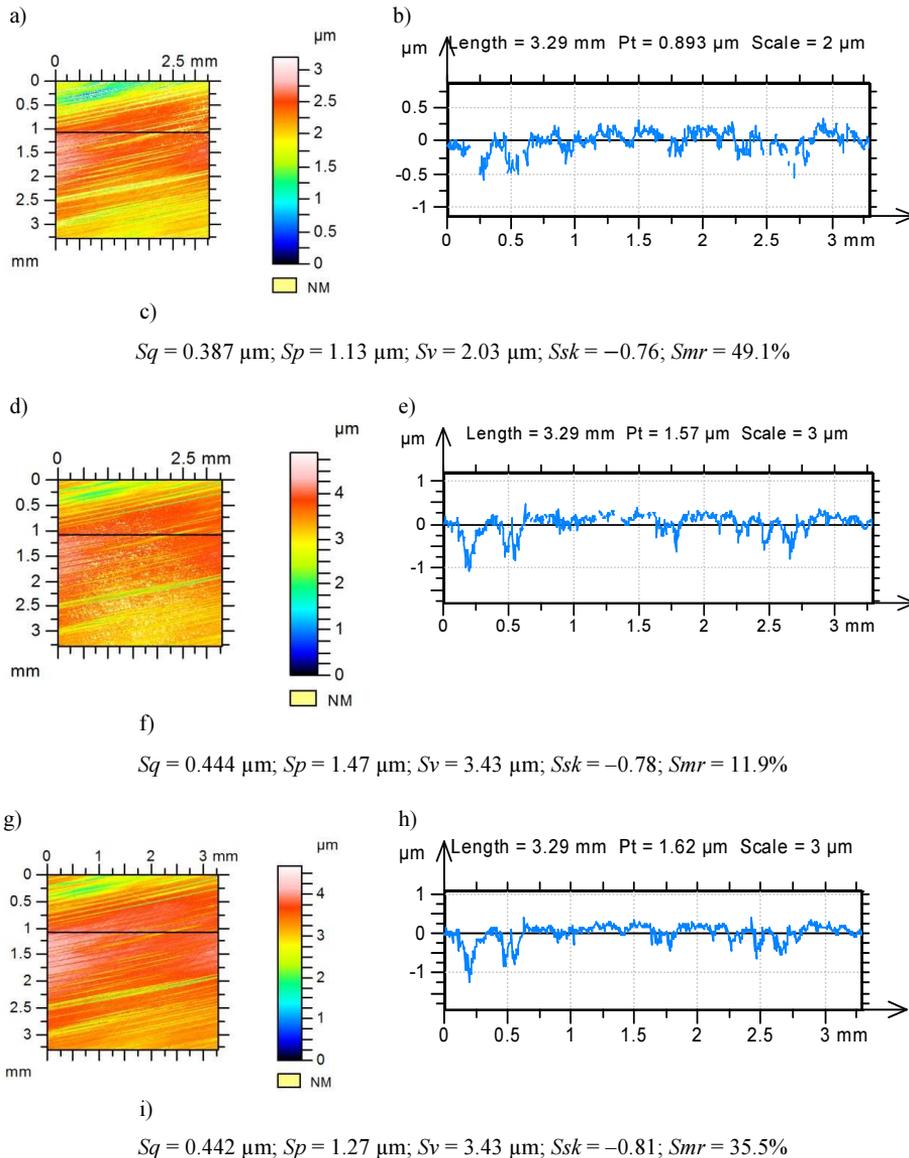


Fig. 3. Contour plots (a, d, g); extracted profiles (b, e, h) and selected parameters (c, f, i) of the polished surface with non-measured points located in a valley part, NM ratio 10.1% (a, b, c) with non-measured points located in a peak part, NM ratio 9.3% (d, e, f) with the smallest number of non-measured points, NM ratio 0.1% (g, h, i).

The non-measured points caused typically an increase of the Ssk parameter and decrease of the Sku parameter values for one-process surfaces. The functional parameters Smc (inverse

areal material ratio) and especially Sxp were more stable than the Smr parameter. A large variation of the Smr parameter value was found in other research reports [26, 27]. Typically, the changes of the values of spatial parameters Str and – especially – Sal were larger than those of height parameters, however a different situation was also possible. The main texture direction Std was constant for the anisotropic surface with the main directionality, contrary to the isotropic textures. It is difficult to find a tendency of changes of the peak density Spd , however variation of this parameter value was large. The following feature parameters: Sda , Sdv , Sha and Shv were also non-stable on the surface. The variability of $Sr2$ material ratio was lower than that of $Sr1$ ratio. Usually, a one-process surface with the highest NM ratio corresponded to maximum changes of parameters.

