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SURFACE TOPOGRAPHY REPRESENTATION IN PROFILOMETRY

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Abstract: In the paper the authors presented a comparison analysis of three different probes used for surface topography measurement. Skid and skidless stylus probes were used as contact pick-ups, while an optical autofocussing pick-up was applied as a non-contact one. The analysis was performed using several different topography parameters. It showed that a skid causes some relatively small distortions as far as the surface representation is concerned. The optical probe on the other hand proved to be a very difficult measuring tool, particularly for surfaces with steep slopes and sharp edges. Yet even for very smooth surfaces a great attention must be paid while measuring with this kind of pick-up is considered.
Keywords: surface topography, profilometry, probes

1 INTRODUCTION

A traditional 2D surface profile analysis is - for some years now - still more often replaced with 3D topographical assessment, as data obtained from only one profile may give distorted information about the analyzed surface. Furthermore, it is well known that a proper functionality and durability of such elements like bearings, gears and cylinder liners can be assured by a proper surface topography. Three-dimensional surface images allow presenting the nature of cutting processes as well as contact mechanisms in much better way. For this reason still more attention is paid to stereometry analysis and it is nowadays quite often applied in many aspects connected with tribology and machine industry in general. It was reported by a many authors, including both - research problems and practical applications for various kind of surfaces. Among many different methods of topography characterization stylus profilometry seems to be the most commonly used one. It is based on multiprofile parallel data tracking, giving as a result a set of points in three dimensions. In the paper the authors compared 3D surface representation for a number of different pick-ups used with a traditional profilometers.

Similarly as for surface roughness assessment basing on a single profile it is also necessary to define topography parameters characterizing the surface in numerical form. However, though it is relatively easy to obtain coordinates of surface points, there is no global agreement as far as the parameter evaluation is concerned. Yet some three-dimensional parameters were already proposed [1] and they were chosen for comparison purposes.

Three different pick-ups were investigated including contact and non-contact ones. The analysis was performed for several different materials. The parameters value as well as the images of surfaces showed how they behave on particular surface and what kind of distortions can be expected.

2 MEASUREMENT CONDITION

The measuring device used in research was based on a digital laboratory profilometer with 16-bit A/C converter. The whole device is composed of two units: a measuring one and control – computing system. The first comprises a column with drive unit and measuring probes as well as X-Y table equipped with a stepper motor to enable automatic pickup movement in Y direction. Thus data points for topography analysis were collected. The latter unit was composed of a specialized microcomputer controlling pick-up and table motions and collecting data. It has also independent memory to store measuring programs and is able to compute simple statistics: mean value, maximum and minimum values as well as range and standard deviation. The output data from this computer were fed into a separate, more powerful one used for calculations. The outlook of the whole measuring setup was presented on figure 1.

In the measurements three different probes were used: skid and skidless stylus probes having a standard 5 µm nose radius and 90° vertex angle and an optical autofocussing probe, basing on the red light wavelength laser and working as an optical follower. The probe that was used in measurements is based on a construction proposed by Brodmann and Smilga [2] is presented on figure 2. A special construction of fastening grip enabled it to apply an autofocussing probe in the same profilometer that was also used for stylus measurements. In this probe a material needle was replaced with a laser bundle that is being autofocussed on an inspected surface.