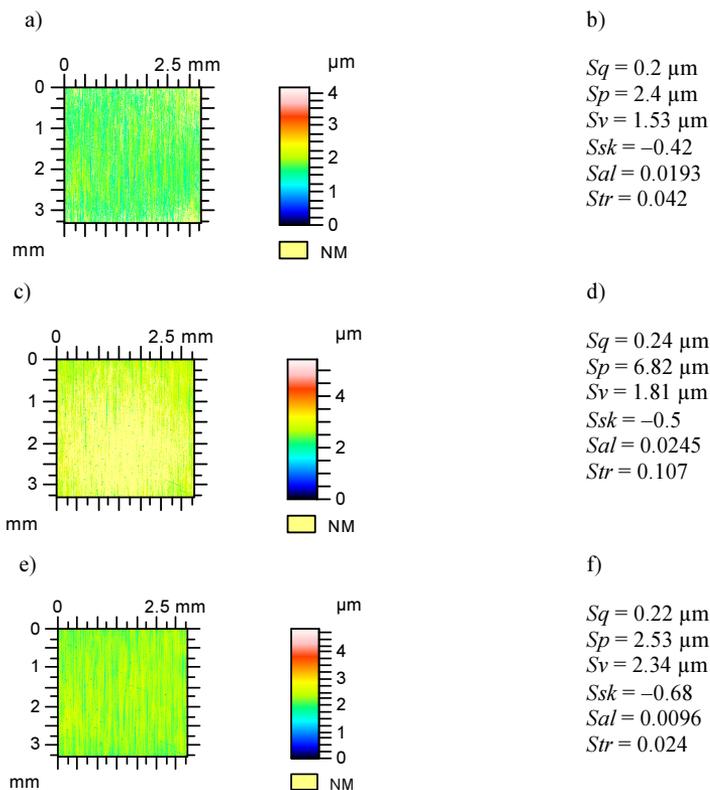


Fig. 4. Contour plots (a, c, e) and selected parameters (b, d, f) of the polished surface with non-measured points located in a valley part, NM ratio 24.2% (a, b) with non-measured points located in a peak part, NM ratio 58% (c, d) with the smallest number of non-measured points, NM ratio 0.00935% (e, f).

Generally, the variability of statistical height parameters Sa , Sq , spatial parameter Std , slope Sdq , functional parameters from V family as well as material ratio $Sr2$ caused by the presence of non-measured points was relatively small. Large errors existed only for a high NM ratio. However the following parameters are susceptible to errors caused by high NM ratios: skewness Ssk , functional parameter Smr and the following feature parameters: Spd , Sda , Sdv , Sha and Shv .

The changes of parameters depend on a location of non-measured points. Fig. 3 presents an example. A surface of a little asymmetric distribution after polishing was studied. An NM ratio of a texture shown in Figs. 3a and 3b is similar to that presented in Figs. 3d and 3e, however one can see from both views of contour plots and extracted profiles that non-measured points

are located in valley and peak parts, respectively. Due to the presence of non-measured points in a valley part the S_v parameter value decreased by about 40% and S_q – by nearly 12%. The presence of non-measured points in a peak surface part led to an increase of the S_p parameter value by more than 15% and a decrease of the S_{mr} value by more than 60%. Due to the presence of non-measured points the S_{sk} parameter value increased. A change of S_{al} parameter value was smaller than 10%, which was probably related to the fact that a mixed surface (S_{tr} about 0.35) was analysed.

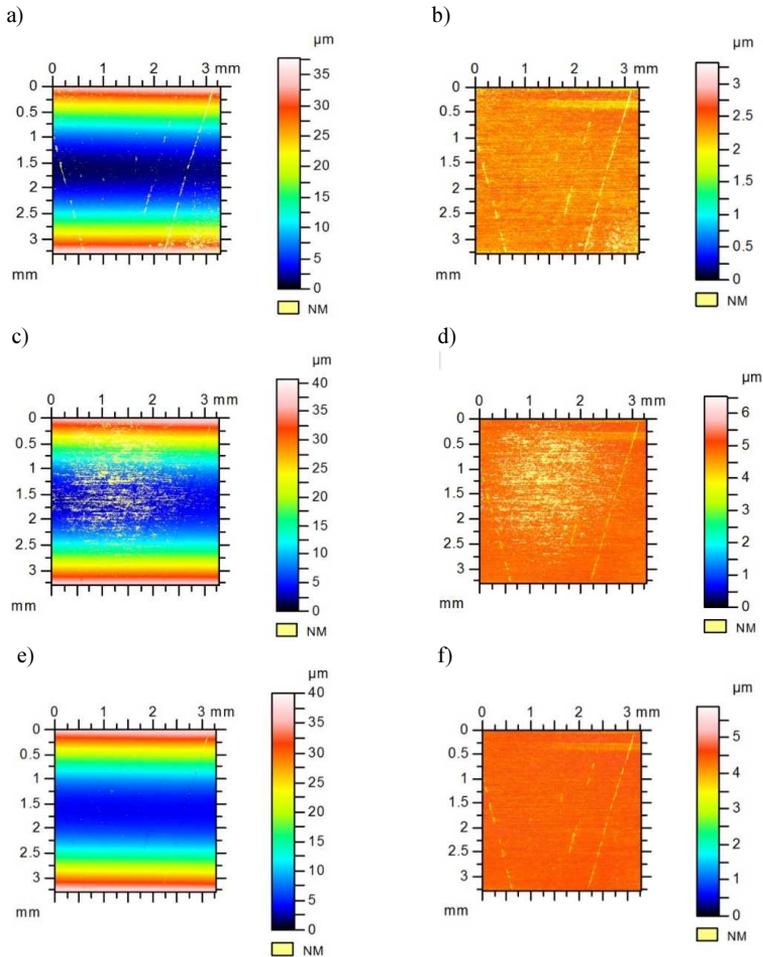


Fig. 5. Contour plots of a worn cylinder surface before (a, c, e) and after form removal (b, d, f) with non-measured points located in a valley region; NM ratio 4.31%(a, b), in a peak part; NM ratio 14.4% (c, d) and with their smallest number; NM ratio 0.102% (e, f).

The statistical parameters S_q and S_a are stable for an extremely high number of non-measured points. When these points are located in a peak surface part (NM ratio was 58% – see Figs. 4c, and 4d) the S_q parameter value was overestimated by 9%. A similar error was obtained when non-measured points were present in a valley part (NM ratio was 24.2% – see Figs. 4a and 4b). Similarly to Fig. 3, the presence of non-measured points in a valley surface part caused large changes of the S_v parameter value, but in a peak part – of the S_p parameter value. In both cases, errors led to an increase of the parameter values: S_{al} , S_{tr} and S_{sk} .

The presented above tendencies are concerned mainly with one-process surfaces. However similar trends were observed also for two-process textures characterized by a negative skewness (usually smaller than -1). An increase of light intensity led in most cases to a decrease of skewness Ssk and usually to an increase of kurtosis Sku values. This is reasonable because a small skewness corresponds to a large kurtosis. This tendency was probably caused by the presence of non-measured points in the bottom of valleys (Figs. 3a and 3b).

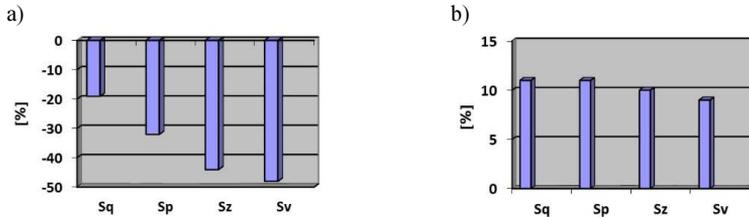


Fig. 6. Relative changes of parameters for the surface presented in Fig. 5a (a) and 5b (b).