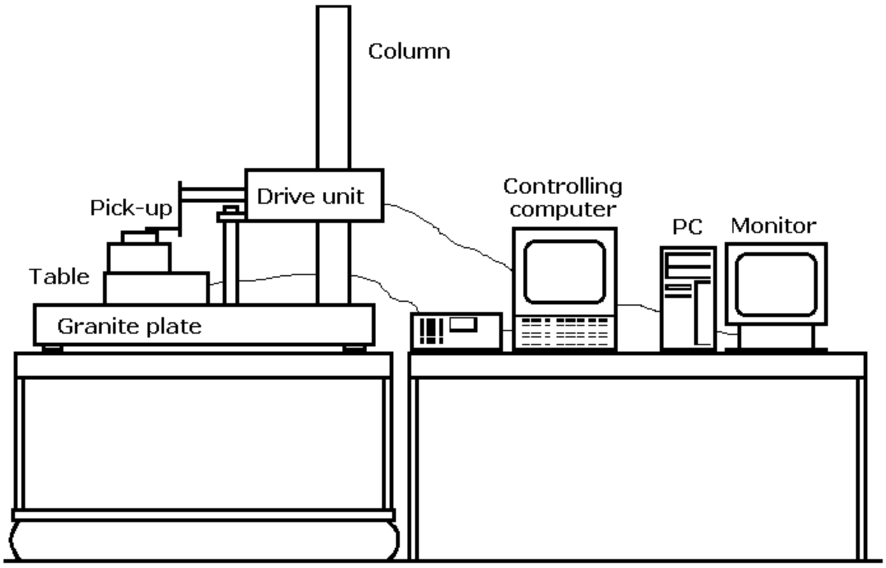


Figure 1. Measuring setup

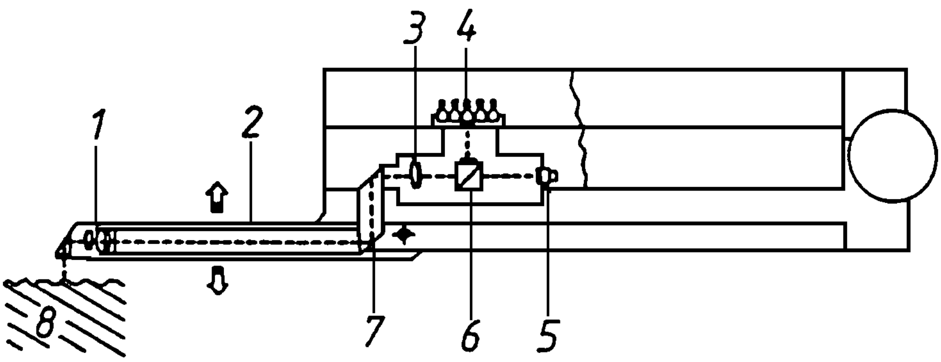


Figure 2. Optical autofocussing follower: working principle

The light source is a laser diode 5 emitting light with 780 nm wavelength. After leaving the diode the bundle is converted into a parallel one and then it follows a special optical path consisted of a system of lenses 3 and prisms 7 and finally reaches a microobjective 1, which creates a measuring optical needle [3]. The measuring bundle is focussed on the surface at a distance of 0.9 mm from the aperture giving a 2 µm diameter spot. The incident light is than a conical one with a very small vertex angle. The light reflected from the surface of a measured workpiece 8 is transmitted to a beam splitting system 6 and than further to a focus detector 4. It is composed of a system of diods that can register the appearance of a laser beam and simultaneously a part of a closed loop in a measuring system.

This detector sends an electric signal with the information whether the bundle is focussed on the surface (central part of the system of diods is illuminated) or not (diods on the border are illuminated). If the second situation takes place a linear motor in a rotary moving arm 2 turns it back to obtain the focal point on the analyzed surface. The value of its movement that is a result of shape and height of irregularities is converted by an inductive transducer into an electrical signal, that is an output signal for further processing. The optical probe used in the research has a vertical measuring range of +/-250 µm and can be used for surfaces with reflectivity from 4 to 95%. Similar measuring systems working with similar laser bundle frequencies were constructed also by Sayles et al. [4] and Breitmeier [5,6]. The autofocussing probe is very apt to distortions, but though some data concerning this were already published [7,8] there is no thorough analysis of how it behaves for various surfaces. Topography was measured on samples made by different types of machining (EDM, sand blasting, grinding, honing, turning and face milling), having the sample rotated at 90° after first full measuring cycle. From every specimen a rectangular area of about 3 - 5 mm in each direction was analyzed with a data points matrix composed of approximately 100.000 points. Sampling grids were constructed with different intervals for different surfaces, depending on the expected roughness. For some surfaces the results were compared with scanning electron microscope measurements.

2D surface parameters were also calculated for every single profile. Basing on this a simple statistical analysis was performed (from 179 samples) i.e. maximum, minimum and mean values as well as range and standard deviation were evaluated.

3 PARAMETERS

For topographical parametric assessment a reference data had to be determined first. Despite a lot of work and the fact that surface topography becomes more and more popular for some years now, the choice of reference plane is still discretionary and arbitrary. Although some reference elements have already been extended from reference lines computed for a two dimensional profile and applied to three dimensional topography characterization, still quite little information is available on the relative efficiency and feasibility of the reference data. The least squares mean plane was chosen as a reference element for plane surfaces and the polynominal quadratic function for curved elements (to remove curvature) [9]. Similarly as for profile analysis three dimensional surface texture parameters can be divided into three groups: height parameters, length parameters and the ones describing shape of irregularities. They are evaluated in reference to a datum, taken as a reference element.

It is relatively easy to compute three dimensional height parameters. They are transferred from two dimensional profile analyses with a reference element changed from the mean line to the mean surface. These parameters are: average roughness of the surface S_a, root mean square surface height S_q, maximum summit-to-valley height S_{max}, maximum summit height S_p and maximum valley height S_v as three dimensional versions of R_a, R_q, R_{max}, R_p and R_v respectively. Only two length parameters were taken into account: surface average wavelength λ_{sa} and root-mean-square surface wavelength λ_{sq}, transferred from λ_a and λ_q profile parameters. As far as parameters describing the shape of irregularities are concerned, skewness, kurtosis and slopes were evaluated.

In two-dimensional profile analysis a slope is represented by an average profile slope Δ_a and root mean square profile slope Δ_q. For topography analysis the respective parameters can be computed. They are denoted as Δ_{sa} (average surface slope) and Δ_{sq} (root-mean-square surface slope).

4 RESULTS AND DISCUSSION

The research was performed for several different surfaces in order to find the differences between pick-ups in various conditions. The results were shown in the form of charts representing the parameter values in two- and three-dimensional meaning. For 2D analysis the minimum, maximum and mean values are shown whereas for 3D one a parameter value from an area was shown.

For stylus probes two different reference systems were used: basing on skid and abstract one, basing on translation tables. For periodical and mixed surfaces except for the ground one bigger values of amplitude parameters were found for a skid probe, what does not always agree with theoretical assumptions due to which a skid should follow the irregularities and mechanically filter some of them. For this reason the parameters values were expected to be smaller. This fact for periodical surfaces can be explained by analyzing the construction of the skid stylus probe used in our work. In this case the distance between the maximum point of the skid and the vertex point of the stylus tip is approximately equal to the half of the wave period of irregularities. That causes a situation in which the skid is on the summit when the stylus is already in the next valley and the opposite. This effects in enlarging the existing heights of asperities and amplitude parameter values for a skid stylus probe. Still this difference wasn't very big and did not exceed 5 to 10 %, which is quite close to the measurement uncertainty. This situation for the turned surface was presented on figure 3a. The stylus - skid distance effect caused also slight variations in slope presentation, which led to differences as much as about 20 % between these two pick-ups.

a) b)

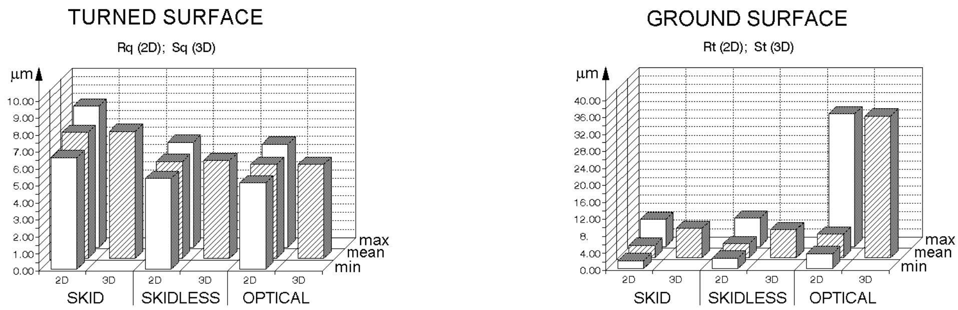


Figure 3. The amplitude parameters values for three different pick-ups:
a) S_q parameter for turned surface, **b)** S_t parameter for ground surface