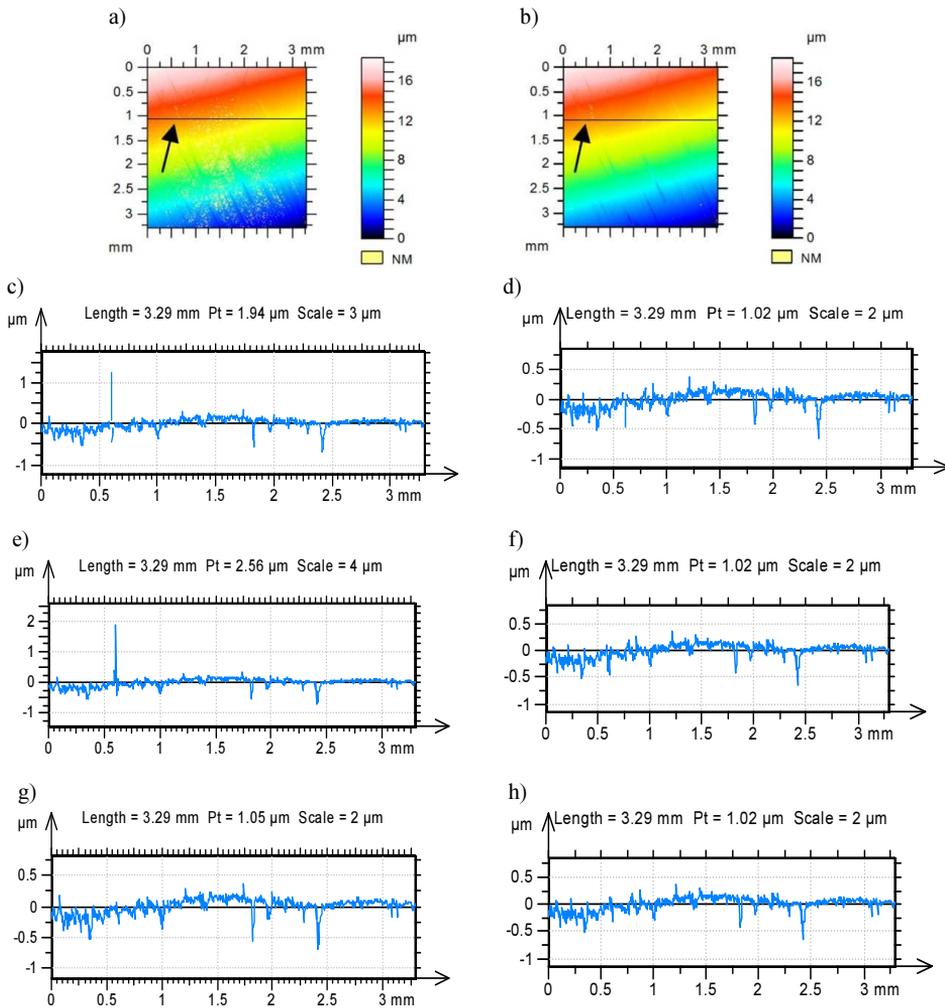


Fig. 7. Contour plots (a, b), extracted profiles before correction – filling in (c, d), after correction of the whole surface (e, f) and after profile correction (g, h); NM ratio 6.68% (a, c, e, g) and 0.079% (b, d, f, h).

For the surface shown in Fig. 3 the change of Ssk parameter value is small, but high errors of this parameter calculation can occur for two-process textures. As a result of it a surface machined well looks like a one-process texture and can be classified as a spoilage. An increase of the Ssk parameter value is related to a decrease of the Svk parameter value. Errors of two-process surface topography parameter estimations are very important, because the functional properties of two-process surfaces are better than those of one-process textures [28–31]. An inaccuracy of a valley part measurement typically led to larger errors of parameter computations compared with a disturbance in a plateau region. For example, the relative errors of parameter values for the surface shown in Figs. 5a and 5b are higher than those for the surface presented in Figs. 5c and 5d, although the NM ratio of the latter is higher. Fig. 6 presents relative changes of typical parameters. Negative changes correspond to underestimation, while positive ones – to overestimation of amplitude parameters. The Ssk parameter values of the surface shown in Fig. 5 are: in 5a and 5b -0.34 , 5c and 5d -1.26 , 5e and 5f -1.25 .

The other tendencies of parameter changes due to the presence of non-measured points found for a one-process surface were also confirmed for two-process textures. The texture direction was typically constant. The feature parameters, especially Sda , Sha , Sdv and Shv were non-stable on two-process surfaces.

An incorrect light intensity could lead to the presence of spikes (Fig. 6). However, erasing non-measured points from the whole honed surface can cause an increase of profile height (Fig. 7c and 7e), contrary to a similar correction of profile only (Fig. 7g). When the light intensity was smaller (Fig. 7b, 7d, 7f and 7h) the non-measured points appeared in the same place (see arrows), but without the presence of spikes. The same profile was obtained after correction of the whole surface or profile (see Fig. 7f and 7h). The Sp parameter value for the corrected surface after form removal with a smaller NM ratio was $1.21\ \mu\text{m}$, but with a higher one – $3.07\ \mu\text{m}$. The arrows indicate positions of errors.

5. Conclusions

The problem of non-measured points is one of the most important issues in surface texture measurements. The presence of even a small number of non-measured points can cause false estimation of surface texture parameters which can substantially affect the quality assessment of machined elements.

When non-measured points were located in one place of a peak surface part, the values of parameters describing this part changed more than the others. A character of parameter changes depends on a surface type.

An increase of light intensity caused typically an increase of the height, hybrid and functional parameter values; the spatial parameter Sal value mainly decreased. The following parameters are susceptible to errors caused by a high NM ratio: skewness Ssk , functional parameter Smr and feature parameters: Spd , Sda , Sdv , Sha and Shv .

For stratified surfaces, an increase of light intensity caused a decrease of skewness Ssk and an increase of kurtosis Sku values. These changes can be large. For this type of surface an inaccuracy of measurement in a valley part led usually to larger errors of parameter computations compared with disturbances in a plateau region.

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