For ground surface (fig. 3b) this situation didn't take place, as the horizontal distance between irregularities was different. For honed surface the difference was on the level of the measurement uncertainty (1 to 2 %), which shows a relatively insignificant influence of the skid on the measurement results for this surface. For random surfaces the results were also very close to each other (3 to 5 % of difference) what can be also explained by the measurement uncertainty. This confirms the fact known already for 2D profile assessment, that for random surfaces the influence of the skid is usually irrelevant. There were generally no great variations between the other parameters as far as the two stylus probes are concerned. Most differences didn't exceed 4% that were considered as the measurement uncertainty. The parameter values for the autofocussing probe differed much more from the two stylus probes. For some surfaces and parameters it was clear that the optical probe represents some elements of the analyzed surface geometrical structure in a totally different way. For periodical surfaces the results concerning amplitude parameters were very promising. The differences between the optical probe and the stylus skidless one didn't exceed 5 % for mean parameters (S_a and S_q) and 8 % for maximum parameters (S_p and S_t) what was shown on fig. 3a. Significant differences (up to 50 %) occurred only for length parameters and slopes. The autofocussing probe showed always greater inclination and smaller wavelength. For the remaining surfaces the variations in parameters values were much higher. In the case of the mean amplitude parameters - although for some surfaces the differences were relatively small (5 - 10 % for sand blasting and grinding) - they reached as much as 65 % for honing and nearly 120 % for EDM, with greater values for the optical probe. This probe showed also bigger values of maximum parameters - from 44 % of difference for sand blasting up to nearly four times for EDM and grinding (fig.3b). Similar situation took place also as far as parameters describing shape of irregularities are concerned - skewness, kurtosis and their modified versions. While for periodical surfaces skewness obtained with the autofocussing probe was a little bigger than for stylus pick-ups, for random and mixed surfaces it had lower values and the difference in some cases was quite significant. For example for honed and EDM surfaces it reached 1.13 and for ground one even 1.33. These differences are presented on fig. 4a for a sand blasted surface. Smaller values of skewness in these cases mean that for the optical probe it was always more negative than for the other pick-ups. This leads further to the conclusion that the autofocussing probe detected some very deep valleys, not found with stylus ones.

a) b)

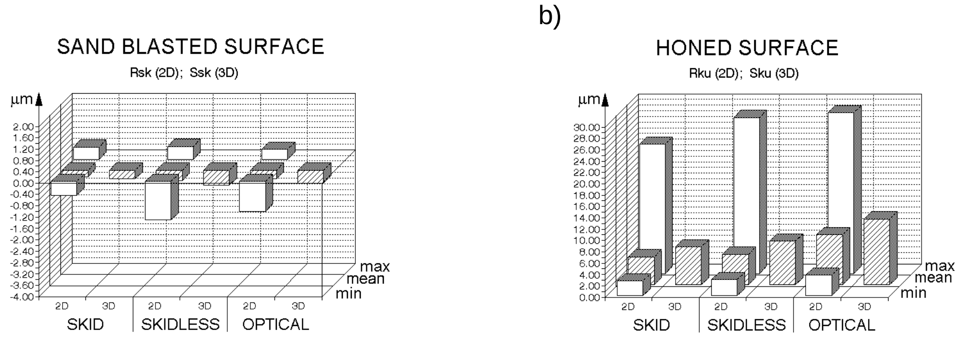
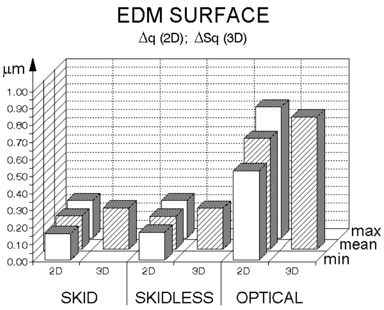


Figure 4. Parameters describing shape of irregularities for three different pick-ups:
a) S_{sk} parameter for sand blasted surface, **b)** S_{ku} parameter for honed surface

For nearly all of the analyzed surfaces kurtosis obtained by means of the optical autofocussing probe was greater than the one obtained with stylus probes. For some surfaces the difference didn't exceed 20 %, but reached as much as 74% for honed surface (fig. 4b), nearly two times for EDM and nearly 9 times for ground surface. This fact confirms that the optical probe detected some very high irregularities on the surfaces.

The differences as far as slopes representation and length parameters are concerned between the autofocussing probe and the stylus ones were the most significant. This fact was particularly clear for the EDM surface, but it was also present for all the other surfaces. In the case of the optical probe the slopes were always much steeper than for the other ones. The smaller differences occurred for periodical surfaces and reached 30 % for turning and 47 % for milling. For random and mixed surfaces they were much higher - about 100 % for sand blasting and grinding and nearly 200 % for honing and EDM (fig. 5a). This fact also confirms that the autofocussing probe detected some high irregularities and shows how difficult it is to get any information from the profile obtained with this pick-up.

a)



b)

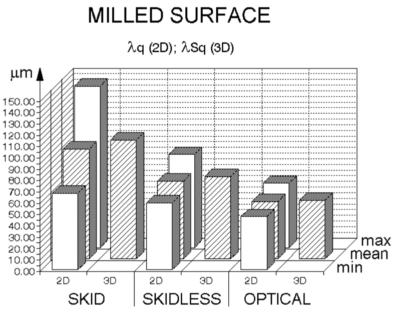


Figure 5. Parameters representing slopes and wavelength for three different pick-ups: **a)** Δ_q parameter for electrodischarged surface, **b)** λ_q parameter for milled surface

The differences in wavelength parameters were also significant for nearly all described surfaces and were usually as big as 50 % (they were less than 10 % only for ground surface) and the values obtained with the optical probe were always smaller than the ones for stylus probes. Figure 5b shows differences in λ_q parameter between the stylus probes (skid and skidless ones) and the autofocussing probe. These values show that the frequency of asperities for the optical probe is smaller (the signal is more shortwave) and the total number of local summits and valleys is bigger.

As it was shown in the case of the optical autofocussing probe the most significant differences occur with λ_q and Δ_q parameters. This means that the autofocussing probe cannot represent slopes, especially the ones that are relatively steep and long. Sometimes this doesn't even effect in any changes as far as amplitude parameters are concerned and the highest summit as well as the lowest valley remains unchanged. Mean amplitude parameters are calculated from a great number of points so they are also not very sensitive to some of the distortions, quite important from the functional point of view. On the other hand λ_q and Δ_q parameters are connected by a functional relation and when one of them changes the other will change as well, maintaining a constant value of R_q parameter. The slope obtained with the optical probe is several times bigger than for the stylus ones, having sometimes values bigger than 45°, which is the maximum of what a stylus probe can represent. However, considering the fact that a surface geometry is a result of a kinematic behavior of a cutting tool with some interference signals, the presence of such an angle is very questionable. For most of surfaces the angle of inclination is usually not bigger than 10° - 20°. If it is so than the optical probe causes the increase of the slope „making” it much steeper than the real value. This action is an effect of optical principles that take place in the probe. A laser beam reflected from the analyzed surface reaches a focus detector and gives an information about surface roughness. But if the surface profile is inclined at the angle bigger than 20° the reflected light cannot get back to the system what makes the probe move vertically searching for the bundle. If this situation takes place for some time not only the shape but also the vertical location of the summit is distorted and maximum amplitude parameters have bigger values than they should (fig. 3b). This problem is particularly visible for the EDM surface, which has numerous individual summits and pitches with steep slopes and for ground surface, which has long steep valleys with sharp edges. These edges disperse the light beam causing troubles with detecting the focal point. Negative values of skewness show that the optical probe tends to „create” valleys that do not exist on the real surface.

As it was shown above it is quite difficult to measure surface topography with an optical autofocussing probe. It can be valuable measuring equipment for some parameters for periodical surfaces, while for random and mixed ones especially with sharp edges or steep slopes it is practically useless. Theoretically the shape of a laser beam should enable for a deeper penetration of the analyzed surface and thus show bigger values of parameters. To make it absolutely clear some tests using a scanning electron microscope were performed. For surfaces with very small roughness they confirmed the results obtained with stylus probes, but generally the vertical range of the SEM is too small for that kind of measurements.

5 CONCLUSIONS

From the research some more general statements regarding reference element in surface topography measurements can be concluded:

- The influence of the skid is visible. Similarly as for profile measurements it is bigger for periodical surfaces and smaller for random ones.
- The autofocussing probe proved to be useful for some parameters for periodical surfaces. For random and mixed ones especially with sharp edges or steep slopes it is practically useless.
- For the optical probe the greatest difference occur as far as slopes and wavelengths are concerned.
- Nevertheless even for periodical surfaces measuring surface topography with the optical autofocussing probe requires a lot of care and practical experience.

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